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Civilian Radioactive Waste Management System
Management & Operating Contractor

10-4-1994

REPOSITORY SUBSURFACE LAYOUT OPTIONS AND ESF INTERFACE

CRWMS M&O Doc. No.: B00000000-01717-5705-00009, Rev.-00

December 17, 1993

Prepared for:

U.S. Department of Energy
P.O. Box 98608
Las Vegas, Nevada 89109-98608

Prepared by:

TRW Environmental Safety Systems Inc.
101 Convention Center Drive
Las Vegas, Nevada 89109

Under Contract Number
DE-AC01-RW00134
WBS 1.2.4
QA:QA

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EXECUTIVE SUMMARY

This report summarizes work completed by the repository subsurface design group during the 1993 fiscal year (FY93), and represents a portion of the ongoing, repository Advanced Conceptual Design (ACD) effort. The ACD work is being performed in accordance with guidance and controls established for the United States Department of Energy's (DOE) Yucca Mountain Project (YMP). This document draws information from other ACD reports prepared and submitted during the year, and from other program studies, including the Exploratory Studies Facility (ESF) Title II design. Site specific data gathered by the Surface Based Testing (SBT) program has been included to the extent that it became available early enough for use in the designs presented herein.

A major area of input to the YMP from the repository subsurface ACD group during FY93 was a proposed reconfiguration of the ESF subsurface layout, including reductions in the gradients of the north ramp and the main test drift. Details of this proposal were worked out by a task force that included members of the repository subsurface design team, the ESF subsurface design and project engineering teams, and ESF testing personnel. The proposed changes are based on new, or different perceptions regarding ESF and repository constructability and operational concerns. In addition, all of the favorable waste isolation attributes identified in the Exploratory Studies Facility Alternatives Study (ESFAS) are accommodated. Documentation and supporting logic for the proposed changes are included in a design analysis report that has been submitted to the M&O Change Control Board (CCB) for baselining.

Several potential subsurface repository layout alternatives that could be integrated with the proposed, reconfigured ESF, are included in the body of this report. One of these layouts, "Option I," has undergone a greater amount of refinement than the others and forms the basis for the repository layout concept presented in the design analysis mentioned above. This concept is described in more detail than what may have been envisioned when the FY93 scope of work was planned, but this was deemed necessary because many of the ideas that are described will be new to the program and because the layout may be called upon to serve as a "placeholder," i.e., representative of a repository layout concept that interfaces well with the proposed ESF reconfiguration.

While it lacks certain optimizations, and numerous personnel radiological safety and performance assessment issues remain to be examined, the Option I layout as presented herein is considered to be a realistic concept that could be safely constructed and operated in an efficient, productive manner. At the same time, the proposed ESF reconfiguration could accommodate numerous other repository layout concepts as well, relieving the YMP from any need to more or less "lock-in" on a specific repository design before the Option I and other layout alternatives have been more fully addressed and before more of the information to be gathered from the subsurface during site characterization becomes available.

Background information provided in the report includes discussions of site specific geology and geoengineering considerations, potential waste package designs, and thermal considerations. A brief description of the currently baselined repository design is provided, potential emplacement modes are presented and discussed, and applicable excavation methods are briefly described.

A preliminary ventilation analysis of the Option I layout is presented, as well as discussions of drainage considerations and potential development and emplacement operational schemes. Potential expansion of the layout within the area that has been traditionally used in YMP repository layout design work, as well as other areas that are outside of those boundaries, is also discussed. Considerations relating to retrieval, backfilling and, to a lesser extent, sealing and decommissioning are also provided. A separate report section addresses the interface between the proposed, reconfigured ESF and the Option I repository layout concept.

A great deal of work remains to be performed in the area of repository subsurface design. This work requires the application of mining engineering techniques normally exercised in developing the layouts and operational systems for underground mines, but using a primary excavation tool, the tunnel boring machine (TBM), that is normally employed only in civil engineering tunnelling projects because of the reduced flexibility inherent in this excavation method. It is doubtful that the TBM has ever been used in what would be called a "production mode" in an underground mine, and certainly not on the scale that is necessary for an underground repository. If one contemplates the logistical problem of developing a functional repository layout that is readily constructable using TBMs, together with the inter-related, yet separate problem of defining an emplacement mode and technique that will perform well in terms of personnel radiological safety and waste isolation concerns, one can begin to appreciate the task that is before us. The work presented in this report represents what is felt to be a start in the right direction, but there is much that remains to be accomplished.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In October 1992, at the direction of DOE, Advanced Conceptual Design (ACD) of the repository was started by the Civilian Radioactive Waste Management System Management and Operating (CRWMS M&O) Contractor. One of the major tasks of FY93 repository ACD was to perform an engineering study under Work Breakdown Structure (WBS) item 1.2.4.3.4- *Subsurface Excavation*, which would consider subsurface layout design options, excavation process systems, and potential areas of ESF/Repository interface. This report summarizes the results of this task and has been prepared in accordance with applicable QA requirements.

A conceptual design of the repository was completed and reported in the Site Characterization Plan Conceptual Design (SCP-CD) report (SNL, 1987). The SCP-CD utilized known site data and identified additional data needs to be obtained during site characterization activities. The SCP-CD demonstrated the feasibility of a potential repository at Yucca Mountain. The ESFAS (SNL, 1991) modified the SCP-CD design. Some of the notable changes introduced were from a design which included two ramps and four shafts connecting the surface facility to the underground in the SCP-CD, to one which used two ramps and two shafts in the finally selected option derived from various ESFAS configurations. Mechanical excavation of emplacement drifts was another major departure from the SCP-CD concepts. Title I design of the ESF (RSN, 1993) reflected a baselined repository design which better accommodated the use of a Tunnel Boring Machine (TBM) for the excavation of subsurface repository openings.

A proposal has been submitted to the M&O Change Control Board (M&O, 1993d) to modify the layout of the ESF drifts. The proposed changes are the logical result of recommendations made in the ESFAS to examine potential ESF/Repository layouts which incorporate waste-isolation attributes of other highly-ranked alternatives included in that study, but which were not incorporated in the selected ESFAS option.

The starting point for development of the subsurface repository layout design options presented in this study differ from pre-ACD designs in the main areas of ESF layout, the approach toward areal thermal loading, waste package design concepts, and waste emplacement mode. The layouts summarized in this report consider these concepts in varying details according to their applicability and relevance.

Sections 2 and 3 of this report provide the objectives, scope and methodology for the study. Section 4 deals with design input, including the requirements, codes and standards, assumptions, and interfaces that were considered. Section 5 is the main body of the report; it provides background information and then goes on to describe subsurface layout options and areas of potential ESF/repository interface. Section 6 presents conclusions and recommendations. References cited in the report are listed in Section 7.

2. OBJECTIVES

The original, primary objectives of the FY93 scope of work covered by this report included the development of alternative, conceptual repository subsurface layouts and identification of areas of potential, ESF/Repository interface in the subsurface. These objectives have been met.

In addition to these primary objectives, another main objective of the studies documented herein dealt with consideration being given to alternative ESF/Repository designs that deviate from that which exists in the Project's technical baseline. An enhanced ESF layout that offers numerous advantages to the YMP program, but which utilizes a different conceptual repository layout than that which currently resides in the project baseline, was developed and submitted to the M&O CCB (M&O, 1993d). The proposed changes are the logical result of recommendations made in the ESFAS to examine potential ESF/Repository layouts which incorporate waste-isolation attributes of other highly-ranked alternatives included in that study, but which were not incorporated in the selected ESFAS option. The level of detail provided in this report should be adequate to answer many questions regarding various elements and features of the conceptual repository layout that was presented with the proposed ESF reconfiguration.

Design objectives which are specific to alternative layouts or other areas covered by this report are provided in the separate report sections to which they apply.

3. SCOPE AND METHODOLOGY

The work that was performed in support of the designs presented in this report was of a conceptual nature. None of the repository subsurface layouts presented herein should be construed as having been developed through, or as a product of, detailed design evaluations. Rather, they should be regarded as the result of iterative thought processes that present ideas in a format that facilitates further review and refinement as the ACD program develops.

Geological and geoengineering information that is provided is based, in part, on a review of available literature and data specific to Yucca Mountain. The latest results from the Surface-Based Testing (SBT) program are included to the extent that they became available early enough to be incorporated into the conceptual designs presented herein. Structural contour, topographic and other base maps that were used in developing the repository layouts included in this report were provided by Sandia National Laboratories (SNL) and were plotted using the Interactive Graphics Information System (IGIS) computer model, a program that has not attained QA status. Additionally, the bulk of the geologic borehole data used by the model was not collected in accordance with QA requirements. While products generated by the IGIS model and much of the borehole data are of indeterminate quality, the information is the best that was readily available when the work was performed and its use is consistent with past YMP design efforts.

Current waste package ACD and systems studies efforts are evaluating a wide range of potential package configurations and capacities. The more in-depth repository layout designs presented in this report utilize one of the larger package sizes for purposes of conservatism, and in conformance with current thinking regarding large, multiple assembly packages such as the Multi-barrier and Multi-Purpose Canister (MPC) concepts. Ultimate selection of a recommended package configuration will influence the required subsurface opening sizes so any dimensional data provided in the report should be considered as very preliminary in nature. If the program were to adopt one of the smaller (6 assembly +/-) waste packages, then an entirely different layout concept might be warranted.

Thermal considerations discussed in the report represent a compilation of the more relevant work that has been performed in the past, little of which considered in-drift emplacement of waste packages as a potential emplacement mode. Much of the layout work described in this report emphasizes the in-drift mode, but does not have the support of detailed thermal, thermomechanical, and thermal-hydrological evaluations.

Rather than adopt a particular Areal Thermal Loading (ATL) as a design basis, some of the layouts that are presented were designed to maximize the utilization of available subsurface area consistent with a set of design objectives. The ATL that a particular area could support, based on emplacement of an assumed total waste inventory, was then back-calculated using the net area available after standoffs and other, non-emplaced zones were subtracted.

Details regarding proposed emplacement drift spacing and waste package spacing are not provided in this report. Determination of these parameters is part of a much larger problem involving the potential systems that are defined by specific waste package sizes and thermal outputs; drift sizes; drift and package spacings; ATLs; host rock thermal, thermomechanical, and hydrologic properties; and thermal goals. Ultimately, through the use of broad ranging systems studies, a design will be developed that optimizes this system, consistent with meeting all of the final thermal goals and extraction ratio constraints that will bound the problem. This study did not have the support of any such analysis.

Some of the emplacement concepts and operational schemes discussed are very preliminary in nature and have not undergone detailed reviews with regard to personnel radiological safety or long term performance assessment considerations. They are presented as potential methods of storing the waste in configurations that include retrieval as one of the primary requirements that must be accommodated. The schemes are purely conceptual in nature.

Potential expansion areas at the site are addressed in terms of which look the most promising if the ATL that is ultimately selected is lower than that which would facilitate emplacement of all of the waste in the primary area. This analysis should be regarded as very preliminary because geologic information outside the primary area is extremely limited.

Most of the layout work covered by this report was performed by inspection and using engineering judgement. In other words, the more refined layouts used the IGIS base maps as control in an iterative process of manually sketching lines on overlay sheets until a layout was established that provided a logistical framework of subsurface openings that fit within various physical boundaries set by both the fundamental program requirements, and the objectives of the particular layout. In some cases, layouts were developed for areas outside the limits of the IGIS model. These layouts used very preliminary manual geologic interpretations that were prepared based on very limited drillhole and surface stratigraphy information that was available.

None of the layouts have benefitted from long-term performance evaluations, but they do not appear to differ significantly from the baseline concept in any way that is considered to be less capable of providing the long-term isolation that is needed.

4. INPUT

4.1 DESIGN REQUIREMENTS

4.1.1 Applicable Documents

The following documents have been referenced as sources of requirements.

	Identifier	Title or Description
A.	29 USC 651 et seq.	Occupational Safety and Health Act
B.	42 USC 10101 et seq	Nuclear Waste Policy Act of 1982 (NWPA, P.L. 97-425) and and Nuclear Waste Policy Amendments Act of 1987 (NWPAA, P.L. 100-203)
C.	10 CFR 20	Standards for Protection Against Radiation
D.	10 CFR 60	Disposal of High-Level Radioactive Wastes (HLW) in Geologic Repositories
E.	10 CFR 960	General Guidelines for Recommendation of Sites for Nuclear Waste Repositories
F.	29 CFR 1910	Occupational Safety and Health Standards
G.	29 CFR 1926	Safety and Health Regulations for Construction
H.	30 CFR 31	Diesel Mine Locomotives
I.	30 CFR 32	Mobile Diesel-Powered Equipment for Noncoal Mines
J.	30 CFR 36	Mobile Diesel-Powered Transportation Equipment for Gassy Noncoal Mines and Tunnels
K.	30 CFR 57	Safety and Health Standards - Underground Metal and Nonmetal Mines
L.	40 CFR 191	Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (under review)
M.	E.O. 11988	Floodplain Management

N.	DOE 5480.4*[1]	Environmental Protection, Safety, and Health Protection Standards
O.	DOE 6430.1A	General Design Criteria
P.	NRC Reg Guides	8.8, Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be ALARA, Revision 3, June 1978 (Second Proposed Revision 4, Draft OP 618-4, 5/82) 8.10, Operating Philosophy for Maintaining Occupational Exposure ALARA, Revision 1-R, September 1975
Q.	YMP/CC-0002	Reference Information Base, Version 4, Rev. 6
R.	YMP/CM-0023	Repository Design Requirements Document (RDRD), YMP/CM-0023, Rev. 0
S.	California Administrative Code (CAC), Title 8	"Industrial Relations," Chapter 4, "Division of Industrial Safety," Subchapter 20, "Tunnel Safety Orders" (required by DOE Order 5480.4)
T.	BFD1	Basis for Repository Advanced Conceptual Design, Underground Facilities - Shafts, Ramps, Subsurface Excavations, CRWMS M&O Doc. No.: B00000000-01717-1708-00002, Rev.-00B
U.	BFD2	Basis for Repository Advanced Conceptual Design, Underground Service Systems, CRWMS M&O Doc. No.: B00000000-01717-1708-00003, Rev.-00B
V.	BFD3	Basis for Repository Advanced Conceptual Design, Underground Operations and Maintenance, CRWMS M&O Doc. No.: B00000000-01717-1708-00004, Rev.-00B

4.1.2 Requirements

The designer's source of requirements is the Basis for Design document, even though many requirements originate in other sources. Information in brackets [ ] gives the source of the requirements. Information in parentheses ( ) gives the location of the requirement in the Repository Design Requirements Document (RDRD). Some requirements appear in more than one BFD, but appear here only once.

1 *The asterisked DOE Orders apply only to the extent they do not conflict with NRC direction.

The following pertinent requirements are quoted from the Basis for Design document (BFD1).

3.1.D.4. The size and arrangement of interior corridors shall accommodate the movement of equipment including initial equipment installation, facility operations, and possible future removal or replacement of equipment. Movement of waste packages into and out of the emplacement drifts requires specific attention. [DOE Order 6430.1A, 0110-99.0.4] (RDRD, 3.2.5.2.2.A)

3.1.D.5. Facility design shall provide access for routine maintenance, repair, or replacement of equipment subject to failure. Accessibility includes proper lighting and utility hookups and acceptable levels of radiological exposure. [DOE Order 6430.1A, 1300-3.5] (RDRD, 3.2.5.2.2.B)

3.1.E.2.e. Natural phenomena and environmental conditions at the GROA considered in the design shall include events and conditions such as earthquakes, tornados, wind, lightning, floods, precipitation, humidity, temperature, sand and dust, and fungus, bacteria, and algae. (RDRD, 3.2.6.1.A)

3.1.E.2.f. The design bases shall reflect appropriate consideration of the most severe conditions reported for the site and surrounding area and appropriate combinations of the normal and accidental conditions and the effects of natural phenomena, with appropriate margins to take into account the limitations of the data and the period of time in which the data have accumulated. (RDRD, 3.2.6.1.B)

3.1.E.2.h. Items important to safety and waste isolation shall not be constructed within the limits of the probable maximum flood (PMF). [TBV]

3.1.E.3.a. The underground facility shall be designed to allow adjustments to accommodate specific site conditions identified through in-situ monitoring, testing, or excavations. [10 CFR 60.133(b)] (RDRD, 3.7.5.H)

3.1.E.3.b. Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement or fracturing of overlying or surrounding rock. [10 CFR 60.133(e)(2)] (RDRD, 3.7.5.E.2)

3.1.E.3.c. Underground openings shall be designed and constructed to provide suitable ground control in compliance with 30 CFR 57 Subpart B. [30 CFR 57 Subpart B] (RDRD, 3.2.6.2.5)

3.1.E.3.d. The openings shall be maintainable until closure. (RDRD, 3.7.5.E.5)

3.1.E.3.e. Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained. [10 CFR 60.133(e)(1)] (RDRD, 3.7.5.E.1)

3.1.E.3.g. The orientation, geometry, layout, and depth of the underground facility, and the design of any engineered barriers that are part of the underground facility shall contribute to the containment and isolation of radionuclides. [10 CFR 60.133(a)(1)] (RDRD, 3.7.5.E.3)

3.1.E.3.h. The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock, and surrounding strata, and groundwater system. [10 CFR 60.133(i)] (RDRD, 3.7.5.E.7)

3.1.E.3.i. The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for groundwater to contact the waste packages or radionuclide migration to the accessible environment. [10 CFR 60.133(f)] (RDRD, 3.7.5.G.2)

3.1.E.3.j. Repository facilities shall be designed and constructed so as not to preclude the later addition, where appropriate, of facilities for offices and laboratories or expansion of its basic mission, e.g. increased storage area, waste consolidation, or increased disposal capacity. (RDRD, 3.2.8)

3.1.E.3.m. The design of the GROA shall include such provisions for worker protection as may be necessary to provide reasonable assurance that all structures, systems, and components important to safety can perform their intended functions. Any deviation from relevant design requirements in 30 CFR 57 will give rise to a rebuttable presumption that this requirement has not been met and shall be justified in writing. [10 CFR 60.131(b)(9), correlated with the revised 30 CFR Chapter I] (RDRD, 3.7.5.F.5)

3.1.E.3.ac. Materials used for stabilization, compaction, dust control, site preparation, surface paving, construction, and utility systems shall be evaluated to ensure that they do not adversely impact waste isolation. (RDRD, 3.3.8.1.E)

3.1.E.3.cj. The Repository shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA. [10 CFR 60.111(a)] (RDRD, 3.2.1.1.D, 3.2.1.2.C, 3.2.1.3, 3.2.1.4.C, 3.2.2.1.C)

3.1.E.3.ck. The GROA shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter until the completion of a performance confirmation program and NRC review of the information obtained from such a program. To satisfy this objective, the geologic repository shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the NRC. 10 CFR 60.111(b)(3) gives guidance for developing the schedule. [10 CFR 60.111(b)(1)] (RDRD, 3.2.1.4.B)

3.1.E.3.cl. The underground facility ventilation system shall control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of 10 CFR 60.111(a). [10 CFR 60.133(g)(1)] (RDRD, 3.7.5.B.1)

3.1.E.3.cn. The underground facility ventilation system shall separate the ventilation of excavation and waste emplacement areas. [10 CFR 60.133(g)(3)] (RDRD, 3.7.5.B.4)

3.1.1.D.1 If shafts are used, the shaft size shall be determined by the size of the conveyances needed to move materials, personnel, and equipment underground; the volume of ventilation flow required; the space required for utility lines; and space for ground control items such as liners, bolts, and foundations. [TBD] (RDRD, 3.7.5.N.5)

3.1.1.1.D.1 The location of underground openings shall be placed such that the effects of a maximum possible flood will not intrude on the operations of the subsurface facilities. (RDRD, 3.7.5.E.4)

3.1.2.D.1. The waste ramp shall permit flow of intake ventilation air for the emplacement area, which, when combined with the airflow in the shafts, is adequate for emplacement operations. [TBV] (RDRD, 3.7.5.N.1)

3.1.2.D.2. The tuff ramp shall permit flow of ventilation airflow capacity adequate to meet the return air requirements of the development area during the construction and operation periods. [TBV] (RDRD, 3.7.5.N.2)

3.1.2.1.D.2. The portal shall be founded in rock. (RDRD, 3.7.5.N.3)

3.1.2.1.D.3. The ramp shall be designed to prevent water from flowing into the ramp. (RDRD, 3.7.5.N.4)

3.1.3.D.1. Drift sizes shall take into account requirements for hauling equipment and shall allow for clearances, ground support, and ventilation. (RDRD, 3.7.5.O.1)

3.1.3.D.2. The service main [TBV] shall be adequate to handle the transport of development personnel, supplies, utility lines, and machinery to the men-and-materials shaft [TBV], to the service facilities for the development area, and to the development area. (RDRD, 3.7.5.O.2)

3.1.3.D.3. The service main [TBV] shall permit flow of adequate ventilation airflow to supply the volumes of air needed in the development area. (RDRD, 3.7.5.O.3)

3.1.3.2.D.1. The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 10 CFR 60.111. [10 CFR 60.133(c)] (RDRD, 3.7.5.D)

3.1.3.2.D.2. Emplacement drift spacing shall consider the heat load as indicated by thermal analysis related to the thermal characteristics of the waste over the life of the repository. (RDRD, 3.7.5.P.1)

3.1.3.2.D.3. The design of the emplacement drifts must take into account requirements for the transporter, haulage equipment, and other support equipment and shall include allowances for clearances, ground support, and ventilation. (RDRD, 3.7.5.P.2)

3.1.3.2.D.4. In an in-drift emplacement concept, the design of the emplacement area shall ensure that the emplacement drifts can accommodate the potential disposal of partial or fully shielded waste packages and the accommodations required for performance confirmation instrumentation. [TBD] (RDRD, 3.7.5.P.3)

The following pertinent requirements are quoted from the Basis for Design document (BFD2).

3.1.E.3.e. Structures, systems, and components that are important to safety shall be designed and located so that they continue to perform their safety functions effectively during and after credible fire and explosion conditions in the Repository. [10 CFR 60.131(b)(3)(i)] (RDRD, 3.2.1.7.C, 3.2.5.1.3, 3.2.6.2.1.A)

3.1.E.3.l. The underground facility shall be designed so that the effects of credible disruptive events during the period of operations, such as flooding, fires, and explosions, will not spread through the facility. [10 CFR 60.133 (a)(2)] (RDRD, 3.7.5.F.2)

3.1.E.3.o. To the extent practicable, the Repository facilities shall be designed to incorporate the use of noncombustible and heat resistant materials. [10 CFR 60.131(b)(3)(ii)] (RDRD, 3.2.6.2.2.D)

3.1.E.3.af. Repository work places shall be designed to comply with occupational safety and health standards promulgated under 29 CFR 1910, 29 CFR 1926, and 30 CFR 57 as applicable. (RDRD, 3.3.6.1.B)

3.1.E.3.ap. The Repository shall be designed and constructed so that facilities are easily and economically maintained. Maintainability considerations include: (RDRD, 3.2.5.2.8.A)

3.1.E.3.ap.(1) Use of easily maintained features and durable materials (RDRD, 3.2.5.2.8.A.1)

3.1.E.3.ap.(2) Ease of replacement of installed equipment (i.e., without structure modification) (RDRD, 3.2.5.2.8.A.2)

3.1.E.3.ap.(3) Accessibility of installed equipment and building systems for performance of maintenance (RDRD, 3.2.5.2.8.A.3)

3.1.E.3.ap.(4) Life cycle costs in selection of features, systems, and finishes (RDRD, 3.2.5.2.8.A.4)

3.1.E.3.bd. The time required to perform work in the vicinity of radioactive components shall be kept to an absolute minimum; for example, by providing sufficient space for ease of operation and designing equipment for ease of repair and replacement. [10 CFR 60.131(a)(2)] (RDRD, 3.2.5.2.8.E)

3.1.E.3.bx. The underground facility shall be designed to control water and gas intrusion. [10 CFR 60.133 (d)] (RDRD, 3.7.5.I)

3.1.E.3.cf. The GROA design and operations shall include provisions for controlling doses such that, when approved operational procedures are followed, the exposure dose limits specified in 10 CFR 20.1201 for occupational doses, and 10 CFR 20.1301 for individual members of the public, are not exceeded. [10 CFR 20] (RDRD, 3.2.2.1.B)

3.1.2.E.3.c. The structures, systems, and components important to safety shall be designed to maintain control of radioactive waste and radioactive effluents, and permit prompt termination of operations and evacuation of personnel during an emergency. [10 CFR 60.131(b)(4)(i)] (RDRD, 3.2.1.7.B)

3.1.2.E.3.d. The GROA shall, to the extent practicable, be designed and constructed to use procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA). ALARA principles shall be based on the applicable sections of NRC Regulatory Guides 8.8 and 8.10. [10 CFR 20.1101(b)] (RDRD, 3.2.2.1.A)

3.1.2.E.3.e. The GROA shall provide means to limit the levels of radioactive materials in effluents, during normal operations, anticipated occurrences, and under accident conditions. [10 CFR 60.131(b)(4)(i)] Releases shall be limited as follows: (RDRD, 3.2.2.1.D)

3.1.2.E.3.e.(1) Under normal operations and anticipated occurrences, the annual dose equivalent to any real individual who is located beyond the controlled area must not exceed 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ as a result of exposure: to planned discharges of radioactive materials, radon and its decay products excepted, to the general environment; direct radiation from Repository operations; and any other radiation from uranium fuel cycle operations within the region <TBR>[40 CFR 191.03(a)(1)<TBR>] (RDRD, 3.2.2.1.D.1)

3.1.2.E.3.e.(2) Under accident conditions, the annual dose equivalent shall not exceed [TBD]. (RDRD, 3.2.2.1.D.2)

3.1.2.E.3.g. Repository facilities shall be designed to operate so that the total effective dose equivalent to individual members of the public from the licensed operation does not exceed 0.1 rem (1 mSv) in a year, exclusive of the dose contribution from the facility's disposal of radioactive material into sanitary sewerage in accordance with 10 CFR 20.2003. However, the facility may apply for prior NRC authorization to operate up to an annual dose limit for an individual member of the public of 0.5 rem (5 Msv) in accordance with 10 CFR 20.1301(c). [10 CFR 20.1301(a),(c)] (RDRD, 3.2.2.2.A)

3.1.2.3.D.a. The underground facility ventilation system shall ensure that ventilation leakage between the emplacement system and the development area system will always be from the development to the emplacement system. (RDRD, 3.7.5.B.4)

3.1.2.3.D.b. The underground facility ventilation system shall supply and exhaust adequate quantities of air [TBD] to and from underground working areas such that operator safety, health and productivity requirements are maintained. (RDRD, 3.7.5.B.6)

3.1.2.3.E.3.a. Concentrations of radioactive material in air shall, to the extent practicable, be controlled through the use of process or other engineering controls (e.g. containment or dilution). [10 CFR 20.1701] (RDRD, 3.2.2.3.A)

3.1.2.3.E.3.c. The underground facility ventilation system shall control the transport of radioactive particulates and gases within and releases from the underground facility in accordance with the performance objectives of 10 CFR 60.111(a) [10 CFR 60.133(g)(1)] (RDRD, 3.7.5.B.1)

3.1.2.3.E.3.e. Ventilation meeting the standards of 30 CFR 57, subpart D shall be provided as applicable in underground facilities. [30 CFR 57, subpart D] (RDRD, 3.3.6.3.G)

3.1.2.3.E.3.f. The ventilation systems shall be designed to be balanced. Temperature, humidity, and air quality shall be controlled in accordance with radiological and air quality requirements.

3.1.2.3.E.3.h. An exhaust ventilation filtration system shall be able to be activated by remote control during accident conditions.

3.1.2.3.E.3.i. Efficiency and dust control shall be taken into account in establishing air velocities.

3.1.2.3.E.3.j. The underground facility ventilation system shall assure continued function during normal operations and under accident conditions. [10 CFR 60.133(g)(2)] (RDRD, 3.7.5.B.2)

3.1.2.3.E.3.n. The underground facility shall be ventilated to comply with the following requirements: (RDRD, 3.7.5.C)

3.1.2.3.E.3.n.(1) 30 CFR 31.9(a) for diesel locomotives, if used. [10 CFR 60.131(b)(9) as correlated with revised 30 CFR Chapter I] [MOU DOE/DOL] [30 CFR 31.9] (RDRD, 3.7.5.C.1)

3.1.2.3.E.3.n.(2) 30 CFR 32.9(a) for other diesel-powered equipment, if used, in a non-gassy environment. [10 CFR 60.131(b)(9) as correlated with revised 30 CFR Chapter I] [MOU DOE/DOL] [30 CFR 32.9(a)] (RDRD, 3.7.5.C.2)

3.1.2.3.E.3.n.(3) 30 CFR 36.45 for other diesel-powered equipment, if used, in a gassy environment. [10 CFR 60.131(b)(9) as correlated with revised 30 CFR Chapter I] [MOU DOE/DOL] [30 CFR 36.45] (RDRD, 3.7.5.C.3)

The following pertinent requirement is quoted from the Basis for Design document (BFD3).

3.1.E.3.d. The repository shall be designed and constructed to permit the retrieval of any SNF and HLW emplaced in the repository, during an appropriate period of operation of the facility, as specified by the Secretary of Energy. [NWPA, 122] (RDRD, 3.2.1.4.A)

4.2 NUMERIC DESIGN INPUT

Numeric design input used for various portions of this study is identified in the individual section to which it applies. The input is referenced if it was derived from other studies, or may be of a conceptual nature based on engineering judgement or assumptions.

4.3 CODES AND STANDARDS

No codes and standards other than those listed in 4.1.1 have been identified for use at this time.

4.4 ASSUMPTIONS

The work covered by this report is entirely conceptual in nature. Rather than listing every conceptual idea here that might be considered an assumption by some, the concepts are presented and described, along with any assumptions that were used, in the applicable sections of the report.

4.5 INTERFACES

The following interface descriptions are quoted from the Basis for Design document (BFD1).

3.1.B.2. Repository Segment - MRS Segment Interfaces

> The Repository Segment and the MRS interface through the combined waste capacity limits in effect when the two facilities are less than 50 miles apart, and during operation when SNF is unloaded from MRS transportation casks and its identity is verified. (RDRD, 3.2.3.1.1)
>
> 3.1.B.2.a. In the event that the MRS is located, or planned to be located within 50 miles of the MGDS, the combined quantity of waste in both the MRS and the first repository shall not exceed 70,000 metric tons of heavy metal until a second repository is in operation. [NWPA Section 114(d)] (RDRD, 3.2.1.2.A, 3.2.3.1.1.A)
>
> 3.1.B.2.b. Assuming the MRS facility is located more than 50 miles from the repository, no quantity of SNF and solidified HLW resulting from the reprocessing of such a quantity of spent fuel containing in excess of 70,000 metric tons of heavy metal shall be emplaced in the repository until such time as a second repository is in operation. [NWPA,114(d)] (RDRD, 3.2.1.2.A)

3.1.B.3. Repository Segment - Site Segment Interfaces

> Portions of the Site Segment will be incorporated into the Repository Segment or will have been closed by the time the Repository Segment is constructed. The exploratory shafts and boreholes that are no longer needed may have been filled and sealed prior to

initiation of Repository Segment Construction, but remnants may still penetrate the underground facility.

3.1.B.4. Repository Underground Segment - Engineered Barrier Segment Interfaces

The Repository Segment provides all mechanical, utility, logistics, safety, administrative, and mechanical support for the Engineered Barrier Segment. It also includes excavation and backfill machinery. The Engineered Barrier Segment has no inherent capability for providing these functions. (RDRD, 3.2.3.2.2)

The Repository Segment provides systems and facilities in support of the function and services listed below: (RDRD, 3.2.3.2.2.A)

Emplacement area development and access

Waste receipt, preparation, transfer, emplacement, and retrieval, including shielding before and during emplacement and during retrieval

Backfilling and sealing (if required)

Closing and decommissioning

Utilities (ventilation, fire protection, electric power, removal of site generated waste, communication, monitoring, water(supply and removal)....)

Performance assessment/confirmation/monitoring

Radiologic protection

Personnel support and habitability

3.1.B.4.a. Physical outputs from the Repository Segment to the Engineered Barrier Segment include: waste packages for emplacement, backfill and other barrier materials, and fresh air. Requirements associated with this interface include the following:

3.1.B.4.a.(2) The design and operation of the repository shall not compromise the Isolate Waste Function of the Engineered Barrier Segment by affecting the performance of the waste packages and the underground facility or the geologic setting. (RDRD, 3.2.3.2.2.A.2)

3.1.B.4.a.(5) The Repository Segment shall accommodate the emplacement concept [TBD] selected during advanced conceptual design. (RDRD, 3.2.3.2.2.A.7)

3.1.B.4.a.(6) The repository layout shall be designed to preclude the potential for nuclear criticality of the stored waste at any time after being received at the MGDS. (RDRD, 3.2.3.2.2.A.10)

3.1.B.4.a.(7)(b) The layout shall also ensure that the design limit temperatures [TBD] for waste forms are not exceeded. [10 CFR 60.113(a)(1)(ii)(A)] (RDRD, 3.2.3.2.2.A.11.b)

3.1.B.4.b. The Engineered Barrier Segment outputs to the Repository Segment include heat, exhaust air, mechanical load, retrieved waste packages, and, performance confirmation data. (RDRD, 3.2.3.2.2.B)

3.1.B.4.b.(1) The Waste Package, coupled with the repository, shall include provisions for controlling doses such that when approved and operational procedures are followed, the exposure doses specified in 10 CFR 20.1201 for occupational doses, and 10 CFR 20.1301 for individual members of the public, are not exceeded. [10 CFR 20.1201] [10 CFR 20.1301] (RDRD, 3.2.3.2.2.B.2)

3.1.B.4.b.(2) The Engineered Barrier Segment shall be able to withstand shock [TBD] and vibration [TBD] levels characteristic of handling, emplacement, retrieval, and seismic environments, without adverse impacts on waste containment and isolation capability. (RDRD, 3.2.3.2.2.B.3)

3.1.B.5. Repository Segment - Geologic Setting Interfaces

The Repository Segment interfaces with the geologic setting at the surface of the rock that is exposed to excavated openings. The geologic setting outputs to the Repository Segment may include water and gas intrusion and preferential pathways for radionuclide travel. The Repository Segment outputs to the geologic setting include heat, radionuclides, and radiation. Requirements associated with this interface are addressed in Section 3.7.2.2 of the RDRD. In addition: (RDRD, 3.2.3.2.3)

3.1.B.5.a. The underground facility shall assist the geologic setting in meeting the performance objectives for the period following permanent closure. [10 CFR 60.133(h)] (RDRD, 3.2.3.2.3.A)

3.1.B.5.b. The underground facility shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to applicable environmental standards for radioactivity established by the EPA with respect to both anticipated processes and events and unanticipated processes and events. [10 CFR 60.112] (RDRD, 3.2.3.2.3.B)

4.6 DEFINITIONS

No definitions other than those in the QARD are needed. The terminology in this report, if considered to be new or unusual, is defined at the point where it is first used.

5. REPOSITORY SUBSURFACE LAYOUT OPTIONS AND ESF INTERFACE

Section 5 consists of two primary subsections: 5.1, which presents potential, alternative repository subsurface layouts developed during the course of the FY93 ACD effort, and 5.2, which discusses interfaces between the ESF and one of the potential repository layout concepts presented in Section 5.1.

5.1 REPOSITORY SUBSURFACE LAYOUT OPTIONS

This report section provides the groundwork for potential repository layout options in terms of site specific geology and geoengineering considerations, potential waste package designs, and thermal considerations. A brief description of the currently baselined repository design is provided, potential emplacement modes are presented and discussed, and applicable excavation methods are briefly described. Several potential repository layout concepts are presented, one of which, "Option I," is described in considerable detail as it could be regarded as a representative case for program guidance purposes in the immediate future.

5.1.1 Baseline Conceptual Repository Design

A conceptual design of a potential, high-level nuclear waste repository at Yucca Mountain is described in Chapter 6 of the SCP and is based on evaluations presented in the SCP-CD Report (SNL, 1987). The configuration of the SCP-CD repository layout, using the vertical emplacement mode, is shown in Figure 5-1.

A later report, the ESFAS (SNL, 1991), evaluated 34 different, integrated ESF/repository configurations. The study concluded that the alternative identified as Option 30 was most preferred, based on a multi-attribute decision analysis that considered waste-isolation, operability, programmatic, and other features of the various designs. This option included two 7.6 m (25 ft) diameter ramps excavated by TBM and two 7.6 m (25 ft) diameter shafts for repository access. Figure 5-2 shows the general layout features of the Option 30 configuration (SNL, 1991). This layout accommodated the use of the TBM excavation method for construction of ramps, access drifts, and emplacement drifts. Option 30 contained the dedicated main test level (MTL) area in the southeast area of the repository foot print, but was later modified to move the MTL into the northeast corner of the repository footprint and to include an optional shaft for site characterization purposes. The resulting layout was called "Modified Option 30."

The Modified Option 30 layout became the starting point for Title I ESF design via a "bridge" document (DOE, 1991) that also stressed the need to pursue development of ESF/Repository layouts that incorporate all of the favorable waste-isolation design features identified in the ESFAS. The Modified Option 30 repository configuration (Figure 5-3) is presented in the baseline document Yucca Mountain Site Characterization Program Baseline (SCPB) (DOE, 1993a), and is the currently baselined conceptual repository design.

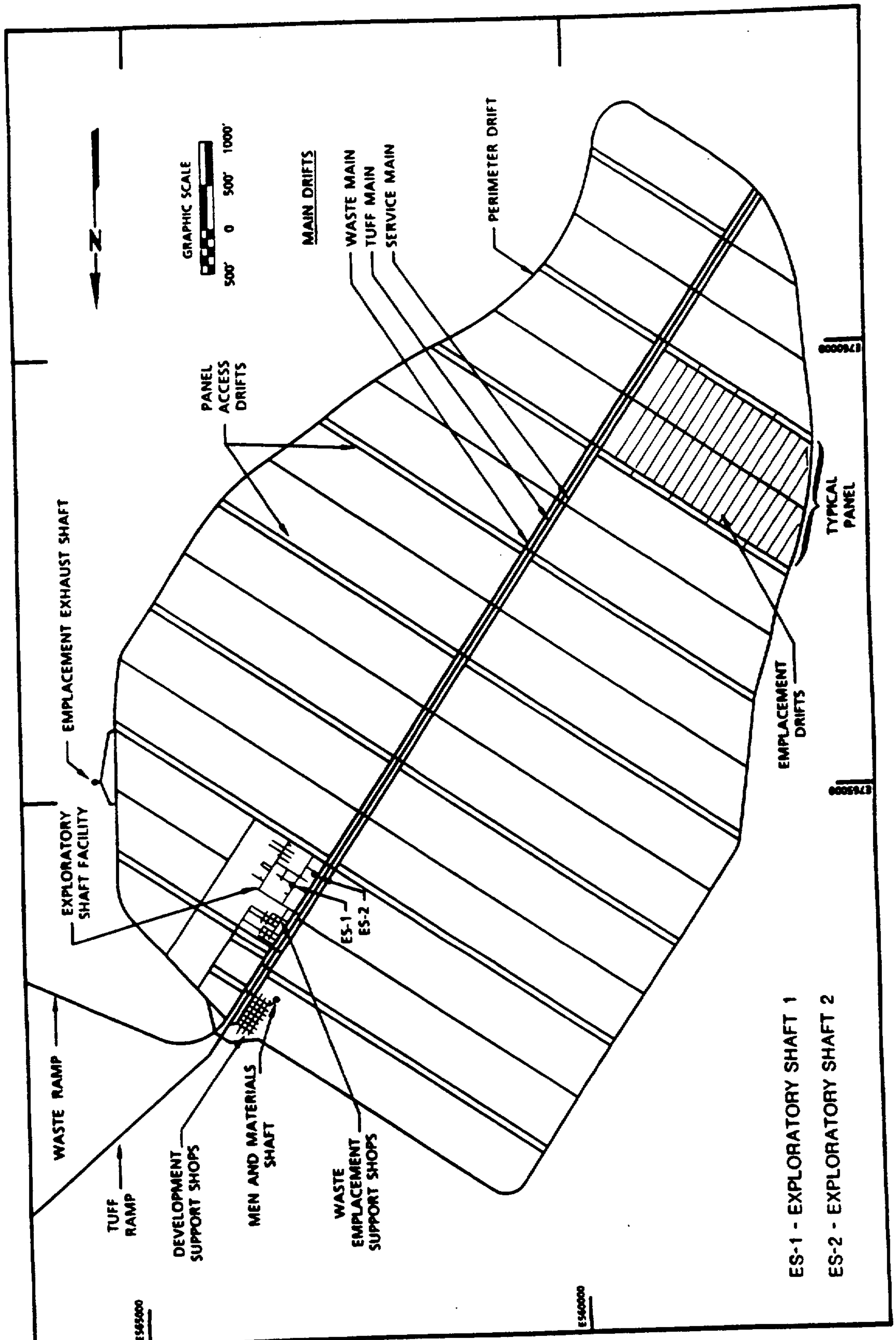


Figure 5-1 Repository Layout in SCP-CDR

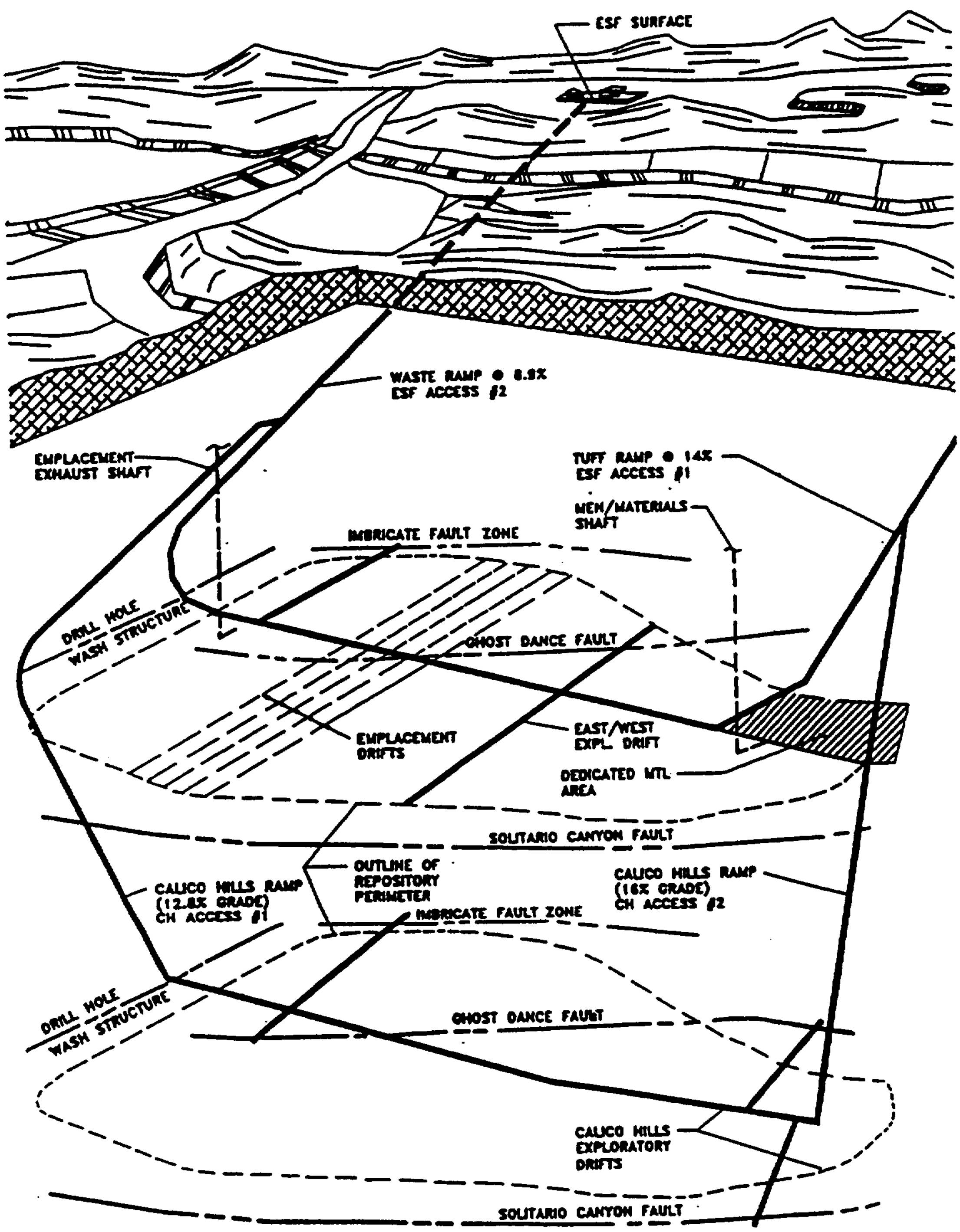


Figure 5-2 Option 30 Repository Configuration

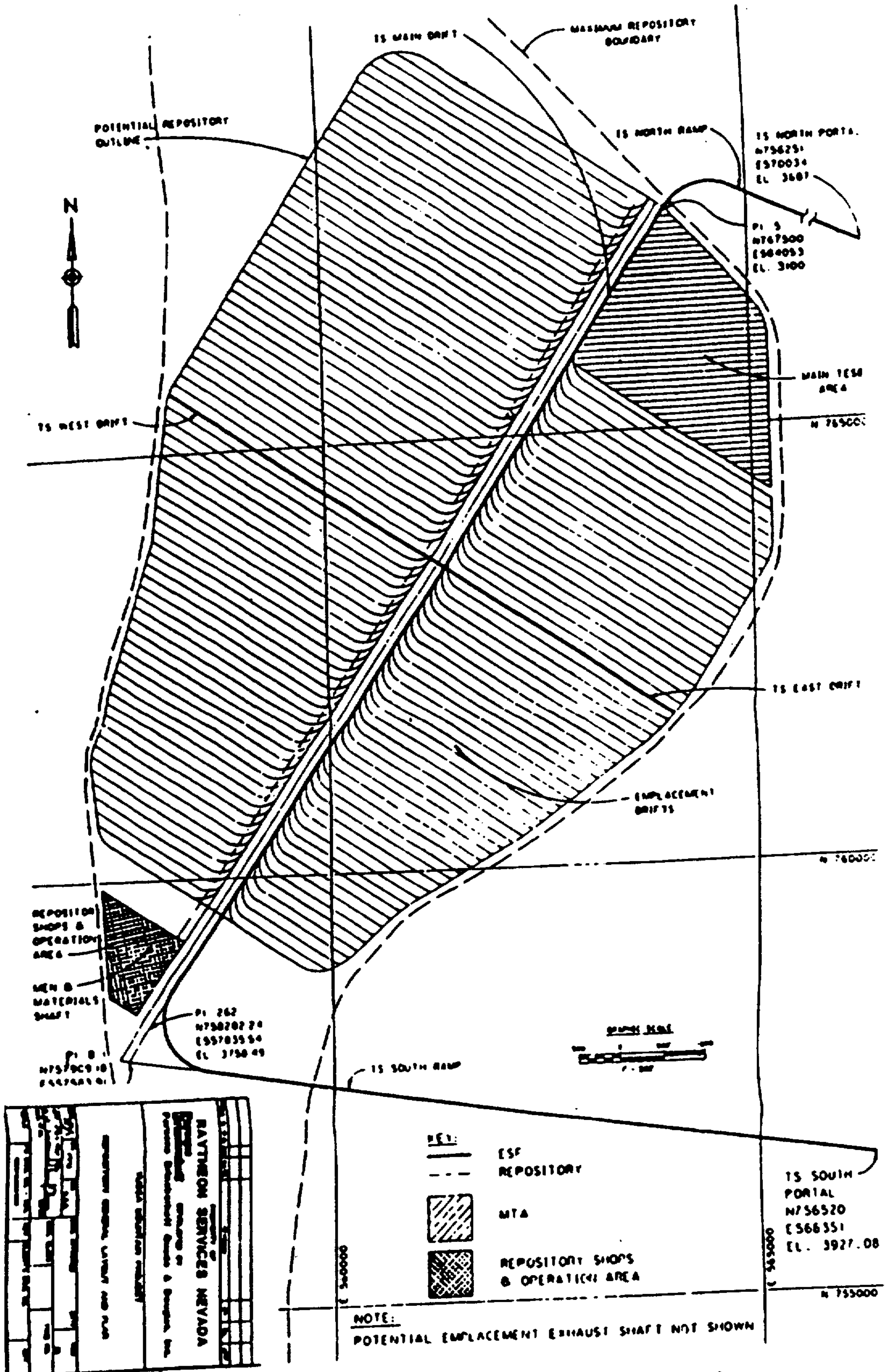


Figure 5-3 Modified Option 30 Repository Configuration

This baseline repository conceptual design is also included in a set of ESF-potential repository interface drawings in the ESF Technical Baseline (DOE, 1992). The repository drawing shows the north Topopah Spring Level (TSL) ramp at a slope of 9.52% and the main TSL drift sloping at 5.92%.

A revision to the slopes of the north ramp and main drift was made during ESF Title I design prior to acceptance of the Modified Option 30 configuration into the baseline, but this revision has not yet been incorporated into the technical baseline documents. The revision consisted of changing the elevation of the "entry point," which is the point where the curve of the north ramp ends and the TSL main drift begins. Re-evaluation of the TSw1/TSw2 geologic contact in drillhole cores allowed the entry point to be raised by 42.7 m (140 ft), thereby reducing the north ramp slope to 6.9% and the TSL main drift slope to 4.7%.

5.1.2 Geologic and Geoengineering Considerations

Geology, including stratigraphy and structure, provides a framework for repository analyses and design activities for Yucca Mountain. In the following sections, available geologic information, in addition to topographic data, site conditions, and material characteristics, is evaluated in regard to data needs for repository location, layout development, excavation stability analysis, and selection of ground support and excavation methods.

5.1.2.1 Topography

DOE (1986, Section 6.3.1.5.5) requires that the site be disqualified if at least 200 m of overburden does not exist over all parts of the potential repository to minimize the chance that erosion could disturb the facility. In addition, the location of repository openings must be chosen to allow for uncertainties in the depth of overburden and in future adjustments to grade. Incorporation of any additional area for the repository will also be controlled by the 200 m overburden requirement. To aid in evaluating the overburden limits, a plot of topography at a depth of 200 m is used (SNL, 1993b).

5.1.2.2 General Stratigraphy and Structure

General stratigraphy of Yucca Mountain is shown on Figure 5-4 with descriptions of geologic units given in Table 5-1 (Lin et al 1993a, Table 2-1). Structure and style of faulting are shown on cross sections by Scott and Bonk (1984) and by USGS (1993). The planned repository horizon is designated for the Topopah Spring Member of the Paintbrush Tuff and specifically for the TSw2 thermal-mechanical unit (DOE, 1993a). The TSw1 thermal-mechanical unit lies above and the TSw3 unit lies below the TSw2 unit. The thickness of the Topopah Spring Member in the Yucca Mountain area ranges from 150 to 374 m and averages 298 m based on 18 boreholes. Only three of the boreholes (USW G1, G3, and G4) provide information on the thickness of the TSw2 unit. These borings give a range in thickness of the TSw2 unit from 152 to 190 m. Structure contour maps on upper and lower contact surfaces of the TSw2 are available from SNL (1993b) and aid in delineating strata for the repository. By inspection (SNL, 1993b, SAN0103), the TSw1/TSw2 contact has a dip varying from about 9% (5°) to the east in the northern part of Area 1 (Figure 5-5) to about 14% (8°) in a N70°E direction in the southern part of Area 1.

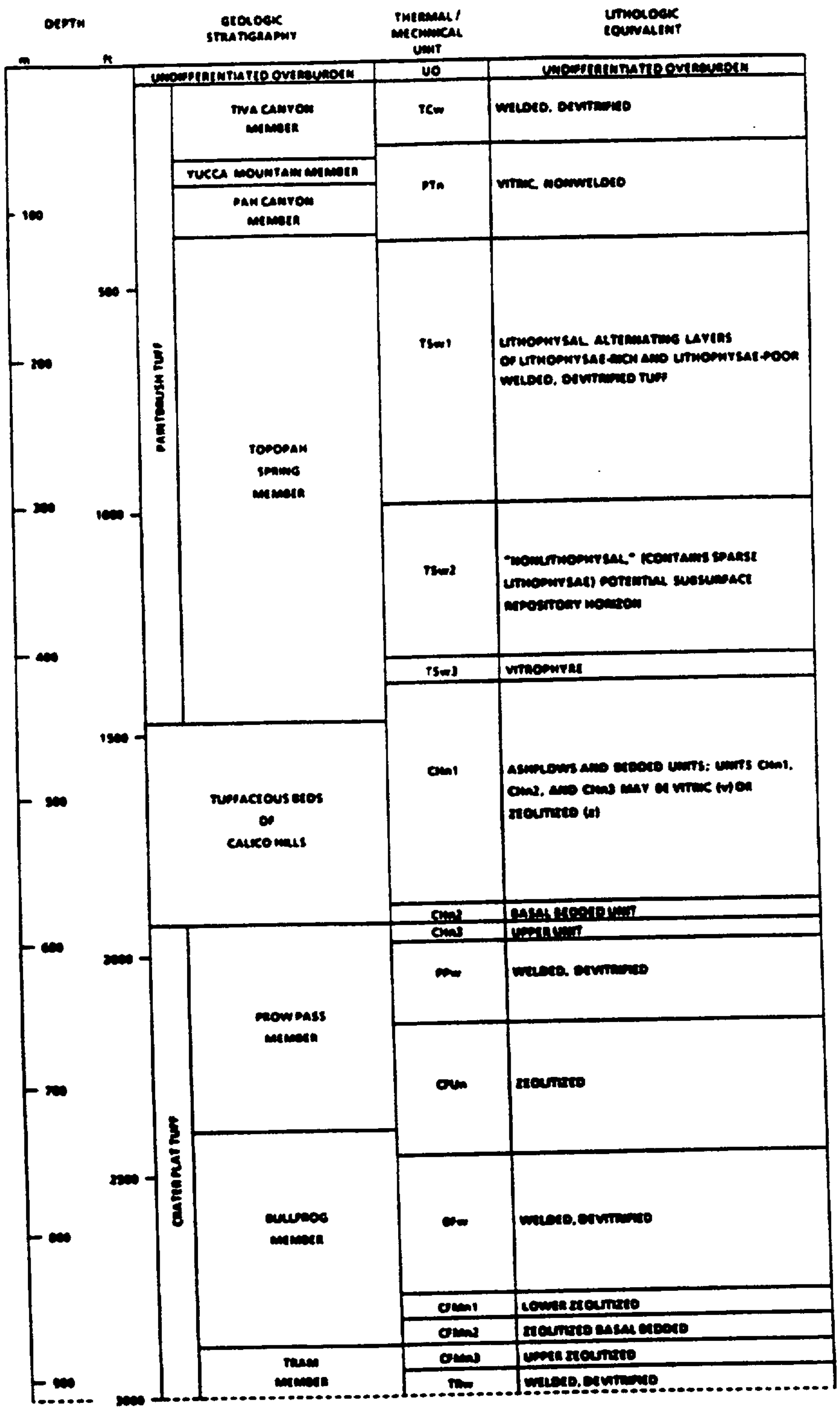


Figure 5-4 General Stratigraphy of Yucca Mountain

Table 5-1 Description of Geologic Units

Reference Stratigraphy Unit Name (Designator)	Description
Undifferentiated Overburden (UO)	Alluvium; colluvium; nonwelded, vitric ash flow tuff of the Tiva Canyon Member of the Paintbrush tuff; any other tuff units that stratigraphically overlie the welded, devitrified Tiva Canyon Member.
Tiva Canyon welded unit (TCw)	Moderately to densely welded, devitrified ash flow tuff of the Tiva Canyon Member of the Paintbrush tuff.
Upper Paintbrush nonwelded unit (PTn)	Partially welded to nonwelded, vitric and occasionally devitrified tuffs of the lower Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members of the Paintbrush tuff.
Topopah Spring welded unit, lithophysae-rich (TSw1)	Moderately to densely welded, devitrified ash flows of the Topopah Spring Member of the Paintbrush tuff that locally contains more than approximately 10% by volume lithophysal cavities.
Topopah Spring welded unit, lithophysae-poor (TSw2)	Moderately to densely welded, devitrified ash flows of the Topopah Spring Member of the Paintbrush tuff that contains less than approximately 10% by volume lithophysal cavities. This is the proposed repository host rock.
Topopah Spring welded unit, vitrophyre (TSw3)	Vitrophyre near the base of the Topopah Spring Member of the Paintbrush tuff.
Calico Hills and Lower Paintbrush nonwelded unit (CHn1)	Nonwelded ash flows, bedded and reworked tuffs of the lower Topopah Spring Member of the Paintbrush tuff and the tuffaceous beds of Calico Hills.
Calico Hills and Lower Paintbrush nonwelded unit (CHn2)	Basal bedded and reworked zones of the tuffaceous beds of the Calico Hills.
Calico Hills and Lower Paintbrush nonwelded unit (CHn3)	Upper partially welded ash flows of the Prow Pass Member of the Crater Flat tuff.
Prow Pass welded unit (PPw)	Moderately welded, devitrified ash flows of the Prow Pass Member of the Crater Flat tuff.
Upper Crater Flat nonwelded unit (CFUn)	Zeolitic, nonwelded to partially welded ash flows and bedded, reworked portions of the lower Prow Pass Member and the upper Bullfrog Member of the Crater Flat tuff.
Bullfrog welded unit (BFw)	Moderately to densely welded, devitrified ash flows of the Bullfrog Member of the Crater Flat tuff.
Middle Crater Flat nonwelded unit (CFMn1)	Zeolitic, partially welded to nonwelded ash flows of the lower Bullfrog Member of the Crater Flat tuff.
Middle Crater Flat nonwelded unit (CFMn2)	Zeolitic, basal bedded, reworked portion of the Bullfrog Member of the Crater Flat tuff.
Middle Crater Flat nonwelded unit (CFMn3)	Zeolitic, partially welded ash flows of the upper portion of the Tram Member of the Crater Flat tuff.
Tram welded unit (TRw)	Moderately welded, devitrified ash flows of the Tram Member of the Crater Flat tuff.

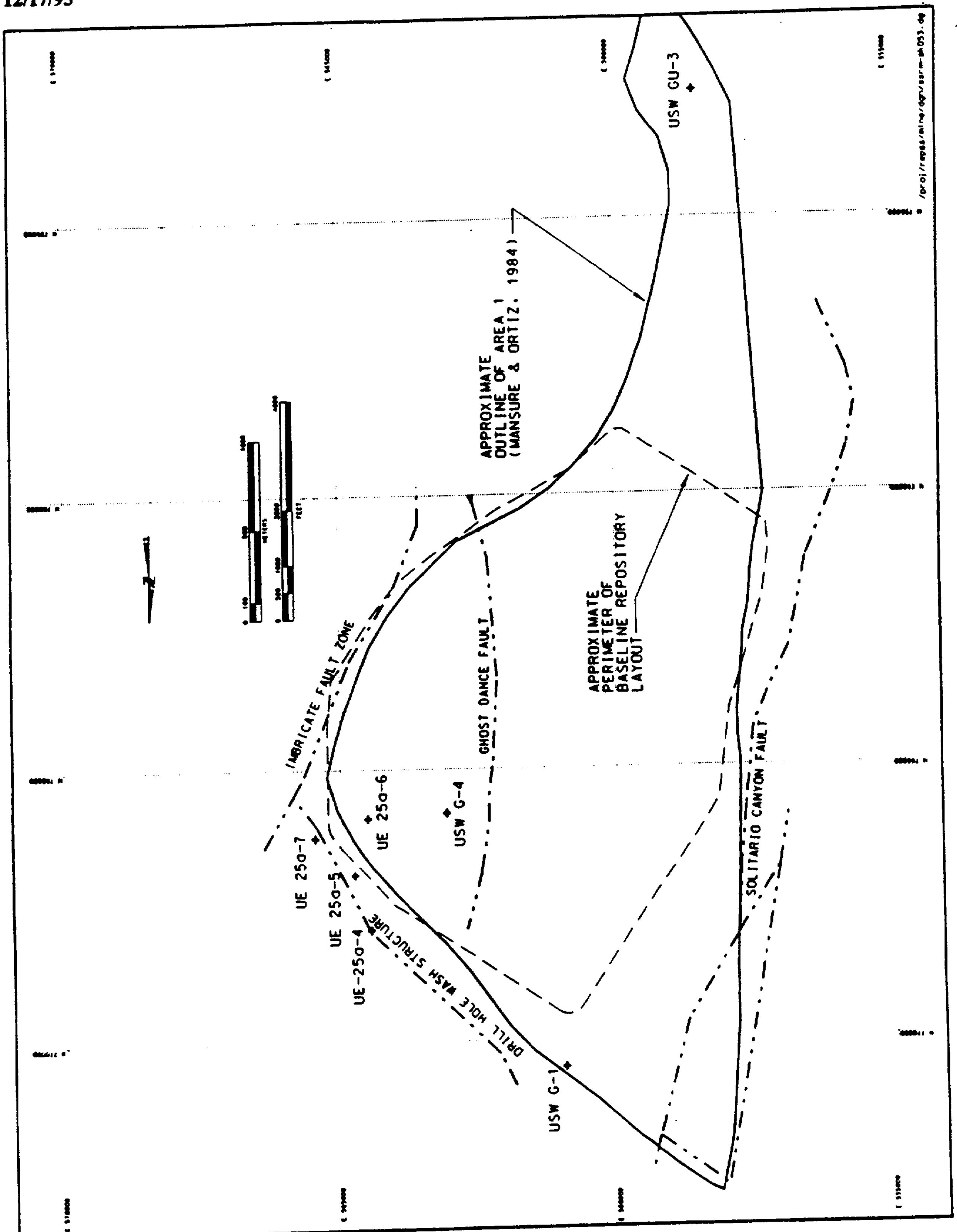


Figure 5-5 Surface Fault Traces Projected to Repository Horizon

5.1.2.2.1 Lithophysal Zones

Lithophysal-rich and lithophysal-poor zones in the Topopah Spring Member are believed to be significant for repository design, although currently, few data exist that clearly define design impacts. Nevertheless, stratigraphic characteristics and rock properties that may be related to lithophysal porosity are evaluated in regard to design.

Lithophysae are present in the Topopah Spring member in varying amounts. Individual lithophysa may or may not contain cavities, but the cavities and their size and distribution are considered to be the features of importance to engineering. TSw1 has a lithophysal cavity porosity varying from about 3 to 20% according to DOE (1993b, Section 1.2.1). TSw2 has a similar lithophysal porosity, from about 9 to 16% (DOE, 1993b, Section 1.2.1). However, Spengler et al (1984, Figures 4 and 5) shows that lithophysal cavities constitute less than 10% of TSw2 and in general, 5 to 30% of TSw1 based on USW borings GU-3, G-4, G-1, and G-2. These values are generally confirmed by preliminary estimates from boring NRG-6 giving porosities for TSw2 from 2 to 9% and for TSw1 from 9 to 50% (SNL, 1993c). The lowermost zone of TSw1 appears consistently mappable on the basis of a high lithophysal content.

In USGS stratigraphic terminology (USGS, 1993) the TSw2 unit includes, from top to bottom, the middle nonlithophysal zone (Tmn), the lower lithophysal zone (Tll), and the lower nonlithophysal zone (Tln). Thicknesses for the three zones based on borings USW G-4 and NRG-6 are estimated to be 59 m for Tmn, 80 m for Tll, and 50 m for Tln (SNL, 1993c; USGS, 1993). Differentiation of the TSw2 unit into three mappable zones on the basis of lithophysae may only be possible locally, judging from a comparison of drill hole data given in Spengler et al (1984). These data indicate that lithophysal porosity in drill holes to the north is distributed more or less uniformly throughout the TSw2 unit and individual lithophysal zones are not discernable.

5.1.2.2.2 Zeolitic Tuffs

The occurrence of thick zeolitic tuffs in continuous zones in the Yucca Mountain area has been a major consideration for choosing Yucca Mountain as a potential repository site. Zeolites provide a barrier to nuclear waste migration because they can sorb certain important radionuclides from the groundwater (Broxton et al, 1986). Zeolitic tuffs occur in intervals that can block downward migration of radionuclides in the unsaturated zone, and they also occur below the water table and can thus hinder lateral migration in the saturated zone (Broxton et al, 1986).

Using available cross sections that show the presence of the important zeolitic tuffs, some broad trends can be observed in the relative thicknesses of zeolitic strata beneath the potential repository area, mainly within the Calico Hills and the Crater Flat Tuff. For example, figures 6-10 through 6-13 in the Environmental Assessment (DOE, 1986) and figures 2 and 3 of Broxton et al (1986) show a concentration of zeolitic material trending generally north-south beneath the east side of Yucca Mountain. This concentration diminishes considerably to the west under Yucca Crest and apparently diminishes also to the northwest. It is uncertain how significant these changes are, but beyond the Yucca Crest to the west there are fewer occurrences of zeolitic tuffs in the unsaturated zone.

5.1.2.2.3 Stratigraphic Criteria for Constructability and Emplacement

Acceptability criteria for the tuff, related to constructability, stability, and thermal/mechanical characteristics for emplacement, are not established. The determination of minimum acceptable rock quality will depend ultimately on the evaluation of ESF development and testing. However, the current approach is to avoid both the TSw1 and TSw3 units and site the potential repository entirely within the TSw2 unit.

A study by Sandia (Mansure and Ortiz, 1984) initially placed the boundaries of the total thickness envelope needed for the proposed repository at 15 m above and below all excavations, including vertical emplacement holes. This vertical standoff amounts to approximately two times a typical drift height of 7.6 m. This was intended to allow sufficient flexibility to accommodate variations in repository design and uncertainties in ground conditions. This standoff was not considered a minimum, that is, with justification a lesser vertical standoff could be selected. The repository envelope was intended to lie completely within the TSw2 unit.

The proposed repository vertical standoff was subsequently reduced based on work by Braithwaite showing that a minimum 5-meter-thick pillar above repository openings is required for stability (Rautman et al, 1987). Upper and lower boundaries of the proposed repository are defined in DOE (1993b, Item 2.1.3) as planes 5 m above and below the maximum limits of mined openings, including vertical emplacement holes. These boundaries were chosen to include the minimum volume of rock within TSw2 required for long-term stability of excavated openings.

For ESF Title I design, the upper boundary standoff requirement of 5 m was applied at the Topopah Spring North Ramp entry point (987.8 m, 3240 ft, elevation; Esp, 1992). Also, upper boundary standoff was increased by 5 m to account for uncertainties in determining the TSw1/TSw2 contact at that point and in choosing the final main drift diameter (Esp, 1992). Thus, the distance between the top of the TS main drift and the upper boundary of the proposed repository thickness at the entry point was set at 10 m.

The Topopah Spring member on north-south sections through the repository area has an apparent dip of 2 to 4% to the north. East-west sections show an apparent dip of 7 to 12% to the east (Scott and Bonk, 1984; SNL, 1993a). Thus, the upper contact of the TSw2 unit has its lowest elevation at the northeast corner of Area 1. A repository layout with nearly horizontal grades has constructability and operational advantages. But to keep the repository as horizontal as possible yet within the TSw2, it is necessary that the upper boundary of key openings coincide as closely as possible with the TSw1/TSw2 contact without violating the requirement for vertical standoff as stated in DOE (1993b, Item 2.1.3). Location of the minimum elevation of the TSw1/TSw2 contact in the repository area is needed to design the repository layout.

5.1.2.3 Faults

Usable repository areas are outlined by major faults, such as the Solitario Canyon fault zone on the west side of the primary area. Another important fault zone, called the Drill Hole Wash structure, defines the north edge of the primary area, and the Imbricate fault zone borders the area on the east. Major faults, such as the Solitario Canyon fault, form boundaries of usable repository areas because they significantly offset the TSw2 unit, are potentially seismogenic, and/or indicate potentially poor ground conditions for underground excavation or waste emplacement. Subsurface projections of faults have been determined with the aid of USGS (Scott and Bonk, 1984) and Sandia (SNL, 1993a) maps and sections and used to define lateral repository boundaries. Projections of important surface fault traces to the proposed repository horizons are shown on Figure 5-5.

5.1.2.3.1 Fault Descriptions

Drill Hole Wash Structure

Northwest-trending Drill Hole Wash marks a change from generally north-south trending normal faults south of the wash to northwest-trending faults with strike-slip displacement on the north side of the wash (Scott and Bonk, 1984). The so-called Drill Hole Wash structure is believed to be part of the series of strike-slip faults that lie between Drill Hole Wash and Yucca Wash. Right-lateral offset is probably less than 100 m and vertical offset less than 4 m (DOE, 1988). The faulting appears to be Tertiary. Alluvial cover in Drill Hole Wash prevents a more detailed investigation of the structures, however, geology of the Yucca Mountain area shows that the wash approximately lines up with a structural low that plunges to the southeast (Scott and Bonk, 1984).

Ghost Dance Fault

The Ghost Dance fault has been the focus of special attention by the U. S. Geological Survey (Spengler and others, 1993) because of its location within the primary area of the proposed repository. The Ghost Dance breaks the horizontal continuity of the potential repository block by displacing the TSw2 unit down to the west. If the required repository horizon crosses the Ghost Dance fault, offset of the TSw2 unit makes a "step" necessary to maintain a flat grade and keep the horizon within the TSw2 unit. The dip of the tuff strata alone would necessitate a stepped repository to maintain a near-horizontal grade, however, the position of the Ghost Dance fault essentially dictates where the step will be.

Important characteristics of the Ghost Dance fault are as follows:

> Orientation - The main surface trace of the Ghost Dance fault is oriented approximately N-S along Nevada State coordinate E562500. The fault dips steeply to the west and the western side is down-dropped. The subsurface trace at the potential repository horizon is about 100 ft west of coordinate E562500, assuming a westward dip of 80^0 (Scott and Bonk, 1984).
>
> Offset - The magnitude and variation of offset along the Ghost Dance fault is known only approximately. Cumulative west-side-down offsets in the 700- to 1200-foot-wide fault

zone being mapped by the USGS range from 21 to 47 m (70 to 155 ft) (Spengler et al, 1993). Vertical offset is 38 m (125 ft) at the southeastern boundary of the proposed repository, decreases northward, and is unmeasurable at Drill Hole Wash (DOE, 1988, Section 1.3.2.2.2). Quaternary offset has not been demonstrated for the Ghost Dance.

Zone of faults - Detailed surface mapping by the USGS is currently being conducted along portions of the Ghost Dance fault which crosses the primary repository area (Spengler et al, 1993). This work has delineated a zone of discrete faults, at least 213 m wide near the southern edge of the repository area but perhaps as much as 366 m wide in the central area. The faults, spaced 15 to 46 m apart, are on both sides of and parallel to the main Ghost Dance fault trace and dip steeply to the west. Displacements range from 3 to 6 m. Predominant attitudes of fractures are steeply dipping and strike between N 10^0 W and N 20^0 W, according to Spengler et al (1993).

Individual faults in the zone mapped by Spengler et al (1993) appear as localized areas of broken and brecciated rock. The breccia is composed of either crushed tuff fragments or is cemented by calcium carbonate and/or silica and occurs in areas at least as wide as 3 m judging from a cross section by Spengler et al, 1993. The breccia appears dense and resistant in outcrop and is confined to relatively narrow areas paralleling fault traces.

Imbricate Fault Zone

The Imbricate fault zone is a zone of imbricate normal faults that bounds the primary area on the east and southeast. The zone is at least a kilometer wide and is generally an area of frequent west-dipping normal faults that follow the northerly trend of the Bow Ridge fault on the east. South of the primary area the zone merges into a broad area of faults between Yucca Crest and Bow Ridge. The Bow Ridge fault has Quaternary offset but more recent offset than Tertiary is not known for faults of the Imbricate zone.

Solitario Canyon Fault

The Solitario Canyon fault lies along Solitario Canyon just west of the N-S trending crest of Yucca Mountain. The fault is normal, downthrown to the west, with offset as much as 500 m and an aggregate length up to 17 km (DOE, 1988). The fault is a zone characterized by closely spaced faults and breccia (Scott and Bonk, 1984). The zone of faulting varies from about 150 to 500 m wide at the ground surface, with much of the zone being covered by the alluvium of Solitario Canyon. The east margin of the fault zone is exposed along the base of Yucca Mountain. The fault extends to the north of Solitario Canyon as a linear trend in bedrock exposures, and although largely obscured to the south by surficial deposits, the fault trend is confirmed in places by aeromagnetic anomaly data (Scott and Bonk, 1984). Quaternary offset has been demonstrated on the Solitario Canyon fault, although there is no evidence of movement during the past 270,000 years (DOE, 1988).

5.1.2.3.2 Expansion of the Usable Portion of the Primary Area

Areas to the north and south of the primary repository area are identified in the SCP-CDR (SNL, 1987, Chapter 8, p. 8-14, "Usable area and flexibility evaluation") as proposed expansion areas. The areas are considered potentially usable because they are geologically similar to the primary area but await further characterization. This implies that the expansion areas are in the same category as the primary area and depend on further subsurface investigation by ESF excavation to determine ultimate acceptability.

Except for the Ghost Dance fault zone, the primary area contains relatively few faults, most with minor offsets (20 m or less), and rare fault breccias (SNL, 1987). The potential expansion areas also have a relatively low fault density. For example, the boundary between the primary area and the expansion area immediately to the southeast is only approximate since the two areas are considered geologically similar. Available thickness of the TSw2 is not well documented, but the total Topopah Spring thickness (Section 5.1.2.2) appears sufficient to indicate a suitable TSw2 thickness. Thus, there do not appear to be any stratigraphic or structural constraints to preclude using the expansion areas to the north and to the south of Area 1 (see Figure 5-5) for a repository.

5.1.2.4 Joints

Typical attitudes of steeply-dipping joint sets in the Topopah Spring member are listed in Table 5-2 based on limited data from borings USW G1, UE 25a-4, 5, 6, and 7, USW G-4, and USW GU-3. Strikes of the steeply-dipping sets fall into three general groups with trends: north, northeast, and northwest. The majority of dips range from 60^0 to 90^0. A fourth group of joint sets has low-angled dips ranging from 10^0 to 30^0.

The dominant trend for all joint data is the approximate north trend of steeply-dipping sets. The northeast trend is significant in the UE 25a holes and in GU-3 and also shows up in USW G-1 and USW G-4. The northwest trend is generally a minor set, although significant locally in USW G-4. For design analysis, the SCP-CDR (SNL, 1987) recognizes sets at N12^0W (north trend) and N34^0E (northeast trend) as being significant, which agrees with the observations presented here.

5.1.2.4.1 Preferred Orientation of Drifts

The designation of a favorable drift alignment does not mean that other alignments are not feasible, only that, based on current information, drifts are likely to be more self-supporting along certain orientations. The preferred alignment for a drift relative to steeply dipping planar structures, such as joints or faults, is perpendicular to the joint or fault strike (SNL, 1987, Section 6.4.2). Likewise, the preferred alignment for a drift that crosses the intersection of a shallow joint set and a steep joint set is perpendicular to the line of intersection.

Data in Table 5-2 show joint sets with dips from 10^0 to 30^0 that appear in at least three of the borings. The intersection of a low-angled set with a steeply-dipping set could form wedges and blocks that have a greater potential for movement for drifts oriented parallel to the line of intersction or close to the strike of the steeply-dipping joint set. A parallel drift/joint-intersection orientation could result in an irregular profile due to fall out. In addition, sidewall fall out could result where thin slabs occur between vertical joints parallel to the opening, although this is not as likely with a TBM-produced circular cross section as it might be in rectangular openings constructed using other excavation methods.

Table 5-2. Strikes and Dips of Joint Sets in the Topopah Spring Member (data from Maldonado and Koether, 1983; Scott and Castellanos, 1984; Spengler, Byers, and Warner, 1981; Spengler and Chornack, 1984).

Borehole	N-trending sets with steep dips	NE-trending sets with steep dips	NW-trending sets with steep dips	Sets with low-angle dips
USW G-1	N5°W; 61°S	N28°E; 64°S	N33°W;50°S	---
UE 25a-4,5,6,7	N12°W; 90°	N37°E; 90°	(N40°W; 78°S)	(N20°W;10°E)
USW G-4	N5°W; 90°	(N30°E; 90°)	N40°W; 90°	(EW;30°N)
USW GU-3	N10°W; 90°	N45°E; 90°	(N40°W; 85°N)	(N28°E;10°E)

( ) indicate an infrequent or minor joint set

A drift oriented perpendicular to a zone of jointed rock encounters the least amount of potentially unstable wedges or blocks. At drift/joint angles less than 90°, a greater length of jointed ground will be encountered. The length of jointed ground is increased 1.4 times at 45°, 2 times at 30°, and 3 times at 20°. For intersections less than 20°, the drift length in jointed ground increases rapidly. As a preliminary criterion, the preferred drift alignment is one that makes an angle of at least 30° with the dominant joint orientations.

In the case of two intersecting, steeply dipping (50-90 degrees) joint sets, the line of intersection is steep, and the optimum orientation for drifts will be close to the bisector of the larger angle between the strikes of the joint sets (SNL, 1987, Section 6.4.2). Applying the 30° criteria, the most favorable drift alignments for the joint set trends in Table 5-2 are between N70°W and S75°W.

5.1.2.4.2 Joint Parameters

Joints are abundant in the tuff rock mass at Yucca Mountain, especially in the densely welded tuff of the Topopah Spring Member (Lin, Hardy, and Bauer, 1993a, Section 6). Since the state of stress at the proposed repository horizon is relatively low, jointing is expected to control the mode of deformation of the underground openings (Section 5.1.2.5.2). Design analysis, therefore, must consider the effect of jointing. Empirical and analytical methods used to examine excavation stability and select rock reinforcement require joint parameters as input. The "Q" and Rock Mass Rating (RMR) systems, for example, are based on such joint-related parameters as Rock Quality Designation (RQD), the number of joint sets, joint roughness, and joint alteration. Additional parameters include rock intact strength, groundwater, and stress state. Numerical codes designed to model jointing require information on joint geometry such as orientation, spacing, and continuity as well as joint strength and stiffness properties.

Sources of joint data for the TSw2 unit are Hardy and Bauer (1991, Section 12.2) and Lin, Hardy, and Bauer (1993a and 1993b). Based on these sources and borehole data from current drilling (SNL, 1993c), the TSw2 unit is a densely welded tuff with one to three near-vertical joint sets that account for the majority of joints and one sub-horizontal joint set that occurs infrequently. The frequency of joints dipping from 60 to 90^0 ranges from 0.19 to 24.07 joints/m, which corresponds to joint spacings from 5.26 m to 41mm, respectively. Joint roughness ranges from smooth and undulating to discontinuous. Fracture fillings are thin and consist of manganese oxide and calcite.

Rock classifications for the TSw2 unit are given in Table 5-3 based on the above sources. These data and preliminary RQD values from Section 5.1.2.2.1 from boring NRG-6, indicate a highly jointed rock mass. However, the presence of at least two major joint trends, joint roughness, and the lack of significant fracture fillings also indicate the TSw2 unit is an interlocking rock mass.

5.1.2.4.3 Rock Quality Categories

Rock mass classification using the Q-system and the RQD index provides a means of characterizing the TSw2 unit. RQD has been used by Lin, Hardy, and Bauer (1993b) to establish five rock quality categories to account for spatially variable rock conditions in the thermomechanical units at Yucca Mountain. These categories can be used to differentiate strata within the TSw2, but borehole data are limited and correlations between boreholes are not apparent. For example, categorization of USW boreholes GU-3, G-4, and G-1 indicates that categories do not occur at the same stratigraphic horizons from borehole to borehole. Although there is typically a change in rock quality category between TSw1 and TSw2, the change is not necessarily the same from one borehole to another. For example, the lower 60 m (200 ft) of TSw1 has a relatively high rock classification category in GU-3, but a low classification category in G-4.

Preliminary RQD measurements from boring NRG-6 (SNL, 1993c) show no distinct mappable zones of rock quality within TSw2. However, there is a definite contrast between TSw2 and TSw1. RQD varies from 0 to 35% with an average of 9% for the upper 71 m of TSw2 and from 0 to 39% with an average of 10% for the upper 125 m. On the other hand the RQD of the lower 61 m of TSw1 ranges from 0 to 80% with an average of about 27%. The major mappable contrast seems once again to be between the TSw1 and TSw2 units.

Table 5-3. Rock Classifications for the TSw2 Unit.

TSw2 Rock Quality Category	1	2	3	4	5
RQD	16 very poor	26 poor	41 poor	62 fair	84 good
Q	0.21 very poor	0.57 very poor	1.94 poor	12.30 good	64.96 very good
RMR	49 fair	57 fair	62 good	73 good	82 very good

Avoidance of zones of apparent low rock quality may prove to be difficult due to lateral and vertical variability of rock quality within the TSw2 based on current borehole data. Indeed, apparent variability in rock quality between the TSw1 and the TSw2 units does not allow a consistent distinction to be made between the two units except on a local basis. As mentioned above, in some borings the rock quality of the TSw1 is better than the TSw2, while the opposite condition exists in other borings. Thus, there appears to be no predictable difference between the TSw1 and TSw2 units based on rock quality.

Although Lin, Hardy, and Bauer (1993a, Section 6.0) state that lithophysal-rich units commonly are associated with a slight decrease in joint frequency, rock quality does not show a significant correlation with lithophysal porosity based on information in Spengler and Chornack (1984) and Lin, Hardy, and Bauer (1993a, Appendix C). Recent data from boring NRG-6 supports this contention (SNL, 1993c).

5.1.2.5 Site Conditions

5.1.2.5.1 Groundwater

A condition for waste disposal in the unsaturated zone is "a water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock" (DOE, 1986, Table 6-15). In the Yucca Mountain area, the regional water table slopes to the southeast from an elevation of about 800 m to about 730 m above sea level (SNL, 1993b). As a reference case, the repository conceptual design presented in the SCP-CDR (SNL, 1987) is approximately 200 to 400 m above the water table.

5.1.2.5.2 In Situ Stress

The maximum principal stress is the vertical stress due to lithostatic load, which at the potential repository horizon has an approximate value of 7.0 MPa. Horizontal stresses are expected to be lower with an average minimum of 3.5 MPa and an average maximum of 4.2 MPa. Values of horizontal stresses could range from 2.1 MPa to 7.0 MPa. The in situ stress components from the SCP-CDR (SNL, 1987, Section 2.3.1.9) are given in Table 5-4 .

The in situ stress values shown in Table 5-4 are generally confirmed by a stress profile in the Reference Information Base (RIB) (DOE 1993b, Section 1.2.10) calculated for the ESF test area , which gives for a 300 m depth: vertical stress = 6.0 MPa, maximum horizontal stress = 4.2 MPa, and minimum horizontal stress = 2.1 MPa. A constant ratio of maximum to minimum horizontal stresses of 2:1 was assumed for the RIB analysis. The same stress ratio in the SCP-CDR, by contrast, is only 1.2:1.

Table 5-4. Average Values and Ranges for Principal Stresses at the Proposed Repository Horizon (SNL, 1987, Section 2.3.1.9).

Parameter	Average Value	Range
Vertical Stress	7.0 Mpa	5.0 to 10.0 Mpa
Min. Horiz./Vertical	0.5	0.3 to 0.8
Max. Horiz./Vertical	0.6	0.3 to 1.0
Bearing Min. Horiz.	N57^{o}W	N50^{o}W to N65^{o}W
Bearing Max. Horiz.	N32^{o}E	N25^{o}E to N40^{o}E

In general, horizontal in situ stresses at the repository site are expected to be low, consequently failure modes around underground openings during construction will be mainly structurally controlled (see for example Hardy and Bauer, 1991, Figure 12-5). Minimum and maximum horizontal/vertical stress ratios are close, indicating a weak horizontal stress anisotropy. Consequently, lateral stresses should be approximately the same and the effects similar for all drift orientations.

5.1.2.5.3 Seismicity

Vibratory ground motions for repository seismic design are given in the RIB (DOE, 1993b, Section 2.1.2). An assessment of regional and local seismicity for ESF design for Yucca Mountain is on-going and will provide an update to the current seismic design basis and further guidance for repository seismic design. Site specific analyses that incorporate earthquake time histories and joint characteristics are expected to aid in understanding design needs for long-term stability.

Rock support conceptual design for the repository, which incorporates rock bolts, mesh, and straps, has inherent flexibility to accommodate seismically generated strains. In addition, the long-term effectiveness of the support system will be enhanced by TBM excavation which produces a stable circular shape and relatively smooth maintainable excavation surfaces.

Empirical evidence and numerical analyses (Hardy and Bauer, 1991; Richardson, 1990) applied to examples of conceptual designs for shafts and ramps indicate long-term seismic stability for the particular thermal conditions considered (Panel Areal Power Density (PAPD) of 14 W/m^2). Significant rock disturbance is noted only for examples where recommended limiting seismic loads of 1.67 times design are combined with in situ and thermal loads. In these cases, additional provision for ground support is indicated (Hardy and Bauer, 1991, Section 12).

5.1.2.5.4 Rock Parameters for Mechanical Excavation

In addition to machine characteristics, the cutting performance of a tunnel boring machine in hard rock is primarily a function of unconfined compressive strength, brittleness, tensile strength, abrasivity, and joint frequency or RQD. Physical and mechanical data for use in the design and production estimation of mechanical excavation systems are given in RSN (1992). Compiled in this report are mineralogical, porosity, density, strength, deformability, hardness, and abrasivity data from tests on intact samples of principal rock units at Yucca Mountain. For further details on data for mechanical excavation, refer to Ozdemir et al (1992), and Gertsch and Ozdemir (1992). Rock parameters for the TSw2 unit that are important to mechanical excavation are given in Table 5-5.

As mentioned in Section 5.1.2.2.1 lithophysal porosity appears to be the most mappable feature of the Topopah Spring member. Bulk density and intact (non-jointed) strength are correlative with porosity and thus variations in these properties can be anticipated on the basis of porosity. TSw2 has an intact compressive strength comparable to TSw1, however, the strength of the lithophysae-rich TSw1 is only about one tenth of the intact TSw2 (DOE, 1993b, Section 1.2.5). RQD and joint frequency, although relatively consistent for thicknesses of TSw2 as great as 60 to 90 m according to data in Lin, Hardy, and Bauer (1993a, Appendix C), is not laterally predictable (Section 5.1.2.4.3). Quartz content is uniform throughout TSw2, except in fractures where quartz content is much higher than the mean, for example, 67% in one case.

Table 5-5. Rock Parameters for the TSw2 unit that are Important to Mechanical Excavation

Parameter	Mean	Range	Source
Unconfined compressive strength	161 MPa	98 to 224 MPa	Lin, Hardy, and Bauer (1993b, Table 3-1)
Tensile strength	3.62 MPa	0.35 to 10.67 MPa	Lin, Hardy, and Bauer (1993b, Table 6-2, rock mass values)
RQD	41 %	16 to 84 %	Lin, Hardy, and Bauer (1993a, Table 5-9)
Joint frequency (volumetric)	19.64 m^{-3}	5.41 to 40.61 m^{-3}	Lin, Hardy, and Bauer (1993a, Table 3-12)
Elastic Modulus	32.7 GPa	28.1 to 37.3 GPa	Lin, Hardy, and Bauer (1993b, Table 3-1)
Quartz content	33 %	29 to 38 %	Bish and Chipera (1989, Appendix A, USW G-4)

5.1.2.6 Geologic and Geoengineering Conclusions

The following conclusions are listed as they relate to aspects of repository horizon selection and selection of drift alignment.

5.1.2.6.1 Repository Horizon Selection

Location of an upper boundary of the repository horizon is principally influenced by the requirement to provide a minimum overburden of 200 m. However, an upper stratigraphic control is not clearly defined. Even though lithophysae porosity of the TSw1 unit appears greater than the TSw2, there is as yet no basis for favoring one unit over the other. Also, differences between the TSw1 and the TSw2 units on the basis of rock quality are not consistent. However, due to uncertainty about differences in mechanical and thermal characteristics between TSw1 and TSw2 units, the TSw1/TSw2 contact should be considered an upper limit for the repository horizon.

The TSw2 unit provides adequate thickness for the repository. There do not appear to be stratigraphic zones within the TSw2 that would limit repository development. The TSw2/TSw3 contact provides a lower limit to repository development that maximizes the distance above the water table and the thickness of underlying zeolitic strata.

The lateral extent of repository development may be limited by some faults. The Ghost Dance fault is apparently the most important of these. Potentially poor ground conditions along the main trace of the Ghost Dance fault suggest that a standoff be established for repository openings. A standoff based on the full width of the so-called Ghost Dance fault zone does not appear to be warranted. Uncertainties in the importance of other faults or zones of faults suggest that standoffs be established for these faults until further field data is available. Potential expansion areas to the north and south of Area 1 appear usable for repository development.

5.1.2.6.2 Drift alignment

Based on the strikes of predominant joint sets, the most favorable drift alignments appear to be between N70°W and S75°W. Drifts aligned north-south may encounter less favorable ground conditions. Lateral in situ stress magnitudes appear to be approximately the same for all drift orientations.

5.1.3 Waste Package Design

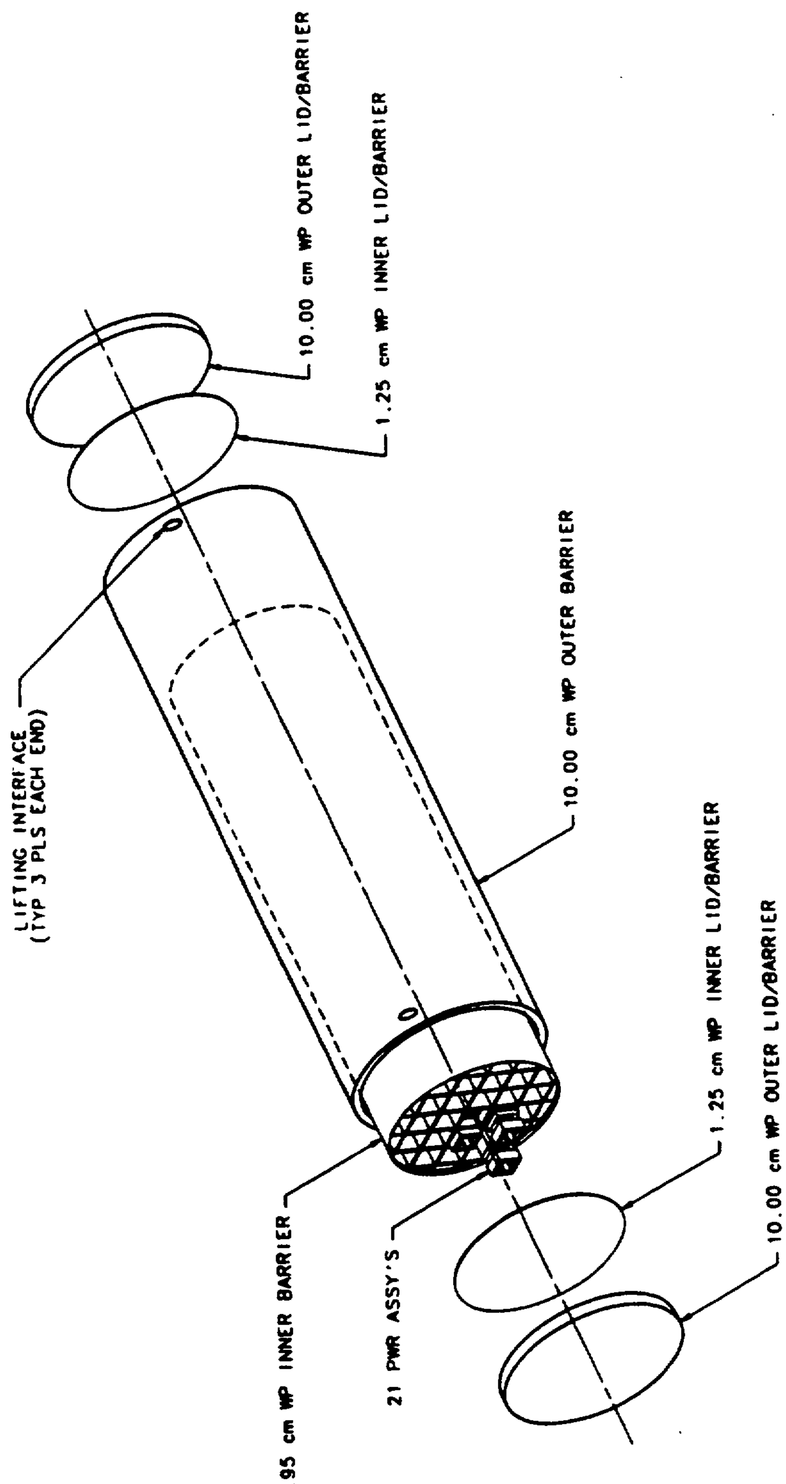
The advanced conceptual design of the waste package, supported by systems study analysis, is considering a wide variety of potential waste package concepts and configurations. The repository ACD effort is evaluating various emplacement mode concepts that are oriented toward compatibility with large, high heat output waste package designs such as the Multi-Purpose Canister (MPC) and multi-barrier waste package concepts currently under consideration.

Pre-ACD waste package designs are described in the SCP-CDR (SNL,1987). These waste packages were designed as thin-walled, right circular cylinders with end closures and a lifting fixture on one end. The metal containers were 710-mm in diameter with a nominal wall thickness of 10-mm. Weights varied from 2.7 to 6.4 tonnes depending on the waste type and packages were estimated to have potential heat output in the range of 3 kW per package.

Waste packages containing as many as 24 Pressure Water Reactor (PWR) or 52 Boiling Water Reactor (BWR) Spent Nuclear Fuel (SNF) assemblies, with individual package heat outputs of more than 10 kW, are presently being given strong consideration in the CRWMS program. The following general concepts are being considered during ACD by the waste package design group:

- Large Metallic Multi-Barrier
- Small Metallic Multi-Barrier (borehole emplacement)
- Metallic Totally Shielded
- Non-Metallic Multi-Barrier
- Overpacked Multi-Purpose Canisters (MPC)
- Universal Cask Waste Package

Figure 5-6 illustrates a preliminary multi-barrier waste package design. Table 5-6 lists conceptual data for some of the multi-barrier concepts that are currently being considered.



MASS	CONTAINER OD	CONTAINER LENGTH
52,570 kg	175.2 cm	530.8 cm

Figure 5-6 Preliminary Multi-Barrier Waste Package

Table 5-6 Selected Examples of Spent Nuclear Fuel Multi-Barrier Waste Packages*

DESCRIPTION	LENGTH cm	OUTER DIAMETER cm.	LOADED WITH PWR WEIGHT tonnes	THERMAL OUTPUT @ 482kw/ASSM
6 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 10 CM	483.1	118.8	23	2.89
12 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 10 CM	483.1	140.6	34	5.78
21 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 10 CM	483.1	175.2	50	10.12
6 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 20 CM	503.1	138.8	41	2.89
12 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 20 CM	503.1	160.6	55	5.78
21 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 20 CM	503.1	195.2	77	10.12
6 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 45 CM	553.1	188.8	102	2.89
12 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 45 CM	553.1	210.6	126	5.78
21 PWR, 1 ST BARRIER 0.95 CM, 2 ND BARRIER 45 CM	553.1	245.2	164	10.12
6 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 10 CM	488.2	123.9	27	2.89
12 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 10 CM	488.2	145.7	39	5.78
21 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 10 CM	488.2	180.3	57	10.12
6 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 20 CM	508.2	143.9	46	2.89
12 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 20 CM	508.2	165.7	61	5.78
21 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 20 CM	508.2	200.3	85	10.12
6 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 45 CM	558.2	193.9	110	2.89
12 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 45 CM	558.2	215.7	135	5.78
21 PWR, 1 ST BARRIER 3.5 CM, 2 ND BARRIER 45 CM	558.2	250.3	175	10.12

* WASTE PACKAGE PERFORMANCE ALLOCATION STUDY REPORT, M&O, SEPTEMBER 29, 1993, DI: B00000000-01717-5707-00010 REV. 00

5.1.4 Thermal Considerations

This section discusses various thermal considerations important to the design, operation and performance of a mined geologic repository. Thermal goals and areal thermal loading issues are briefly described, access drift standoff distances are addressed, and various thermal factors related to opening stability are presented.

5.1.4.1 Thermal Goals

A series of thermal goals have been developed by the YMP to assist in the evaluation of repository performance. These goals can be traced back to applicable federal regulations that govern the development of a high-level nuclear waste repository. The bulk of the applicable federal regulations are contained in 10 CFR, Section 60.133.

The thermal goals that currently form the basis for performance evaluations were published in the SCP (DOE, 1988) and are listed in Table 5-7. (The SCP utilized horizontal and vertical emplacement modes, in which the waste packages were emplaced in drilled boreholes, so many of the thermal goals listed in Table 5-7 relate to temperatures surrounding the borehole and are not relevant to other emplacement modes, such as in-drift.)

These thermal goals are being reevaluated at this time to incorporate the in-drift emplacement mode.

Table 5-7 SCP Thermal Goals

Performance Measure	Goal
Cladding Integrity	Container Centerline T < 350°C Borehole Wall T < 275°C
Near-Field Rock Mass Integrity	1-m from Borehole T < 200°C
Access Drift Wall Temperature	T < 50°C for 50 years after Waste Emplacement
Temperature Change in Adjacent Strata	TSw2/TSw3 Interface T < 115°C
Surface Environment	Temperature Change < 6°C
Limit Corrosiveness of Canister Environment	Majority of Borehole Walls Above Boiling Temperature of Water for > 300 yr

5.1.4.2 Repository Areal Power Density Considerations

The thermal conditions in the repository depend upon the Areal Mass Loading (AML) (defined as the mass of the waste in the repository divided by the area in which it is emplaced), as well as the thermal characteristics of the waste. The unit of areal mass loading is in Metric Tons Uranium equivalent per acre (MTU/acre). Depending upon the age, burnup rate and the radionuclide content of the waste, the areal mass loading can be converted to an Areal Power Density (APD), also referred to as an Areal Thermal Loading (ATL).

One definition of APD is the Local Areal Power Density (LAPD). Defined as the initial (i.e., at the time of emplacement) thermal power, or output, of a single waste package divided by the area of a unit cell, the LAPD is useful in monitoring the near-field thermal effects of a waste package that is not situated near the edge of an emplacement area. The area of a unit cell is the emplacement drift centerline spacing multiplied by the waste package centerline spacing. The unit of LAPD is in W/m^2; however, the YMP has historically referred to APD and LAPD in terms of kW/acre.

Another definition of APD is one that includes the effect of repository layouts in which the emplacement area is divided into distinct "panels." The panel areal power density (PAPD) is calculated as a reduction in the value of LAPD because the area that is not used for actual waste emplacement, such as panel access drifts, panel abutment pillars, and thermal standoff zones located around the edges of each panel are included in the calculation of the PAPD. It should be mentioned that YMP has historically used the term APD when actually referring to PAPD, e.g., the PAPD of the SCP repository layout is 14.1 W/m^2 (57 kW/acre), while the LAPD is considerably higher, at approximately 17.7 W/m^2 (70 kW/acre).

The APD or ATL is a very important characteristic related to the design of a repository. If we assume a total waste inventory of 70,000 MTU, then the APD is directly related to the available area, or "capacity" of the repository site, the repository subsurface layout, and repository performance. In principle, the higher the APD, the smaller is the required emplacement area of the repository, which is desirable from a construction/development cost and schedule viewpoint. The effective use of available area requires that the APD be maximized to the extent possible while meeting all of the performance requirements of the system.

The construction of emplacement drifts represents a major portion of the total underground construction effort. As indicated in a total system life cycle cost estimate (Bechtel and PBQ&D, 1990), for a 70,000 MTU repository facility, the excavated volume of the emplacement drifts accounted for about 70% of the total underground excavation quantity. This indicates the importance of optimizing the design of the waste emplacement layout, in terms of waste package spacing and emplacement drift spacing, for a particular thermal loading scenario and consistent with applicable thermal goals. The optimum solution will be one in which the number of waste packages per unit length of emplacement drift is maximized, while satisfying all of the thermal, mechanical and performance constraints which bound the problem.

The thermal loading of the repository is currently being reevaluated using a wide spectrum of APDs, ranging from "cold" to "extended hot" concepts. The "cold" concept represents a low

ATL strategy in which repository temperatures do not exceed the boiling point of water. The "extended hot" concept represents a high ATL strategy in which temperatures are maintained above the boiling point of water for thousands of years in the host rock. Various repository program participants are currently evaluating APDs ranging from 5 to 28.2 W/m^2 (20 to 114 kW/acre) to predict thermal, thermal-hydrological and thermomechanical responses.

A recent study by Hertel and Ryder (1991) recommended a reasonable limit for LAPD of approximately 25 W/m^2 (100 kW/acre), based on meeting various thermal constraints, and using the SCP layout design with 10-year-old waste emplaced in both the vertical and horizontal modes. In another thermal calculation study, using a range of LAPDs from 5 to 28.2 W/m^2 (20 to 114 kW/acre), and the SCP layout (Ryder, 1992), it was indicated that a maximum LAPD of 25 W/m^2 (100 kW/acre) could be considered viable using both vertical and in-drift emplacement for 30-year-old nuclear waste. Due to the lack of a suitable near-field thermal goal for in-drift emplacement, the thermal criteria used for in-drift emplacement in this study was based on a far-field response temperature limit of 115°C at the TSw2/TSw3 interface (see Table 5-7). Using a LAPD of 28.2 W/m^2 (114 kW/acre), the TSw2/TSw3 interface temperature was calculated to exceed the thermal goal of 115°C in this study.

The distance between the repository floor and the TSw2/TSw3 stratigraphic interface is an important consideration in the design of the repository layout, as this offset determines the temperature increase at the interface, which is limited by the thermal criteria listed in Table 5-7. Figure 5-7 is taken from Hertel and Ryder (1991) and shows the relationship between the TSw2/TSw3 interface temperature and various LAPDs at a distance of 60 m, for vertical emplacement. This figure shows an approximately linear relationship between LAPD and the temperature at the interface. A similar linear response was indicated for horizontal emplacement. The results also showed that for the case of 40 m below the repository floor, the TSw2/TSw3 interface temperature limit may be violated for LAPDs above 22.2 W/m^2 (90 kW/acre). There is an "edge effect" which can be considered when only a portion, or an edge of an emplacement area approaches the TSw2/TSw3 interface because the thermal effect is mitigated by a greater mass of rock available for heat dissipation. Thus, the relationship between LAPD and the temperature response at various stratigraphic interfaces provides guidance for repository horizon selection from a thermal point of view.

5.1.4.3 Standoff of Waste Packages from Access Drifts

Defined as the distance that waste packages are set back from the nearest accessway, a thermal buffer, or "standoff distance" is desirable in order to limit the maximum rock temperature in the access drift. This is considered important in terms of both the working environment in the access drift and the influence that elevated temperatures might have on the stability of the drift. While few studies have been performed to determine appropriate standoffs for various LAPDs, past work such as the SCP (DOE, 1988) has allowed adequate standoff to limit the access drift wall temperature to less than 50°C for the first 50 years after waste emplacement. (In the SCP, the access drift for the vertical emplacement case is analogous to the emplacement drift for the long horizontal borehole emplacement case.)

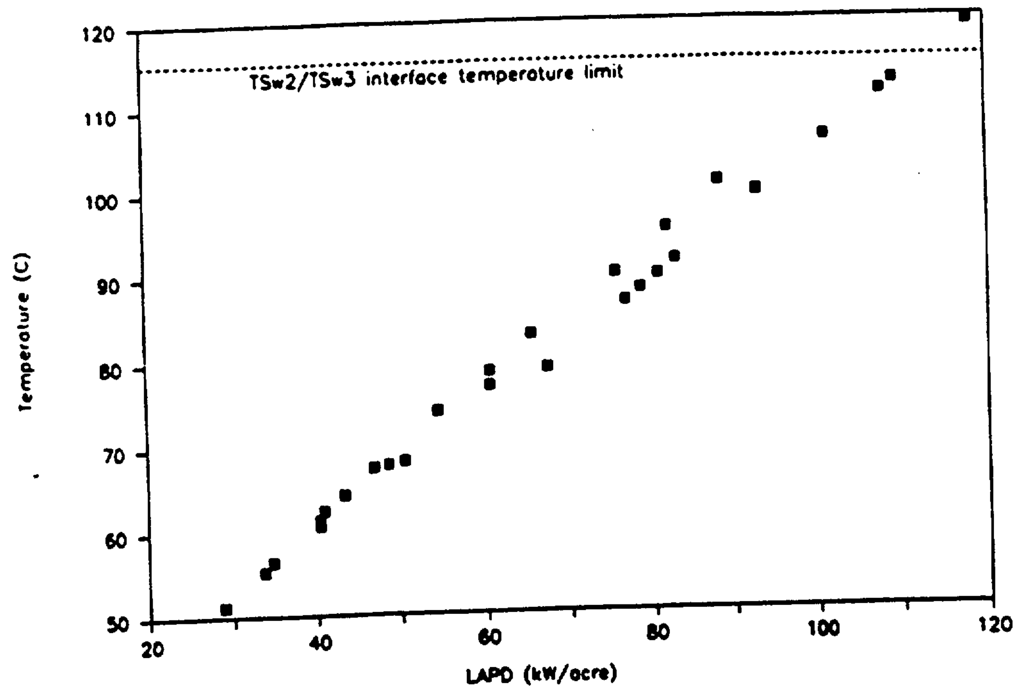


Figure 5-7 TSw2/TSw3 Interface Temperature vs. LAPD

Table 5-8 is derived from various sources as indicated therein and summarizes standoff distances for both the vertical and horizontal waste emplacement modes. The standoff for the vertical emplacement cases is the distance from the centerline of the closest emplacement borehole to the access drift wall, whereas for the horizontal emplacement cases, it is the distance from the end of the closest waste package to the wall of the emplacement drift. Based on the data shown, standoff distances for vertical emplacement range between 28 and 34 meters for LAPDs of approximately 17.3 to 23.0 W/m^2 (70 to 93 kW/acre). Standoff distances for horizontal emplacement are 33 to 41 meters for a LAPD of approximately 17.3 W/m^2 (70 kW/acre). In one sensitivity study (Hertel and Ryder, 1991), it was found that standoff distances remain almost the same for different LAPDs, e.g., 30 meters for 19.5 to 23.0 W/m^2 (79 to 93 kW/acre) and 35 meters for 20 to 25.7 W/m^2 (81 to 104 kW/acre), for vertical and horizontal emplacement, respectively. These results are listed on Tables 5-9 and 5-10.

Studies have not been conducted to evaluate standoff distances for LAPDs of less than 17.3 W/m^2 (70 kW/acre) or higher than 24.7 W/m^2 (100 kW/acre). However, it appears that standoff distances for LAPDs of 5 to 28.2 W/m^2 (20 to 114 kW/acre) may remain in the same range, within approximately 10 meters deviation for different waste package and drift spacings.

To date, standoff distances for in-drift emplacement have not been evaluated. Since the temperature distribution around an emplacement drift is similar for both the vertical and the in-drift emplacement modes, it may be expected that standoff distances for both of these modes will also be similar. However, it must be pointed out that the studies mentioned above did not consider the cooling effect of ventilation air in the access drifts and most used smaller packages containing younger waste. Future work should consider ventilated access drifts as results could differ significantly from the unventilated case.

Table 5-8 Summary of Drift Standoff Distance for Vertical and Horizontal Emplacement a/

Empl. Mode	Initial Heat Output (kW/pkg)	Waste Age (yr)	LAPD (W/m^2)	Borehole Dia. (cm)	Drift Width (m)	Borehole Spacing (m)	Drift Spacing (m)	Standoff (m)	Ref.	Remark
vert.	3.0	10	~17	74	4.9	4.6	38.4	28	1	
vert.	3.0	10	~17	71	-	4.9	32.6	34	2	
vert.	2-4	10	19-23	74	-	2.9-6.9	30	30	3	see Table 5-9
hori.	3.0	10	~17	94	7.0	20.7	228	41	1	
hori.	3.0	10	~17	79	-	33	-	35	2	
hori. b/	6-12 c/	10	20-26	94	-	7.2-18.2	65	35 d/	3	see Table 5-10
hori.	-	10	~17	84	5.5	31	-	33	4	

Note:
a/ Standoff is referred to the panel access drift for vertical emplacement and to the emplacement drift for horizontal emplacement, unless otherwise noted. Only spent fuel is considered.
b/ Short horizontal emplacement.
c/ Total borehole loading.
d/ This value is for panel access drift.

References:
1 - DOE, 1988
2 - Mansure, 1985
3 - Hertel and Ryder, 1991
4 - St. John, 1987a

Table 5-9 Panel Access Drift Temperatures 50 yr After Vertical Emplacement with a 30-m Standoff (Hertel and Ryder,1991)

Initial Canister Loading (kW/pkg)	Canister Spacing (m)	Drift Spacing (m)	LAPD (W/m^2)	Panel Access Temperature (°C)	
				Central	Average
2	2.90	30	23	50.0	44.2
3	4.35	30	23	51.6	45.4
4	6.85	30	19.5	48.6	43.2

Table 5-10 Panel Access Drift Temperatures 50 yr After Horizontal Emplacement with a 35-m Standoff (Hertel and Ryder,1991)

Initial Canister Loading (kW/pkg)	Canister Spacing (m)	Drift Spacing (m)	LAPD (W/m^2)	Panel Access Temperature (°C)	
				Central	Average
6	7.2	65	25.7	50.2	46.7
9	11.2	65	24.7	51.2	47.6
12	18.5	65	20.0	50.1	46.3

5.1.4.4 Thermal and Hydrothermal Models

The emplacement of waste packages will produce a thermal perturbation in the surrounding rock mass. The distribution of temperature and the effects of temperature on the stress regime and on groundwater can be addressed by numerical models. Repository-scale hydrothermal flow calculations for APDs ranging from 5 to 28.2 W/m^2 (20 to 114 kW/acre) and average spent fuel ages of 30 and 60 years have been studied using the V-TOUGH computer code (Buscheck and Nitao, 1992). For low APDs, repository-heat-generated flow of vapor and liquid in fractures is found to dominate the ambient hydrological system. For high APDs, boiling conditions can persist for 10,000 years or longer and rock dry-out benefits for at least 100,000 years.

5.1.4.5 Opening Stability

Subsurface opening stability is an important personnel, radiological, and non-radiological safety issue for a nuclear waste repository during construction, waste emplacement, retrieval (if required), and closure of a repository. It is also a post closure waste isolation issue related to the development of potential pathways for radionuclide migration. Stable openings are produced through use of appropriate excavation techniques and ground support systems based on a design that takes into account the effect of long-term loads, especially the waste-generated thermomechanical loads.

Since empirical data in general are lacking for underground design under thermal loads, numerical analysis is considered a useful tool in the process of determining the potential stability of repository openings at Yucca Mountain. In this regard, a review was made of currently available numerical studies of underground openings for vertical, horizontal, and in-drift emplacement modes under different thermal loads. This evaluation supports the development of advanced conceptual design options for subsurface repository design.

For repository opening design, stresses resulting from three sources must be considered: in situ, thermal, and seismic (caused by earthquake or underground nuclear events (UNE)). The major concern in this evaluation is the rock mass response under different thermal loadings; the effect of seismic loading is not considered. Since the thermal loading due to waste emplacement has more impact on the rock mass at the repository horizon, the evaluation of opening stability to support repository ACD, to date, has mainly concentrated on emplacement drifts and boreholes, with limited study of shafts and ramps.

Stability of openings under different thermal loadings was assessed by utilizing studies performed by SNL and others. The studies compared the strength of the rock mass with the computed stress and evaluated the importance of any zones where stresses exceed the rock mass strength, or where there is a potential for slippage on pre-existing joints. Data regarding actual ground conditions at the proposed repository location is limited, consequently, available studies on the subject are also limited. However, the evaluation presented in this report provides guidance, at least of a preliminary nature, for current studies.

5.1.4.5.1 Drift Stability

Ryder and Holland (1992) conducted two-dimensional structural analysis of both SCP-type vertical and in-drift emplacement drifts using the compliant joint model option of the JAC finite element code. The initial local areal power density was 25 W/m^2 (100 kW/acre) and 30-year-old waste was assumed. Rock mass properties with Rock Mass Categories (RMC) of 1 (extremely poor), 3 (poor), and 5(good) were chosen in the analysis. The results of the study indicated that no intact rock failure is predicted for any of the scenarios examined except that local tensile failure may occur near the top of the waste canister borehole for vertical emplacement drifts in extremely poor rock, 75 years after waste emplacement. For the extremely poor category, more tensile failures may develop in the rock mass if a thermal loading higher than 25 W/m^2 (100 kW/acre) is applied for vertical emplacement. Also, predicted joint slip is very small even though the zone of slippage extends to a few meters around the drifts in some cases. Vertical joint apertures above and below the drift close with the application of thermal loads, with larger closure for in-drift emplacement, which is desirable from a stability viewpoint.

From the stability viewpoint, the above mentioned analysis indicates in-drift emplacement is preferred over vertical emplacement for extremely poor rock. However, no distinction exists between the two emplacement options for poor and good rock mass categories. For the in-drift emplacement mode with circular drifts of 7.9 m diameter, no intact rock mass failure is predicted for all rock mass categories under thermal loadings less than 25 W/m^2 (100 kW/acre).

The thermomechanical analysis by Christianson and Brady (1989) for vertical and horizontal emplacement drifts for an LAPD of 20 W/m^2 (81 kW/acre) indicates a thermomechanical response similar to that of the previous study for 25 W/m^2 (100 kW/acre). No shear failure is indicated for either emplacement mode.

Particular aspects of drift stability are discussed in the following:

Drift Shape
Based on the theory of elasticity, stresses around openings are independent of the size of the opening and the elastic constants of the material. However, the shape of the opening does affect the stress distribution. For instance, stress concentrations increase as the radius of the corner of the boundary decreases. In general, from the stress concentration viewpoint, a circular opening is most preferable. This conclusion is supported by a study of underground excavations in tuff (St. John, 1987b), which indicated that among three excavation shapes, i.e., rectangular, rectangular with arched roof, and horseshoe, the horseshoe shape is considered preferable to the others, even though there is a potential for some activation of vertical or near vertical joints in the sidewall.

Drift Intersection
The stability of an intersection of an emplacement drift and a panel access drift has been analyzed by St. John (1987c) for a PAPD of 14 W/m^2 (57 kW/acre). Results indicated no stability problem at the intersection because waste emplaced in the adjacent panel increases the horizontal stress and decreases the vertical stress in the roof, thereby enhancing roof stability.

Ventilation
The effect of ventilation on drift stability is more pronounced for vertical than for horizontal emplacement. As indicated by St. John (1987a), the maximum crown stress for horizontal emplacement varies little (5 MPa) between ventilated and unventilated cases. For vertical emplacement, the difference between the maximum crown stress for ventilated and unventilated cases is much greater (41 MPa). The actual effect of ventilation on thermomechanical behavior will probably be less than the continuous ventilation assumed in the model.

Sudden ventilation of a previously unventilated drift has been addressed in a study by Svalstad and Brandshaug (1983). It was concluded that stability would not be affected by the so-called blast cooling. Since this conclusion is based on the vertical emplacement mode and the particular conditions assumed for the study, additional study would be required to judge the effect for different emplacement modes and thermal loadings.

Backfill
One of the most noticeable differences between the vertical-borehole and in-drift emplacement approaches is the thermal response of the modeled heat source to backfilling (Ryder, 1992). The heat source for the vertical emplacement showed only a modest increase in temperature following backfill (less than 5°C). For the in-drift emplacement, however, the rise in heat source

temperatures following backfill ranged from approximately 140°C to 300°C depending on waste age and LAPD. Further study of backfill properties and its timing for the in-drift option will be required.

5.1.4.5.2 Borehole Stability

With regard to the response of the rock mass surrounding the boreholes for horizontal and vertical emplacement, zones of joint slip may develop around emplacement boreholes prior to heating depending on the in situ stress. In general, the predicted zones of slip are smaller for the vertical than the horizontal boreholes due to the fact that vertical boreholes are likely to be subject to more equal biaxial stresses in the horizontal plane whereas horizontal boreholes may be subjected to a greater stress difference in the vertical plane. Also, vertical boreholes may intersect fewer vertical joints than horizontal boreholes. Heating has the effect of reducing the tendency for joints to slip for both emplacement modes. However, for 45° joints and horizontal emplacement under a local stress ratio of unity, progressive deterioration of the boreholes may accompany heating (Christianson and Brady, 1989). The results also indicate that for horizontal boreholes at various local field stress ratios, boundary compressive failure either occurs prior to or after heating, but the failure zone does not increase in size with time. This suggests that an unlined borehole would be subject to sidewall spalling. Installation of a liner at an earlier time will overcome this problem. For the same situation and vertical boreholes, no compressive failure is indicated except near the hole collar, where a very limited failure zone existed prior to heating and disappeared 10 years after heating.

Although no thermal loading higher than a LAPD of 20 W/m^2 (81 kW/acre) has been considered in the analyses of borehole stability, it is expected the thermomechanical responses will be similar for higher thermal loads. However, this conclusion is based on SCP-type borehole sizes. For waste packages of larger sizes, which are currently being considered, such as 1.41 m to 2.50 m diameters for 12 and 21 PWR waste packages (Bahney and Doering, 1993), the thermomechanical response of the rock mass around the boreholes will probably be different. Further studies of borehole stability for larger borehole sizes and updated information of the orientation and frequency of joints and the in situ state of stress subject to various thermal loading are needed.

5.1.4.5.3 Shaft and Ramp Stability

Very few studies have been done about the stability of shafts and ramps under various thermal loadings. However, studies by St. John (1987d) and Richardson (1990) provide some insight into response of the rock mass around ramps and shafts, and of shaft liners for a PAPD of 14 W/m^2 (57 kW/acre). The analysis of ramps indicated that there would be no development of new fractures in the rock matrix, but there is some potential for joint activation in the roof and sidewalls of the openings. Generally, the regions of joint activation are localized and indicate no stability problems for openings. The results of shaft stability analyses indicated that the highest induced horizontal thermal stresses occur at the repository horizon. They are greatest close to the emplacement area and decay rapidly away from there. The induced vertical stresses and axial strains are tensile in the rock and in the liner. There is little potential for the development of new fractures in the rock mass. For a shaft centrally located in a 200-m diameter shaft pillar, the vertical stresses in the liner appear to be sufficiently high so that there will be a potential for development of horizontal cracks in the liner. Such cracking is not expected to be detrimental to the performance of a liner. However, the occurrence of thermally induced stresses within the liner should be considered in the design of the shafts for a repository. It was also found that the thermally induced horizontal stresses are anisotropic if wastes are not symmetrically emplaced around the shaft, which should also be considered in the liner design. Furthermore, the results indicated that shafts should be located 100 m from the adjacent waste emplacement panel to avoid inducing high horizontal stresses for an APD of 14 W/m^2 (57 kW/acre).

Hardy et al. (1993) predicted stresses at shafts and ramps based on a more recent repository layout for APDs of 14 and 20 W/m^2 (57 and 80 kW/acre). The results indicated that the induced stresses at shafts and ramps are small and the difference in maximum stress between the two loadings is not significant due to their location on the periphery of the waste emplacement area.

No studies have been done about the structural behavior of ramps and shafts for thermal loading greater than an APD of 20 W/m^2 (80 kW/acre). It appears that shafts will be stable for higher thermal loadings up to an APD of 25 W/m^2 (100 kW/acre) if an adequate standoff distance is established between the shaft and emplacement area. Ramps will be expected to be stable due to their distant locations relative to thermal loading caused by waste emplacement.

5.1.4.5.4 Opening Stability Conclusions

Based on the studies discussed above, stable conditions are indicated in general for various underground opening conceptual designs for a potential repository under thermal loads due to LAPD's ranging from 5 to 25 W/m^2 (20 to 100 kW/acre). Also, the reviewed studies show that deformations of both drifts and boreholes are relatively small. Nevertheless, further studies will be needed to improve the accuracy of this assessment and to incorporate new field data and design concepts.

5.1.5 Excavation Concepts

Early repository conceptual design studies, including Jackson (1984) and the SCP-CDR (SNL, 1987), focused on the use of traditional drill/blast techniques for repository emplacement drift and panel access drift excavation. In the SCP-CDR, the use of mechanical excavation techniques (the TBM) was limited to the main access ramps and drifts and the perimeter ventilation drifts. Comments and concerns expressed by the Nuclear Regulatory Commission (NRC, 1989), the Nuclear Waste Technical Review Board (NWTRB, 1990), and others regarding the large-scale use of drill/blast excavation concepts resulted in a programmatic shift toward emphasizing the use of mechanical excavation techniques for practically all areas of repository subsurface design.

Comments and concerns expressed regarding the use of drill/blast techniques included:

- Excess fracturing of the wall rock could, potentially, produce pathways for radionuclide migration.

- Blasting by-products could compromise long-term repository performance.

- Opening stability could be compromised, necessitating more extensive ground support measures and increased opening maintenance requirements.

- Potentially, greater excavation productivity could be achieved using mechanical excavation techniques such as the TBM.

The ESF Alternatives Study was undertaken in 1989 and evaluated numerous, integrated ESF/potential repository layouts, including options that emphasized mechanical over drill/blast methods. The selected option from that study proposed the use of TBMs for the majority of ESF and repository development and was used as a basis for preparing a revised ESF Title I Design Summary Report (RSN, 1993). This report included ESF/Repository interface drawings that were based on the use of TBMs for the excavation of all subsurface openings except for shafts (drill/blast) and minor support and testing/training facility development (unspecified mechanical excavation).

This report section discusses primary excavation methods, as well as several smaller-scale techniques which are available for minor excavations. A distinction is made between primary and secondary excavations, and the suitability of various methods or machines in either a primary or secondary mode.

Mechanical techniques which are available, or in some cases currently under development, can be divided into several machine or method categories:

- Tunnel boring machine (TBM)
- Roadheader or roadheader variations
- Mobile miner
- Impact hammer
- Horizontal reaming

A brief discussion of each of these methods is included in the following sections. More in-depth descriptions for most, along with diagrams and figures, may be found in Ozdemir et al. (1992). Performance predictions in Yucca Mountain tuff formations targeted for potential repository development can be found in Ozdemir et al. (1992) and Gertsch and Ozdemir (1992). Minor or secondary excavation techniques, including drill-and-blast methods, are discussed in section 5.1.5.6.

5.1.5.1 Excavation by Tunnel Boring Machine

In hard rock excavation, the TBM method actually consists of several key components that, together, form a unique excavation system. The main component is the TBM, a massive machine that weighs, for instance, an estimated 680 tonnes (750 tons) in the case of the 7.62 meter (25 ft) diameter machine currently being manufactured for the YMP site characterization program. Each TBM is built to the diameter of the tunnel for which it was originally intended; major modification is necessary to change its diameter and can only be considered in small increments relative to the original diameter of the machine.

All TBMs function by thrusting a rotating, full-face, circular cutterhead against the rock surface in the direction of opening advance. The cutterhead is outfitted with cutters appropriate for breaking the material to be excavated. The thrust necessary for loading the cutters to the level necessary to effect rock breakage is supplied by hydraulic propel cylinders, one end of which is attached to the cutterhead support; the other end is attached to a set of grippers. The grippers are located some distance back from the cutterhead support and function by using large, radial acting hydraulic cylinders to press two or more gripper pads, or shoes, against the excavated surfaces of the opening. The total force generated by the grippers is on the order of two to three times the total exerted by the propel cylinders. The resistance to sliding friction between the gripper shoe and the rock surface thus generated is what anchors the machine to react the propel thrust necessary to advance the cutters a slight distance into the rock face. The length of a TBM, in proportion to its diameter, varies according to its design and/or manufacturer, but is usually on the order of one to three tunnel diameters.

Behind the TBM, and pulled along by it, is a string of decks called, interchangeably, the "trailing floor," "trailing gear," "backup system," or simply, "backup." These decks provide space for materials and supplies offloading and storage, they house various pieces of support equipment such as the electrical transformers, and they serve as the muck handling interface between the TBM and whatever system is used to transport the muck to the surface. These backup systems can be on the order of 100 meters (300 ft) or more in length, depending upon the various operational functions they are required to support.

The final, major equipment component in a TBM excavation system is the muck removal or handling system. Continuous conveyor systems are gaining acceptance in the commercial market but their use has been limited to straight tunnels or those with long radius curves (300 meters/1000 ft). The alternative, and more commonly used method in the past has been muck train setups, where a diesel-powered underground locomotive is used to move trains of two to four muck cars into and out of the subsurface or to a shaft.

Historically, hard rock tunnel drives on the order of 3000 meters (10000 ft) or more in length have been necessary in order to provide economic viability in terms of writing-off the cost of purchasing and mobilizing a TBM tunneling system against the length of tunnel to be driven. In the commercial market, it is difficult to compete with conventional, drill-and-blast methods if the higher productivity available using a TBM cannot offset the higher capital expenditure associated with the method. However, used machines of various diameters are more readily available now than in the past. This fact, coupled with higher labor costs, has shortened the economical length of tunnel that can be driven with a TBM. A recent project in Utah, the 1520 meter (4985 ft) long Olmstead Tunnel, was competitively bid and awarded to a contractor who used a TBM. The venture was successful and was completed on time (Blyler, 1993). At any rate, write-off of the TBMs is not a factor in a repository layout because there is a tremendous amount of tunneling to be performed.

For repository design, the TBM is considered to be the preferred, primary method of excavation because of its potential for excavating large or small diameter openings at advance rates far in excess of those attainable using other excavation methods in the relatively high strength rock typical of the TSw2 thermomechanical unit, and because these machines produce relatively smooth excavated surfaces with minimal rock damage.

Tunnel boring machines, by nature of design, excavate fixed diameter circular openings. Compared with drill-and-blast methods, flexibility for development of alternative subsurface layouts is limited because of the machine and backup system's inability to make sharp, or short-radius turns and because of difficulties associated with moving the TBM intact from one location to another.

Another potential disadvantage of using TBMs is that the primary function that a subsurface opening must accommodate may not conform to the circular cross-section produced by a TBM. Consequently, portions of an opening excavated using a TBM may have to be enlarged, or otherwise modified to accommodate the intended purpose. For instance, the floor of a 7.62 meter (25ft) diameter opening excavated using a TBM may require up to one meter (3 ft) of fill to create the same flat work area available in the 6.7 meter (22 ft) high by 5 meter (16 ft) wide vertical emplacement openings included in the SCP conceptual design. In this example, the TBM opening would produce approximately one-third more excavated rock to handle and dispose of compared to the custom shaped rectangular opening.

By and large however, the benefits of using a TBM for the development of a repository at Yucca Mountain are considered to outweigh any potential disadvantages. Various advantages of using this excavation system are summarized as follows:

- minimized wall rock fracturing or damage
- elimination of blasting by-products which could impair waste isolation performance
- circular shaped opening is optimal in terms of long-term stability
- potential for higher productivity/lower unit costs substantially enhanced when compared to any other excavation method in the TSw2 unit

5.1.5.2 Excavation by Roadheader or Roadheader Variations

Early designs of roadheaders for underground applications were of relatively lightweight construction, and as a consequence, were only applicable to softer rock conditions of approximately 70 MPa (10,000 psi) unconfined compressive strength (UCS) or less. To increase the possible range of application, the weight and power of these machines was increased, and boom designs were changed in an effort to economically cut the higher strength rocks. Long-cantilever soft rock booms used in-line "milling" (spiral auger) heads, and a boom mounted cutter motor as a load carrying member. These were replaced for harder rock formations with stiff, heavy-duty, cylinder supported booms with transverse "ripper" cutting heads, and the practice of using the motor as a load carrying member was eliminated. Machines of this design are now considered to be capable of economically cutting some rock formations in the 60 to 100 MPa (8,700 to 14,500 psi) UCS range (Whittaker, 1990) and, in some cases, as high as 130 MPa

(18,900 psi) UCS (Kogelmann, 1992). The degree of fracturing in the rock formation is an important factor in determining the applicability of roadheaders. More fracturing in the rock formation can enhance cutting performance. For rock formations above 150 MPa (21,750 psi) UCS, successful excavation cannot be guaranteed (Whittaker, 1990). Presently, carbide-tipped picks are considered to be one of the limiting factors for rock cutting, although, special picks tipped with carbide and diamonds have cut rocks up to plus 200 MPa (29,000 psi) UCS (Kogelmann, 1992; and Whittaker, 1990). It should be pointed out however, that while the higher strength rocks may have been cut on a limited basis in various research and development type tests, many roadheaders have failed when used to excavate in the harder, 100 MPa plus rock types on a day-in, day-out basis.

Table 5-11 presents basic geomechanical data for the TSw2 thermomechanical unit. Unconfined compressive strength data is from drill holes USW A-1, USW G-1, USW G-2, USW GU-3, and USW G-4, as listed in Lin et al. (1993b, p. B-2), as well as RIB data (DOE, 1993b, Section 1.2.5). Some published strength values are from tests on saturated samples (Tillerson and Nimick, 1984), which may underestimate the strength of the in-situ rock. Ranges of the degree of fracturing is also presented, based upon data presented in Lin et al. (1993a, pp. 23 and D-6) for the same drill holes, both per linear meter of core and as a function of unit volume of rock. Prudence must be exercised when applying the referenced data to roadheader suitability, as the strengths and fracturing indicated may not be fully representative of the materials which may be encountered during excavation.

Table 5-11 Unconfined Compressive Strength and Fracture Data

TSw2 T/M Unit	Lin et al.(1993b) Unconfined Compressive Strength Ranges (MPa)	RIB Unconfined Compressive Strength Ranges (MPa)	Linear Fracture Frequency Ranges (per meter)	Volumetric Fracture Frequency Ranges (per cu. meter)
Range	12 - 326	Not Listed	1.7 - 5.7	5.4 - 40.6
Average	161 ± 63	155 ± 59	3.0	19.6

From examination of Table 5-11, portions of the TSw2 unit appear to be in the range of suitable application of roadheaders; however, "average" strength material is above the range where successful excavation of the material can be guaranteed. Based upon predictions of roadheader performance which have been previously made for the TSw2 unit, it is currently considered that the TSw2 unit would require a machine with capabilities that go beyond, or are just at the edge of, current roadheader technology and that low productivities and associated high costs would result (Ozdemir et al., 1992). The degree of fracturing within the formation may help extend the limits of practical applicability somewhat.

A promising development is underway at the Colorado School of Mines (CSM) research facility that may result in secondary, mechanical excavation tools that are useful for repository development and that are targeted toward cutting the higher strength rocks typical of the TSw2 unit. The CSM researchers (Friant et al., 1993) have designed and tested a small diameter (813mm / 32 in) cutting head that looks and acts much like a TBM cutterhead. The head is outfitted with small diameter (127 mm / 5 in dia) disc-type cutters. Designs for larger cutterheads, on the order of 183 mm (72 in) diameter have also been developed in which the "mini-disc" cutters would be mounted on both the face and sides of the rotating head to permit cutting in both a sumping mode and in a slewing mode. A design has been developed for an "alcove miner" which can be transported on a railcar to the alcove location and set up to excavate alcoves of various dimensions starting from a 7.6 meter diameter drift. The alcove miner would be outfitted with the mini-disk cutterhead and is designed to excavate the alcove to a depth sufficient to provide a starter cut for a heavy-duty roadheader, allowing the roadheader to work without blocking traffic in the larger, 7.6 meter diameter opening and providing anchoring positions for the roadheader's stabilizing jacks. Preliminary designs for adapting the mini-disc cutter to a roadheader cutterhead are also being investigated (Rostami, et. al., 1993); results so far look very promising. This work is being performed in support of, and under a contract funded by the YMP.

Specific testing on fully representative samples of all types of TSw2 material which could be encountered during repository construction is required to make an actual determination of roadheader suitability. At the present time, a standard, heavy-duty commercial roadheader is not considered to be suitable for use as a production (primary excavation) machine, but may be useful as a tool for secondary excavations (Gertsch and Ozdemir, 1992, p. 4-31).

5.1.5.3 Excavation by Mobile Miner

The Mobile Miner is a relatively new mechanical excavator developed by the U.S. Robbins Company for both soft and hard rock formations. The Mobile Miner consists of a heavy, tracked carrier with a tail conveyor for muck discharge and a massive cutter boom to which a rotating cutting wheel is attached. The cutting wheel rotational axis is perpendicular to both the main axis of the machine and the direction of heading advance. The boom moves up and down and from side to side while the cutter wheel rotates. The cutting wheel is equipped with a single row of cutters around its perimeter. It is the only machine, other than a roadheader, currently available to mechanically excavate rectangular shaped openings in rock. It can also produce a pseudo-arched profile by incorporating a different cutting boom configuration.

The Mobile Miner is a partial-face cutting machine (compared to a TBM which is a full-face machine), and because of this, it cannot match TBM production rates (Ozdemir et al., 1992, p 1-2). For comparable 45.5 m^2 opening cross-sectional areas (rectangular for the Mobile Miner versus circular for a TBM), preliminary instantaneous penetration rate and cost predictions for the Mobile Miner are 0.9 m/hr and \$ 9.7/m^3 in the TSw2 unit, compared to a standard powered TBM with 127 mm cutter spacing at 2.2 m/hr and \$6.2/m^3 (Gertsch and Ozdemir, 1992, p. 5-2). These performance and cost predictions tend to suggest that, compared to a TBM, the Mobile Miner is not well suited as a machine for primary excavation.

The nominal minimum opening size for the smallest available machine is 3.5 m by 3.5 m (12 m^2). The Mobile Miner's size and weight potentially limit mobility and make its use questionable as a machine for secondary excavation.

5.1.5.4 Excavation by Impact Hammer

Modern impact hammers are becoming increasingly more powerful and have seen increasing use on a project-wide basis in Italian civil tunneling projects. The technique has been termed "hammer tunneling". The technique has advanced to such a point in Italy, that it is now unusual to find an Italian tunnel that does not use an element of hydraulic breaking at either the tunnel face or bench. Overbreak experienced is reported to be minimal (Smith, 1992).

Impact energies for primary-breaking-type hydraulic hammers range from approximately 5 kJ, up to 12 kJ for the largest classes of hammers, with hammer unit weights ranging from approximately 2 to above 6 tonnes. Large hydraulic excavator carriers are typically used to achieve the dead weight required to react the dynamic forces generated by the hammer. For the above impact energies, carrier weights range from a minimum of 25 tonnes for the smallest primary breaking hammers, to as high as 100 tonnes for the largest.

An example of the scale that hammer tunneling has been used is the Sanremo tunneling project in Italy, where 7.2 km of 12.4 m wide by 10.3 m high arched tunnel was excavated using a fleet of eight hydraulic impact hammers with carriers (Enotarpi, 1991).

Competent, but preferably layered and fissured rock, with crushing strengths of up to 100 MPa UCS are most suitable to the use of hydraulic impact breakers (Smith, 1988). Compressive strengths higher than 100 MPa should be appraised based upon the extent of fracturing and layering to determine the hammer production that may be attainable. The more highly fractured or faulted, stratified, or weathered a formation is, the higher will be the excavation rate. On projects where the technique has been used, tunnel advance rates were entirely comparable with what would be expected with excavation by drill-and-blast or roadheading techniques (Smith, 1988).

From examination of Table 5-15, portions of the TSw2 unit appear to be in the range of suitable application of impact hammers; however, "average" strength material is above the generally accepted range of applicability. The degree of fracturing within the formation may help extend the limits of practical applicability somewhat.

Specific testing on fully representative samples of all types of TSw2 material which could be encountered during repository construction is required to make an actual determination of impact hammer suitability. However, because of the potential limited applicability, it is likely that hammer tunneling would only be suitable for further consideration as a secondary excavation method.

5.1.5.5 Excavation by Boring Machines

Boring machines may use rock fragmentation techniques similar to a TBM, but they differ in their method of applying thrust to the cutting head. The TBM advances its thrust reaction point (the grippers) along the drift as it advances; a boring machine thrusts from a fixed reaction point, and is therefore limited in terms of the horizontal distance it can bore. Another distinction is that operating personnel work within the TBM opening during excavation; conversely, personnel are not normally inside of an opening being excavated by a boring machine.

Boring machines might be applied to repository construction in the following ways:

- Shaft development using raise boring, or pilot boring with down-hole reaming
- Horizontal long boreholes for emplacement of low heat output waste packages
- Bored alcoves for waste emplacement,
- Vertical boreholes for emplacement of low heat output waste packages,
- Short ventilation cross-cuts.

There are essentially three types of boring machines that may be usable at the repository. These are:

1. The conventional type boring machine where the cutting head receives its thrust in the direction of advance through a string of steel drill pipe extending from a vehicle or thrusting devise blocked into the access opening.

2. The "raise boring" or back-reaming type machine where the cutting head receives its thrust through a string of steel drill pipe pulled through a previously drilled pilot hole.

3. The box-hole type boring machine which is launched from a portable tube and continues to provide its thrust from inflatable packers much like a TBM.

5.1.5.6 Minor Excavations Using Traditional and Non-traditional Methods

While mechanized excavation will undoubtedly retain favor as the preferred, principal excavation method, there is still the possibility that specific applications will favor drill/blast techniques because of its flexibility and its suitability in creating custom excavation shapes or profiles. Some potential applications of the drill/blast method include:

- Invert excavation to obtain a squared off floor,
- TBM launch chambers
- Specific test room alcoves,
- Sub-surface shops and utility room alcoves,
- Excavation of vertical shafts or raises.

The state-of-art using controlled blasting has developed to a point that allows the excavation of fairly precise openings that can be excavated with little wall rock damage. Such methods use closely spaced, accurately drilled holes in a pattern that reduces wall rock damaging fractures. By-products of blasting include: dust, oxides of carbon, oxides of nitrogen, and other compounds. Potentially, significant quantities of these could combine with moisture to produce corrosive agents or agents that may help to mobilize radionuclides. In addition to fracturing of the wall rock, this is another reason that suggests the minimization of drill/blast methods to small, specialized applications.

A new, pseudo-drill/blast technique that offers advantages in terms of energy efficiency and limited flyrock problems is called the Penetrating Cone Fracture (PCF) method (Young, 1991). This recent development is predicated upon the initiation and propagation of a controlled fracture from the bottom of a shallow and rapidly pressurized borehole. The hole is drilled to a depth equal to approximately three hole diameters, and is then pressurized using a "mine gun," which injects and initiates a charge of commercially available gun propellent. The rapid increase in pressure results in fractures that extend radially from the bottom of the hole and then turn toward the face of the excavation, resulting in a cone shaped depression in the rock face.

Other, non-blast, pseudo-mechanical methods that are available for minor, specialized excavations include: (1) drilling and hydraulic splitting, (2) drilling and chemical agent splitting, (3) ultra-high pressure water jet cutting, or (4) a new technique using drilling and a splitting system known as the "Core Cracker". The "Core Cracker" system uses a principle known as impact hydraulics, where a soft metal sphere is placed in a short hole (1m ± deep) and deformed using a hydraulic impact hammer. The deformed metal produces high pressures at the bottom of the hole which are sufficient to break a conical section of rock away from the rock face (Klemens and Hudson, 1991).

5.1.6 Waste Emplacement Concepts and Considerations

This report section presents brief overviews of various emplacement concepts, including the in-drift emplacement mode that is of particular interest for disposal of very large, high heat output waste packages. Most of the information provided here is discussed in considerable detail in the report titled: "Alternatives for Waste Package Emplacement, Retrieval, and Backfill Emplacement," (M&O, 1993b). Please refer to that document for more in-depth coverage of various emplacement configurations.

Four waste package emplacement modes have histories of consideration in the YMP. The Site Characterization Plan-Conceptual Design Report (SCP-CDR) (SNL, 1987) addressed vertical and long horizontal borehole emplacement of thin-walled waste packages. It also evaluated operational concepts for emplacement, retrieval, and backfill for these emplacement modes. Other modes that have been given various levels of consideration include short horizontal borehole and in-drift emplacement.

Retrieval of waste packages has undergone limited analysis in past conceptual repository design work. The demonstrated ability to retrieve the entire inventory of waste packages is required by both the Nuclear Waste Policy Act (NWPA, 1987) and by 10 CFR 60, and is recognized as being an important criterion for waste emplacement mode design. The total retrieval system, from an operational point of view, needs conceptual development so that its interfaces with other design areas can be better established.

5.1.6.1 General Emplacement Considerations

As waste package and repository ACD evolve, a number of significant changes are being considered that affect waste package emplacement and retrieval. These include:

- The proposed use of TBMs for emplacement drift excavation results in a circular excavated cross-section. The circular cross-section suggests consideration be given to construction of a flat invert, using concrete or engineered fill, or further excavation of the invert by mechanical or other methods.

- Consideration being given to multi-barrier and MPC waste package concepts that weigh up to 175 tonnes, at diameters of 2 meters or more, impacts all areas of waste transport and emplacement design. The heaviest waste packages in the SCP-CD were in the range of 6 tonnes.

- Waste packages containing as many as 24 PWR or 52 BWR spent nuclear fuel assemblies, with individual package heat outputs of more than 10 kW, are being given strong consideration. The SCP-CD type packages were estimated to have potential heat output in the range of 3 kW per package.

Studies by Sandia National Laboratories (Ryder, 1992) have indicated that waste packages with heat outputs of more than 5 kW may not be suitable for emplacement in a borehole sized just large enough for insertion of the waste package. These indications have been confirmed by preliminary thermal analyses prepared in support of various waste package ACD studies, which showed that waste packages containing 12 or more PWR spent fuel assemblies will heat internally above the current maximum design temperature of 350 °C at the canister centerline if emplaced in a borehole.

Since numerous other studies are available for discussions of vertical and long horizontal borehole emplacement, and because of thermal limitations as discussed in the preceding paragraph regarding the size of packages that can be emplaced in boreholes, this report will not attempt to address these emplacement modes further. Rather, discussions will be limited to emplacement modes which can accommodate the large diameter, high heat output waste packages that are currently being given a considerable amount of attention in the YMP program.

5.1.6.1.1 Emplacement in Alcoves

Alcove emplacement has not been addressed in earlier work under this title. Alcove emplacement offers a potential advantage over in-drift emplacement because the entrance to each alcove can be covered with a shielding fixture that isolates the waste from the travelway in the emplacement drift. As used herein, the term "alcove" implies an opening large enough to accommodate the largest waste packages currently under consideration, in terms of both the waste package dimensional requirements, and the thermal constraints that require sufficient rates of heat transfer from the package to its surroundings.

Bored Alcove Emplacement

The bored alcove emplacement mode was not described in the SCP-CDR, however, it is similar to the short horizontal borehole mode considered in other reports, which was appropriate only for relatively small diameter, low heat output waste packages. Oriented more or less perpendicular to the longitudinal axis of the emplacement drift, alcoves circular in cross-section would be mechanically bored into either of the emplacement drift walls using large-diameter drills, boxhole drills, raise boring machines, modified TBMs, or other specialized equipment. Other concept features include:

1. Waste packages would be placed horizontally in each bored alcove, and would be oriented parallel to the long axis of the alcove.
2. One to three waste packages would be placed in each bored alcove.
3. The depth of the alcove would be determined by the number of waste packages, the setback distance from the emplacement drift walls needed to spread the thermal energy from the waste into the pillars, the additional length necessary to accommodate at least one shield/seal plug, and the wall interface plug or surface shield cover plate.
4. The bored alcove diameter would be determined by operational and thermal constraints of the waste package.
5. Defense high level and other low heat output wastes could be emplaced by dispersing them between the spent fuel packages in each alcove, or in smaller diameter boreholes spaced between the alcoves.
6. Waste packages would be inserted from a transportation cask into the alcoves through a radiation shielding device, and under remote operational control. Retrieval would use the same equipment sequence in reverse.

Emplacing or retrieving the multi-barrier or MPC waste packages using the bored alcove mode will require engineered permanent support and transfer systems. Major components of this emplacement mode include an isolation plug, which is only slightly smaller in diameter than the alcove, and an isolation cover which fits completely over the opening to the alcove and seats within an oversized, milled surface.

Mined Alcoves off the Emplacement Drift

The major differences between the mined alcove and the bored alcove include the excavation method used to create the alcove, its shape, and the orientation of the waste packages emplaced therein. This alcove concept could be mined by a mechanical excavator similar to those under study by the Colorado School of Mines as reported by Friant et al., 1993 (see Section 5.1.5.2).

This method of excavation allows custom shaping of the alcove as necessary and would allow the packages to be aligned at whatever horizontal orientation is deemed appropriate. Major operational differences would relate to the package orientation and the resulting shielding fixtures that would be necessary.

5.1.6.1.2 In-Drift Emplacement

The in-drift mode is defined as emplacement of waste packages in the open, inside an emplacement drift. No special alcoves or boreholes would be constructed to isolate individual packages from the travelway in the emplacement drift. Large, multi-barrier or MPC type waste packages with high heat outputs would be placed lengthwise along the longitudinal drift centerline, or adjacent to the opening wall, depending upon various emplacement and retrieval operational schemes and the attendant drift sizes that might be considered.

Open emplacement of waste packages in a drift includes the following features or considerations:

1. All waste packages will be placed within the envelope of the drift itself, along the centerline or offset to either side of the drift. It is assumed that the packages will be placed horizontally and end toward end, however other configurations are possible under the in-drift classification.

2. The number of waste packages that may be placed in a drift is dependent on the length of the drift, the length of the waste package and the spacing between waste packages. The spacing between waste packages is a variable which must ultimately be optimized through the use of a broad ranging systems analysis that addresses parameters such as the waste package size and thermal output, package spacing, drift diameter and spacing, areal thermal loading, intermingling of DHLW, and various thermal goals.

3. The cross-sectional dimensions of the emplacement drift are determined by the operating envelope of the emplacement equipment and by the thermal constraints of the waste package/host rock system.

4. Defense high level waste may be disposed of by interspersing it among the spent fuel packages.

5. In-drift emplacement is unique with respect to other modes in that the waste packages are not isolated from the travelway in the emplacement drift.

6. Emplacement openings may be excavated using TBMs sized to match emplacement equipment operating envelope requirements and thermal considerations.

7. Waste packages may be emplaced in drifts of sufficient cross-sectional dimensions to allow access to individual waste packages, or in smaller drifts that require sequential removal of intervening waste packages for relocation or retrieval purposes.

8. To preclude radiation exposure in access drifts and to restrict human access to emplaced waste packages, doors or barriers must be installed and maintained at the entrance(s) to each emplacement drift. These doors or barriers must be designed to accommodate equipment access.

9. Emplacement drifts must be designed and constructed to accommodate backfilling and/or sealing.

10. Maintenance or repair of the emplacement drift opening and various instrumentation devices must be possible until a decision is made to seal each drift.

5.1.6.2 In-Small-Drift-On-Rail Emplacement Concept

The previous section discussed the in-drift emplacement mode, especially as it pertains to the large diameter waste packages currently under consideration in the MGDS program. One variation of this general concept that appears to warrant further investigation is the In-Drift-On-Rail (IDOR) emplacement mode.

The IDOR concept utilizes rail systems for emplacement of waste packages on railbound carriers in the emplacement drift. Obvious advantages of using rail transport include the ability to accommodate extremely heavy loads without proportional increases in the carrier's operating envelope, as compared with rubber-tired vehicles, and the relative ease with which railbound systems can be reliably automated or controlled from remote locations. Railbound systems in which the waste package carrier remains with the package also facilitate retrieval in a relatively straightforward manner.

For the larger waste packages containing approximately 12 or more spent fuel assemblies, the diameter of the emplacement drift must be sufficient to provide adequate surface area to accept heat radiated from the waste package, conducting it away through the rock mass at a rate sufficient to maintain a package core temperature that doesn't exceed allowable limits. Besides this thermal constraint, the diameter must permit passage of the carrier mounted waste package and a prime mover through the drift.

Preliminary thermal analyses (Bahney and Doering, 1993) have indicated that waste packages containing up to 21 PWR fuel assemblies should maintain core temperatures within acceptable limits in a 4.3 meter (14 ft) diameter drift. Equipment surveys (M&O, 1993c) have indicated that underground locomotives which could be used for pushing or pulling a 21 assembly package would fit inside drift diameters as small as 3.7 meters (12 ft). (Thermal analyses were not performed for drifts smaller than 4.3 meters in diameter but smaller drifts should be considered in future work.) Given that even the larger waste packages should survive in a relatively small diameter drift, and considering the obvious advantages that smaller drifts offer when contemplated on a repository scale, the In-Small-Drift-On-Rail (ISDOR) emplacement mode can be viewed as one adaptation of the more general IDOR concept.

Figure 5-8 presents the ISDOR concept under consideration for purposes of this report. As shown on the figure, the waste package would be centered in the drift atop a rail mounted carrier,

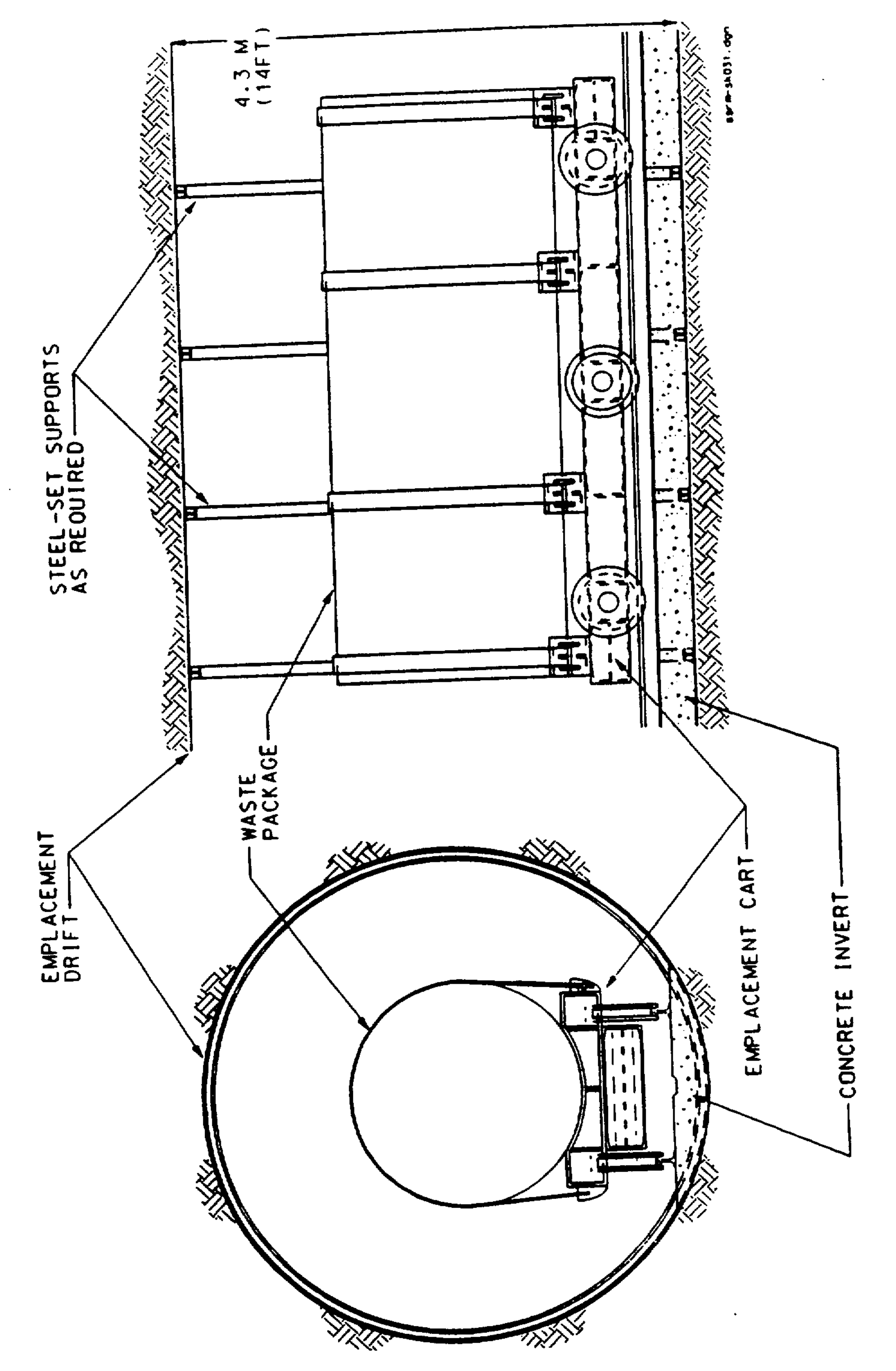


Figure 5-8 In-Small-Drift-On-Rail (ISDOR) Emplacement Concept

or "cart". The rail would be attached to a cast-in-place concrete invert that is poured after excavation of the drift is complete. The minimum depth of the concrete would be sufficient to afford adequate tolerance in the as-bored line and grade of the emplacement drift to permit an acceptable degree of precision in the final positioning of the rail. The cart would include a "stop" or brake mechanism that could be activated to prevent it from rolling in the drift.

Table 5-6 listed potential waste package lengths that ranged from 4.83 to 5.58 meters (15.8 to 18.3 ft); package diameters that ranged from 1.19 to 2.50 meters (3.9 to 8.2 ft) and package weights that ranged from 23 to 175 tonnes (26 to 196 tons). Figure 5-8 shows a waste package that is 1.95 meters (6.4 ft) in diameter and is 5.0 meters (16.5 ft) long, or roughly about the size of the 21 PWR assembly, 3.5-cm thick inner barrier, 20-cm thick outer barrier package in Table 5-6. This particular selection has no basis in terms of any conclusions or recommendations proposed by the waste package design or systems studies groups involved in preparation of the waste package ACD. Rather, the size of package shown is a diagrammatic representation of what could be considered a conservative case from an operational viewpoint, and has therefore been adopted for purposes of figures and operational discussions in this and other sections of the report.

Considering the potentially hazardous working environment resulting from the heat output and radiation effects of waste packages emplaced in-drift, one must seriously evaluate requirements for ground support in the emplacement drifts during the repository operational and caretaker periods. While engineering solutions can be formulated to cope with potential environments, it is viewed as impractical to consider that ground support in emplacement drifts would be designed and constructed in a way that would require periodic maintenance or reinforcement. It is considered wiser to design the extraction ratio/ground support system to perform maintenance-free throughout the pre-decommissioning stages of the program so that maintenance of an emplacement drift, if required, is treated as an off-normal condition.

This philosophy is especially true for the ISDOR emplacement mode, and represents both an advantage and a disadvantage of the concept when comparing small drifts to large. On one hand, besides the fact that smaller drifts are inherently more stable, installation of a robust ground support system in a small drift is less expensive than in a larger one. On the other hand, maintenance of the ground support in a small drift would require extraction of the intervening waste packages, while it may be possible to work around the packages in a much larger drift.

It may be possible to utilize some types of ground support to perform secondary functions. One example would be the use of lightweight steel sets and partial steel lagging, or rock bolts and partial liner plate, to absorb heat radiated from the waste packages and distribute it throughout the crown of the tunnel, in effect "spreading" the heat into the space between adjacent packages. Potentially, this could reduce the required drift diameter or decrease the required package spacing, thereby offsetting costs associated with the support installation.

It is beyond the scope of this report to more fully analyze the potential merits or problems associated with the ISDOR emplacement concept. Numerous performance, radiological safety, and other issues remain to be examined. However, it is felt that the basic concept is a credible and practical solution to many problems associated with emplacement and retrieval operations, and therefore warrants additional study during repository advanced conceptual design.

The following report sections describe a repository layout concept that adopts the ISDOR emplacement mode as a basic design input or objective. A discussion of operational considerations associated with the mode is also presented.

5.1.7 Repository Subsurface Layout, Option I

The preceding sections have provided the groundwork upon which development of the Option I layout concept is based. The following sections will attempt to describe a subsurface repository system that, while not viewed as optimal or to have considered every performance issue that might be applicable, does provide a realistic concept worthy of some deliberation.

5.1.7.1 General Layout Features

Consistent with past repository conceptual designs, a primary feature of the Option I layout is provision for the separation of subsurface ventilation systems, a basic program requirement listed in 10CFR60.133(g)(3). Strict compliance with this requirement leads to a design that divides subsurface operations into two separate systems, separated by physical barriers. Operations in one half, the "development side", involve the construction of emplacement drifts and other work that prepares dedicated areas for acceptance and emplacement of nuclear waste. Operations in the other half, the "emplacement side", include the actual transportation of the nuclear waste to the subsurface and its emplacement. Each "side" has two separate accesses to the surface that also serve as primary ventilation airways and as alternate means of egress.

Another feature included in the Option I layout results from a program requirement directing the development of an integrated ESF/Repository design (DOE, 1985). Previous efforts culminated in preparation of the Exploratory Studies Facility Alternatives Study (ESFAS) (SNL, 1991), a comprehensive assessment of 34 different options for development of an integrated ESF/Repository design. The "bridge" document (DOE, 1991) that brought forward results from the ESFAS as a basis for Title I ESF design stressed the need to pursue development of ESF/Repository layouts that incorporate all of the favorable design features identified in the ESFAS. The Option I layout represents one method directed toward meeting this goal.

Other primary features incorporated into the Option I layout include a framework of large diameter access openings matched with smaller diameter emplacement drifts, and the absence of secondary access drifts, or "submains". The use of the large diameter access drifts in conjunction with small diameter emplacement drifts simplifies launching and recovery of the emplacement drift TBMs, minimizes excavation quantities, and lends itself to the development of straightforward concepts regarding emplacement and retrieval of waste packages. The absence of submains implies the lack of distinct panels in the layout, an important distinction between this and other designs that have been developed in the past (SNL, 1987). This feature helps conserve space, eliminates a regular pattern of "cold spots" in the thermal "plate", and adds flexibility in terms of scheduling the turnover of fully developed areas to the emplacement side of operations.

The following sections discuss design objectives and provide operational and other descriptions that more fully define the Option I layout concept.

5.1.7.2 Design Objectives, Option I

Besides addressing the fundamental program requirements listed in Section 4.1, development of the Option I layout was predicated on a desire to incorporate the following design objectives, or concepts, into a functional repository subsurface design. Many of these objectives are more fully developed interpretations or ideas that represent proposed methods of complying with some of the program requirements listed in Section 4.1. References to specific requirements are provided where appropriate.

a) **Maintain Linkage with Previous Work-** Develop a layout that accomplishes objectives regarding ESF/Repository integration as outlined in the ESFAS (SNL, 1991) and that, as a minimum, embodies all of the favorable features identified for Option 30 in that document. Maintain the portal location and the azimuth of the north ramp as currently defined in ESF Title II design (DOE, 1992) (10CFR60.15(c)(3); BFD1, 3.1.B.3; NUREG 1439).

b) **Avoid Faults-** Situate emplacement drifts in such a manner that they are not intersected by faults known to traverse a major portion of the primary area (BFD1, 3.1.E.3.b, 3.1.E.3.c, 3.1.E.3.d, 3.1.E.3.e; 10CFR60.122(c)(21)).

c) **Utilize Flat/Horizontal Gradients in Emplacement Drifts-** Orient emplacement drifts with absolutely flat gradients in order to maximize safety and stability of emplacement operations (BFD1, 3.1.D.4). Provisions should be made, however, which will permit future ACD to make minor adjustments, just sufficient to provide drainage out of the emplacement drifts in a yet-to-be-determined, most favorable direction (BFD1, 3.1.E.3.a; BFD2, 3.1.E.3.bx).

d) **Utilize the ISDOR Emplacement Mode Concept-** As described in Section 5.1.6.2, this concept is directed toward heavy, large diameter (2 m ±) waste packages mounted on railbound carts that are emplaced in relatively small diameter (4 m ±) emplacement drifts. Besides the obvious advantages that a smaller diameter drift offers in terms of opening stability and ground support requirements, this concept also helps maximize rates of progress in the construction of emplacement drifts while minimizing the amount of excavated tuff, all of which lends itself to minimizing the cost of repository development operations. Additionally, this concept supports retrieval in a straightforward manner and could be automated relatively easily. Because each waste package requires its own emplacement cart, use of this mode introduces significant expenditures associated with purchase of the carts. To help offset or mitigate this additional expense, emplacement drifts should be designed to run perfectly straight so that the carts do not have to be manufactured with any turning capability, thus greatly simplifying their design and fabrication requirements (BFD1, 3.1.3.2.D.3).

e) **Maximize the use of TBMs as the Principle Excavation Tool-** The layout should accommodate excavation by TBM as the primary development tool, both for main drifts and emplacement drifts. Where practical, curves or other features should permit muck removal by conventional conveying systems (BFD1, 3.1.E.3.i).

f) **Minimize the number of Main and Secondary Access Drifts-** Previous designs (SNL, 1987; Grieves, 1989) have utilized extensive systems of main and secondary access drifts that tend to consume space, create potential thermal perturbations, prolong construction schedules, and ultimately, raise costs. A simplified layout that reduces the number of main and secondary access drifts while meeting all of the fundamental program and safety requirements is considered highly desirable (BFD2, 3.1.E.3.ap.(4)).

g) **Use Conventional Rail Transport for both Emplacement and Development Operations-** Larger, heavier waste packages make transport on conventional rail systems a practical option or solution. In addition, TBM operations are almost universally supported by railbound equipment. Conventional rail (sometimes termed adhesion rail) systems rely on the friction developed between steel wheels and steel rail to provide the resistance necessary to accommodate both starting (acceleration) and stopping (deceleration) of trains. To a large extent, the safety of operations in these systems relates to the maximum gradient upon which the trains are required to operate. For purposes of this layout, limit the maximum grade on main ramps to 3.0% or less and the maximum grade "on block", e.g., main drifts used for emplacement drift access, to 2.0% or less (BFD1, 3.1.E.m; BFD2, 3.1.E.3.e).

h) **Utilize Primary Area Identified by Previous Work-** Develop a repository layout that generally fits the primary block identified as Area 1 in Figure 5-9. Determine the maximum areal thermal loading supportable by the available acreage assuming a waste stream totaling 68,200 kW output at the time of emplacement (Mansure and Petney, 1991).

i) **Provide a Common Drainage Point for all Main Drifts-** Ensure that all main drifts are sloped to facilitate water drainage to a common underground location for pickup and removal to the surface (BFD2, 3.1.E.3.bx).

5.1.7.3 Repository Layout Description, Option I

Figure 5-10 portrays relevant site features and the conceptual repository layout presented as Option I. Basic features of this layout include north and south main ramp accesses to the repository horizon; north and south ramp extensions; a service main; a TBM launch main; a potential, dedicated, waste handling main; a perimeter ventilation main; development and emplacement ventilation shafts; and a system of emplacement drifts oriented more or less orthogonal to the main drifts. The function, size and strategy for positioning each of these primary layout components is described in the sections that follow.

5.1.7.3.1 North Ramp

The north ramp's initial function will be to provide first time access to the repository horizon to support site characterization activities. It may also be used as a launch point for exploratory

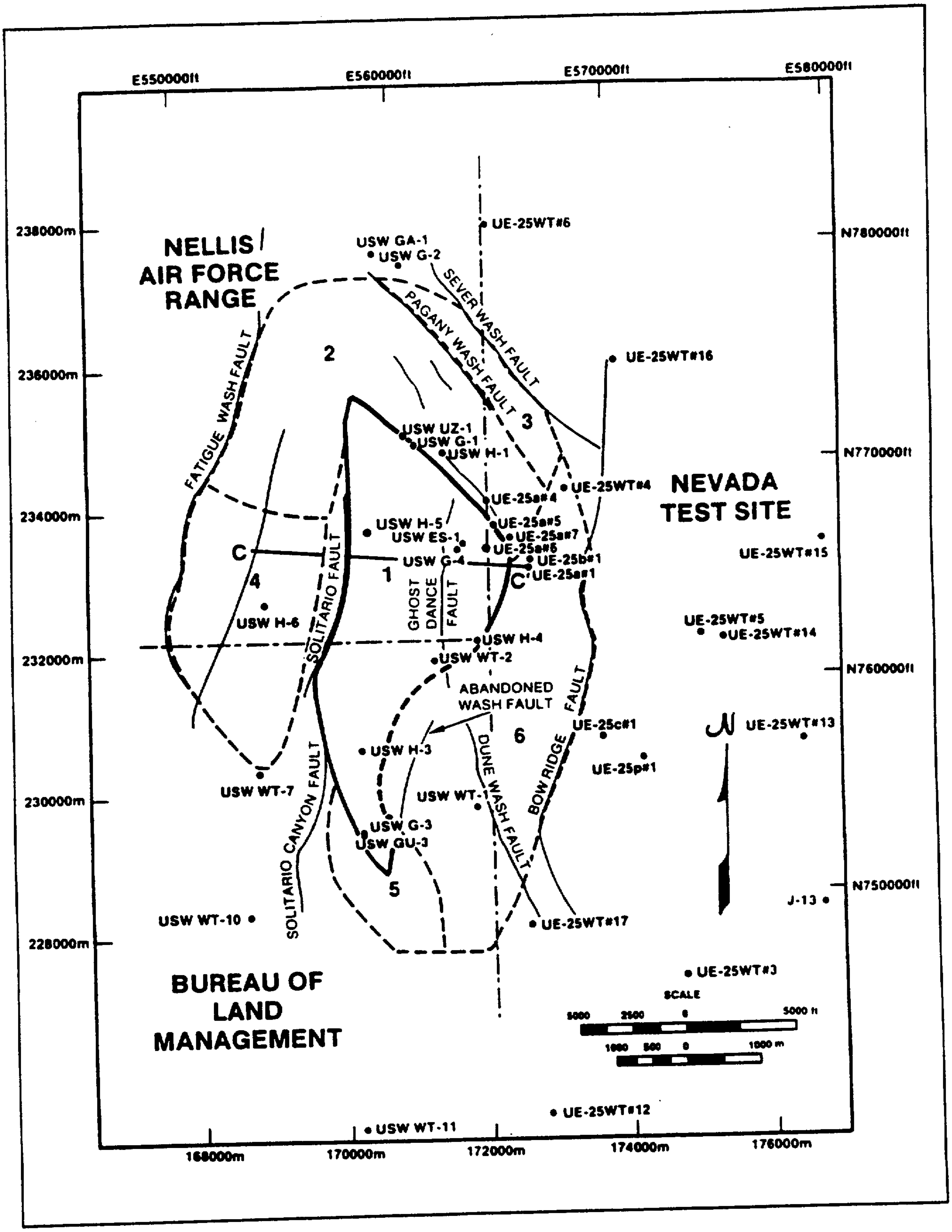


Figure 5-9 Potentially Usable Repository Areas

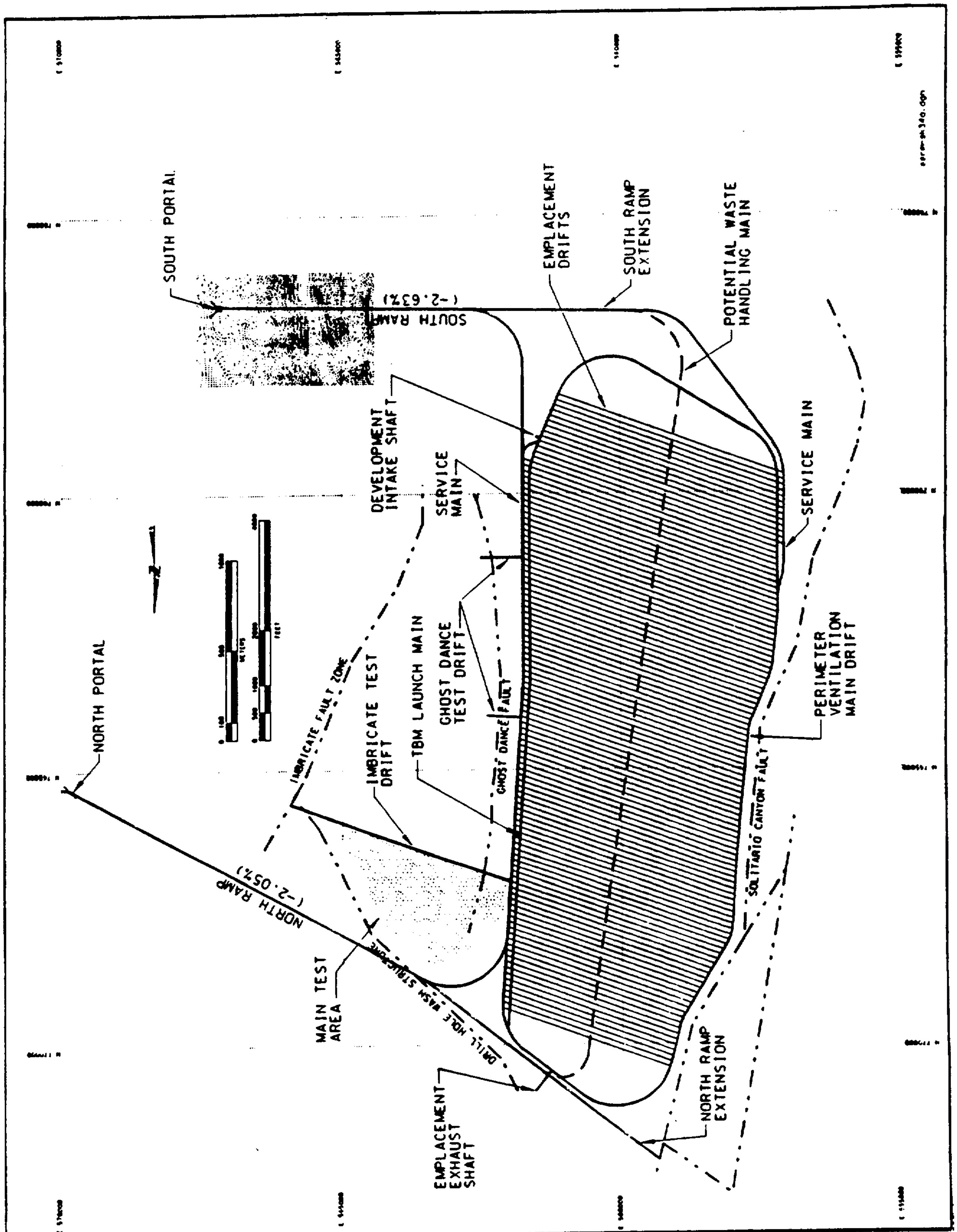


Figure 5-10 Conceptual Repository Layout, Option I, with Various Site Features

drifting access to the underlying Calico Hills unit.

The ramp will be 7.62 meters (25 ft) in diameter. The location of the north portal and the alignment and diameter of the ramp were set during ESF Title II design. A starter tunnel for launching a 7.62 meter diameter TBM is currently under construction.

During repository operations, this ramp would provide primary access for transporting waste packages to the subsurface from a waste handling building located on the surface, adjacent to the north portal. It also affords primary access for transportation of materials, personnel, and equipment to the subsurface for support of emplacement operations and would function as the main ventilation intake airway for the emplacement side of the repository.

The gradient of this ramp was -8.9% in the SCP-CDR (SNL, 1987). Later geologic interpretations that raised the TSw1/TSw2 contact in the northern portion of the primary area allowed the gradient to be decreased to -6.9% during ESF Title I design. The gradient of the north ramp in the Option I layout is -2.05% (M&O, 1993d), beginning at a point just inside the starter tunnel, extending through the 305 meter (1000 ft) radius curve, and ending at the intersection of the curve with the service main.

5.1.7.3.2 North Ramp Extension

The north ramp extension continues in a westerly direction from the intersection located at the beginning of the 305 meter radius curve. Its initial function, during site characterization, would be to provide an east-west crossing of the potential repository block to explore for north-south trending geologic features and to examine the Solitario Canyon Fault.

During repository operations, this ramp extension may provide access to a dedicated waste emplacement main, if such is determined to be necessary based on retrieval, backfilling or other concerns. If lower areal thermal loadings or other conditions result in a need to develop emplacement areas on the east side of the Ghost Dance Fault, then this extension would provide a launch point for driving an emplacement operations access ramp to the lower block. (As discussed in Section 5.1.2.3.1, an emplacement block located east of the primary block would be significantly lower in elevation due to the eastward dip of the formation.)

The diameter of the extension would be 7.6 meters, consistent with other openings that serve as primary accesses and airways in the Option I layout.

5.1.7.3.3 Service Main

Except for a short reach extending north from the intersection with the bottom of the north ramp, the remainder of the service main would be excavated during site characterization where it is called the "TS Main Drift" or the "North-South Drift".

This opening is the primary feature in the Option I layout that controls the gradient of all other main drifts and of the north and south ramps. It also controls the elevation of the emplacement drifts.

One of the previously stated design objectives was to avoid crossing of faults, such as the Ghost Dance, with emplacement drifts. This led to a basic design decision to orient the service main more or less parallel to the Ghost Dance Fault, on the fault's west side due to a larger area available for waste emplacement, with emplacement drifts extending to the west. Because very little is known about the character of the Ghost Dance Fault at depth, and because it is doubtful that much additional information will become available prior to excavation of this drift during site characterization, it was decided that a 122 meter (400 ft) standoff distance should be allowed between the drift and a projection of the main surface trace of the fault to the TSw1/TSw2 contact (M&O, 1993d).

As described in Section 5.1.2.2, the dip of the Topopah Spring Unit is basically to the east. Therefore, in order to accommodate the design objective dealing with flat-lying emplacement drifts, it was necessary to situate this opening as high as possible in TSw2 in order to provide for maximum utilization of the unit when horizontal emplacement drifts are extended to the west.

In this layout, the service main slopes upward to the south at 0.5% until passing under a structural low in the TSw1/TSw2 contact located at the approximate midpoint of the drift, then continues upward at 2.0% to the bottom of the south ramp (M&O, 1993d). The crown of the service main is located a minimum of 5 meters below the contact. Its closest approach occurs at the structural low. (It may be that the structural low doesn't really exist, but is merely a computer generated feature of the IGIS model. Its elimination, however, will not change the layout, and should permit establishing a more uniform grade throughout the service main.)

During repository operations, the service main would function as the primary, on-block accessway for development operations personnel, equipment, and materials haulage, and would provide space for utilities installation and a conveyor system for transporting excavated tuff away from the active development area. It would accommodate a movable, raised platform upon which numerous rail switching tracks and crossovers would be mounted to facilitate access into several different emplacement drifts in varying stages of construction at any given time.

A short section of service main is also located in the southwest corner of the potential emplacement block. This feature of the layout was necessitated by a need to begin a climb away from the emplacement area in order to minimize the grade of the south ramp and to avoid an area of low cover in the southeastern corner. The operational functions of the TBM launch main and the ventilation perimeter main would reverse during the period that development of emplacement drifts in this area takes place, i.e., the emplacement drift TBMs would traverse the block from west to east during this time.

The service main would also function as a primary ventilation airway in both emplacement and development operations.

5.1.7.3.4 TBM Launch Main

The TBM launch main is oriented parallel to the service main and the two are interconnected by crosscuts at each emplacement drift location. This opening would be constructed during the initial phase of repository construction, prior to emplacement of waste. It would be 7.6 meters in diameter.

The function of this main in development operations, as implied by its name, would be to provide space for launching a smaller, 4.3 meter diameter (14 ft) TBM for excavation of emplacement drifts, without the need to construct individual launch chambers at each emplacement drift location. It is conceivable that the service main could provide this function and thereby eliminate the need for construction of an additional 7.6 meter diameter opening. However, it is highly probable that more than one TBM will be required in order to maintain a sufficient rate of emplacement drift construction to support the waste receipt schedule. Without a dedicated launch main, it would be extremely difficult to launch one TBM while servicing another from the same primary access opening.

In emplacement operations, the function of this opening would depend upon whether or not it is deemed necessary to provide a dedicated waste handling main through the middle of the emplacement block. If the waste handling main is unnecessary, then the launch main would serve as the primary waste handling main on the emplacement side of the repository.

In either case, this opening would serve as a primary ventilation airway for both development and emplacement operations.

5.1.7.3.5 Potential Waste Handling Main

A potential waste handling main is included in the Option I layout to address concerns relating to retrieval of waste packages and backfill of emplacement drifts. While it provides an extremely conservative approach toward accomplishing these tasks by way of halving the maximum length of emplacement drift, it complicates development operations and doubles the number of radiation doors or fixtures for the emplacement drifts. In addition, it would create a "cool corridor" through the center of the emplacement block that may be undesirable from a thermal management point of view. As mentioned above, the TBM launch main could accommodate the waste handling function on the emplacement side of the repository.

The purpose of this opening would be to provide access to the emplacement drifts for emplacement of waste packages. Shielded packages could be transported to the mouth of an emplacement drift with their long axis oriented parallel to the longitudinal axis of various drifts along the transportation route and then be rotated 90 degrees in the 7.6 meter diameter waste main for insertion into the emplacement drift.

The waste handling main would serve as a primary ventilation airway on the emplacement side of the repository. It would also provide access for backfilling or retrieval of waste packages if these activities are determined to be necessary.

5.1.7.3.6 Perimeter Ventilation Main

The perimeter ventilation main functions as a primary ventilation airway in both development and emplacement operations. It would be 7.6 meters in diameter and would be excavated during the initial stages of repository construction, prior to waste emplacement.

In addition to providing ventilation, this main also affords an alternate means of access to the emplacement drifts for carrying out instrumentation monitoring, performance confirmation, or similar tasks that might interfere with actual emplacement activities being conducted in the waste handling main. It would also serve as a backup means of access to retrieve or extract waste packages in the unlikely event of a rock fall or other off-normal condition that might occur in an emplacement drift.

On the development side of the repository, this opening provides space for specialized equipment to "pick up" a 4.3 meter diameter, emplacement drift TBM as it completes a drive across the block and provides a route for it to be transported back to the east side of the repository, into the launch main, to begin another emplacement drift.

The location of this drift is determined by physical conditions of the site. Along much of the north-south trending portion of this opening, its location in plan was established by allowing for a 61 meter (200 ft) standoff from the Solitario Canyon Fault. Toward the south end, however, it was necessary to limit westward extension of emplacement drifts in order to avoid either violation of the 200 meters minimum cover constraint or to maintain at least 5 meters standoff between the invert of this opening and the top of the vitrophere as is required in the RIB (DOE, 1993b).

Since flat-lying emplacement drifts are at the same elevation where they intersect the perimeter main as they are at the east end where they join with the launch main, and since grades in the launch main parallel those in the service main (the basis for elevations in the service main was discussed in section 5.1.7.3.3), grade control in the perimeter main is determined by elevations in the service main throughout the emplacement area. At the south end of the layout, the perimeter main would slope up to a high point at the intersection with the potential waste handling main. At the north end, the perimeter main would slope downward to a collection sump located at the emplacement operations ventilation shaft.

The curved portions of the perimeter main at the north and south ends of the repository block are configured to provide for ease of constructability through the use of long radius curves. At the south end of the block, the main is situated to avoid increased faulting and areas where the 200 meter cover restriction becomes limiting. At the north end of the layout, the perimeter main is located just south of the north ramp extension to avoid having to establish a firm tie between these two openings at this point in the program. Since it is proposed to construct the ramp extension during the site characterization phase of the project, a certain amount of flexibility in repository design could be sacrificed by a design that attempts to extend the perimeter main farther north, beneath the ramp extension, at this time.

5.1.7.3.7 Waste Emplacement Drifts

The diameter of waste emplacement drifts in the Option I layout is 4.3 meters (14 ft), for reasons discussed in section 5.1.6.2. These drifts provide space for emplacement of waste packages on railbound carts in the center of the drift.

As concluded in section 5.1.2.4.1, the optimum orientation of subsurface openings at Yucca Mountain from a ground control or stability point of view appears to lie between bearings of N70W and S75W, with approximately east-west being the most favorable direction. The waste emplacement drifts in the Option I layout are oriented at a bearing of N70W, at one "edge" of this "most favorable window". It is considered important that the emplacement drifts be aligned within this window in order to minimize support requirements and to reduce chances that ground support maintenance will be required after emplacement of waste packages. In other words, the alignment of openings such as the main drifts and ramps, which can be accessed and maintained throughout all phases of the repository program, is considered to be of considerably lower priority than the alignment of emplacement drifts, where heat and radiation pose formidable problems if maintenance is required.

The N70W orientation selected for this layout was based on a desire to stay inside the favorable window while maximizing the length of individual emplacement drifts for operational reasons relating to the use of TBMs as the primary excavation tool. Longer drifts mean lower costs and greater average advance rates because less time is spent in a moving/launching mode, thereby enhancing the utilization of each machine. Additionally, the number of emplacement doors or other fixtures at the mouth of each emplacement drift are minimized.

The basic layout concept utilized by Option I will accommodate other emplacement drift orientations inside the favorable window. The selected orientation was based on inspection that indicated a best fit to the physical shape of the available area on the west side of the Ghost Dance Fault. Future work should investigate optimization of emplacement drift alignment.

As mentioned in section 5.1.7.2, a primary objective in developing the Option I layout was to maintain level gradients in the emplacement drifts to facilitate safety and equipment stability aspects of emplacement operations. While this goal has been attained in the layout, future work should investigate introduction of shallow slopes ranging between, say, 0.3% and 0.6% to provide drainage out of these drifts while maintaining downhill gradients in the perimeter main and the service/launch mains that preclude the occurrence of "low spots". Whether the drifts should be sloped to drain east or west, or toward or away from a centrally located waste handling main, or sloped at all for that matter, will likely be the subject of great debate during future work if the Option I layout undergoes further refinement.

As discussed in section 5.1.4.2, determination of the optimum spacing for emplacement drifts involves a great deal of design analysis to weigh the effects of waste package size, heat output, and spacing against drift diameter and spacing and against various thermal loads and thermal goals. An emplacement drift spacing of 30.5 meters (100 ft) is shown on Figure 5-11 but it is used for diagrammatic purposes only and is not considered to be optimum.

5.1.7.3.8 South Ramp

The south ramp will be excavated during site characterization. It will be 7.62 meters in diameter. The ramp includes a 305 meter (1000 ft) radius curve which connects to the service main and completes the primary loop to be excavated during ESF construction.

During repository operations, it would afford primary access for transportation of personnel, equipment and materials to the subsurface for support of repository development operations. It would also serve as the main ventilation exhaust airway for the development side of the repository.

Title I ESF design (RSN, 1991) located the south portal next to the nose of a ridge on the southeast flank of Yucca Mountain. For purposes of the Option I layout, the same ridge was utilized but the portal was moved downhill and farther to the east in order to maintain a slope on the ramp of less than 3.0%, consistent with the Option I design objectives, but still above the flood plain. The resulting slope of the ramp is 2.7% (M&O, 1993d).

The ramp was oriented by inspection to lie directly beneath the spine of the portal ridge as shown on Figure 5-10, a practice generally considered to be favorable in terms of opening stability. When extended straight into the mountain, this orientation gave a reasonably good fit with the emplacement block area and kept gradients comfortably beneath the 3.0% maximum.

5.1.7.3.9 South Ramp Extension

The south ramp extension continues in a westerly direction for approximately 960 meters (3150 ft) from the intersection located at the beginning of the first 305 meter radius curve. It then curves northwest and enters another tangent section that terminates in a final curve that turns the ramp extension north. At this point it connects to a short section of service main that parallels, and then intersects, the ventilation perimeter main. The ramp extension is 7.6 meters in diameter, consistent with other Option I main drifts that function as primary accesses and ventilation airways.

With the exception of the final curve, the extension would be excavated during site characterization to provide a second east-west crossing of the potential repository block to explore for major, north-south trending, geologic features. It may be used as a launch point for exploratory drifting access to the underlying Calico Hills unit. Because it approaches within 5 meters of the underlying vitrophere, this drift might also be utilized for numerous site characterization tests throughout the TSw2 unit.

During repository operations, this drift would provide access to the short section of service main located on the west side of the potential repository block. It would function as a primary ventilation airway for development operations during the period when this section of service main is supporting emplacement drift excavation.

The south ramp extension may also provide access to a dedicated waste emplacement main if such is determined to be necessary based on retrieval, backfilling, or other concerns. If lower areal thermal loadings or other conditions result in the need to develop an emplacement area east of the Ghost Dance Fault, then this extension provides a launch point for driving a development operations access ramp to a lower block. (An emplacement block located east of the primary block would have to be significantly lower due to the eastward dip of the formation.)

5.1.7.3.10 Ventilation Shafts

Two ventilation shafts, one to support repository development operations and another for support of repository emplacement operations, are included in the Option I layout. Sizing of these shafts was considered beyond the scope of this study but it is probable that they would be on the order of five to eight meters in diameter. Both shafts would be constructed during the initial phase of repository construction, prior to emplacement of waste.

Additionally, both shafts are situated toward the eastern side of the layout to facilitate access from an emplacement block located to the east if lower areal thermal loadings or other conditions warrant development in that area.

The development operations shaft would be outfitted with a surface ventilation plant housing a main fan(s) at the collar and would function as the primary ventilation intake airway for repository development operations. It would also be outfitted to provide a secondary means of escape as mandated by regulatory requirements (30CFR57). It is not envisioned that this shaft would be required to support routine hoisting of personnel or materials since a direct and relatively short route is available for these purposes via the south ramp. This shaft is conceptually located on a ridge adjacent to the main road leading to Yucca Crest.

The emplacement operations shaft would function as the principle ventilation exhaust airway on the emplacement side of the repository. It could include means for emergency egress and would be outfitted for installation of high efficiency particulate (HEPA) filters in an interconnected branch circuit. It is conceptually located on the side of a ridge adjacent to Drill Hole Wash.

It should be noted that shaft (and ramp) functions other than described here are being considered as part of ongoing repository ACD efforts and are discussed further in M&O (1993f, Section 5.4.2).

5.1.7.4 Description of Subsurface Operations, Option I

This section will describe the general concept of subsurface operations envisioned for the development and emplacement sides of the Option I repository layout.

5.1.7.4.1 Subsurface Development Operations

Figure 5-11 presents the arrangement of subsurface openings comprising the Option I layout. As mentioned in section 5.1.7.3, excavation of the TBM launch main, the perimeter ventilation main, and the ventilation shafts would occur during the initial stage of repository construction, prior to emplacement of waste. Excavation of the short section of service main located just north of the bottom of the north ramp, and the short section in the southwest corner that joins with the

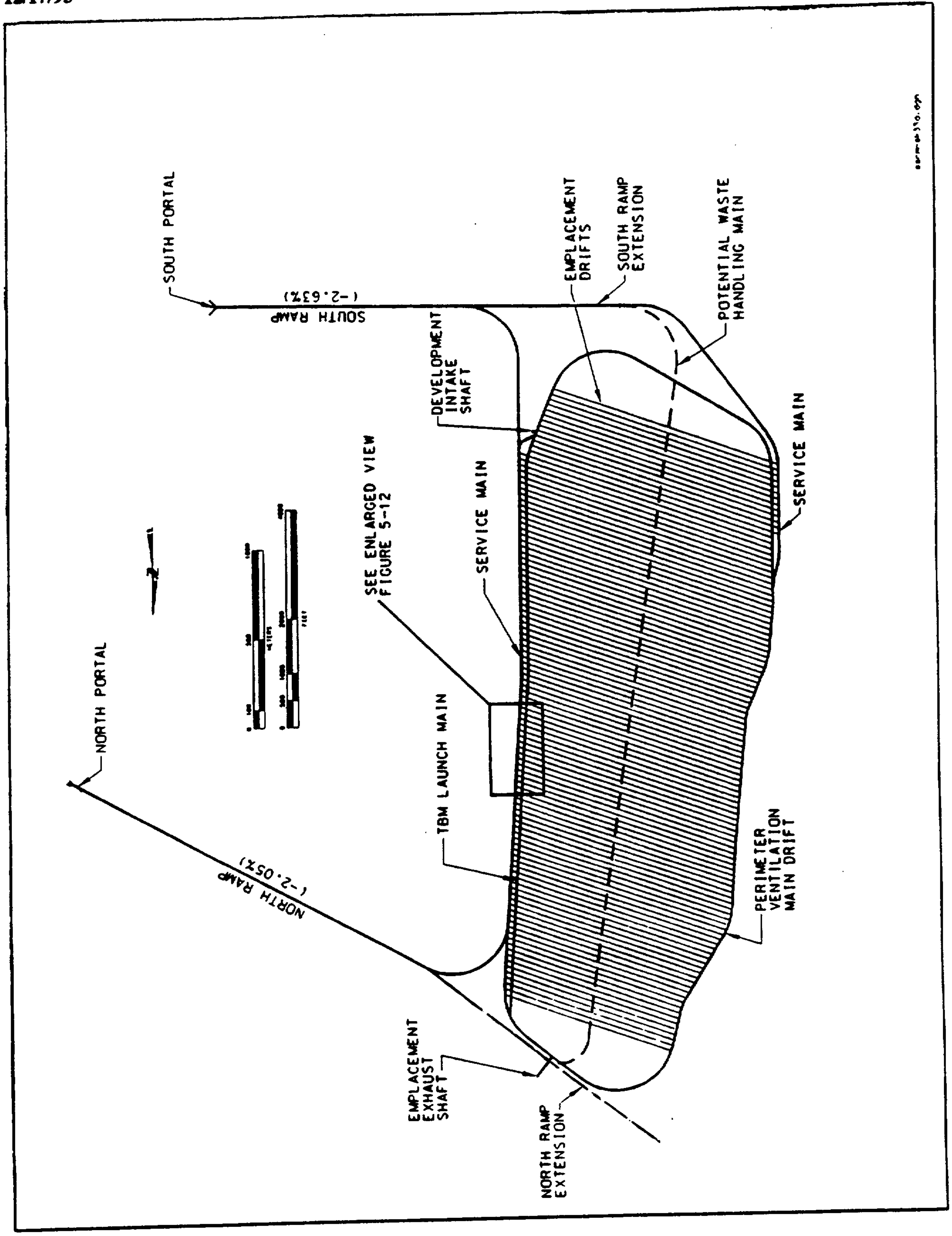


Figure 5-11 Conceptual Repository Layout - Option I

south ramp extension, would also occur at this time.

Upon completion of this system of main drifts, or "mains", excavation of emplacement drifts would begin. Emplacement drift construction would begin at the north end of the layout and would proceed sequentially toward the south. It is envisioned that the construction of approximately ten emplacement drifts would have to be completed prior to emplacement of waste, in order to establish proper ventilation circuitry, and to allow erection of substantial stoppings or bulkheads in the mains to provide physical separation of development and emplacement operations.

Figure 5-12 is an enlarged view showing the typical arrangement of openings in the service main/launch main portion of the layout. Prominent features on this figure include the crosscuts which interconnect the service and launch mains. Excavation of each of these crosscuts would precede excavation of its adjoining emplacement drift, as the crosscut provides the development operations access link between the emplacement drift and the service main. The crosscut is curved (30.5 meter/100 ft radius) to permit installation of a railway system to support TBM excavation of the emplacement drift and to service follow-on construction in the emplacement drift necessary to prepare it for receiving waste packages.

It is envisioned that excavation of the crosscuts would be performed using a specially designed alcove miner to create a starting cut for a heavy-duty roadheader, which would then be used to complete the rest of the crosscut. Section 5.1.5.2 discussed the limitations of currently available roadheader machines in the TSw2 unit, but also pointed out that the Colorado School of Mines is developing both the alcove miner and a special cutting head for a roadheader that may work in this rock. A specialized, forward gripper, unshielded TBM may also be adapted for this requirement, but, for purposes of this discussion, it is assumed that the alcove miner and a modified, heavy-duty roadheader will be developed.

Both the alcove miner and the roadheader would operate out of the launch main and would advance the crosscut toward the service main. This approach would minimize disturbance to operations associated with actual emplacement drift excavation/construction and would help prevent contaminated ventilation air exhausted from the roadheading operation from polluting the air stream used by the other operations. Crosscut excavation would be maintained several positions ahead of emplacement drift excavation. Roadheader muck would be discharged onto a segmental conveyor or into a shuttle car and would then be transferred into a railbound muck car situated in the closest crosscut accessible from a switching platform located in the service main. The muck car would then travel to and discharge in the primary conveyor feeder located in the service main.

Another feature shown on Figure 5-12 is an enlargement, or cut-out, in the launch main at the entrance to each emplacement drift. These are for installation of concrete filled radiation doors, approximately one meter thick, that cover the entrance to each emplacement drift and provide shielding for emplacement operations personnel on the emplacement side of the repository. Excavation of these cut-outs would be performed by the alcove miner, during the same time that the starter cut for the adjoining crosscut is excavated. Cut-outs for radiation doors are also required at the opposite ends of the emplacement drifts. These would be excavated, one at a

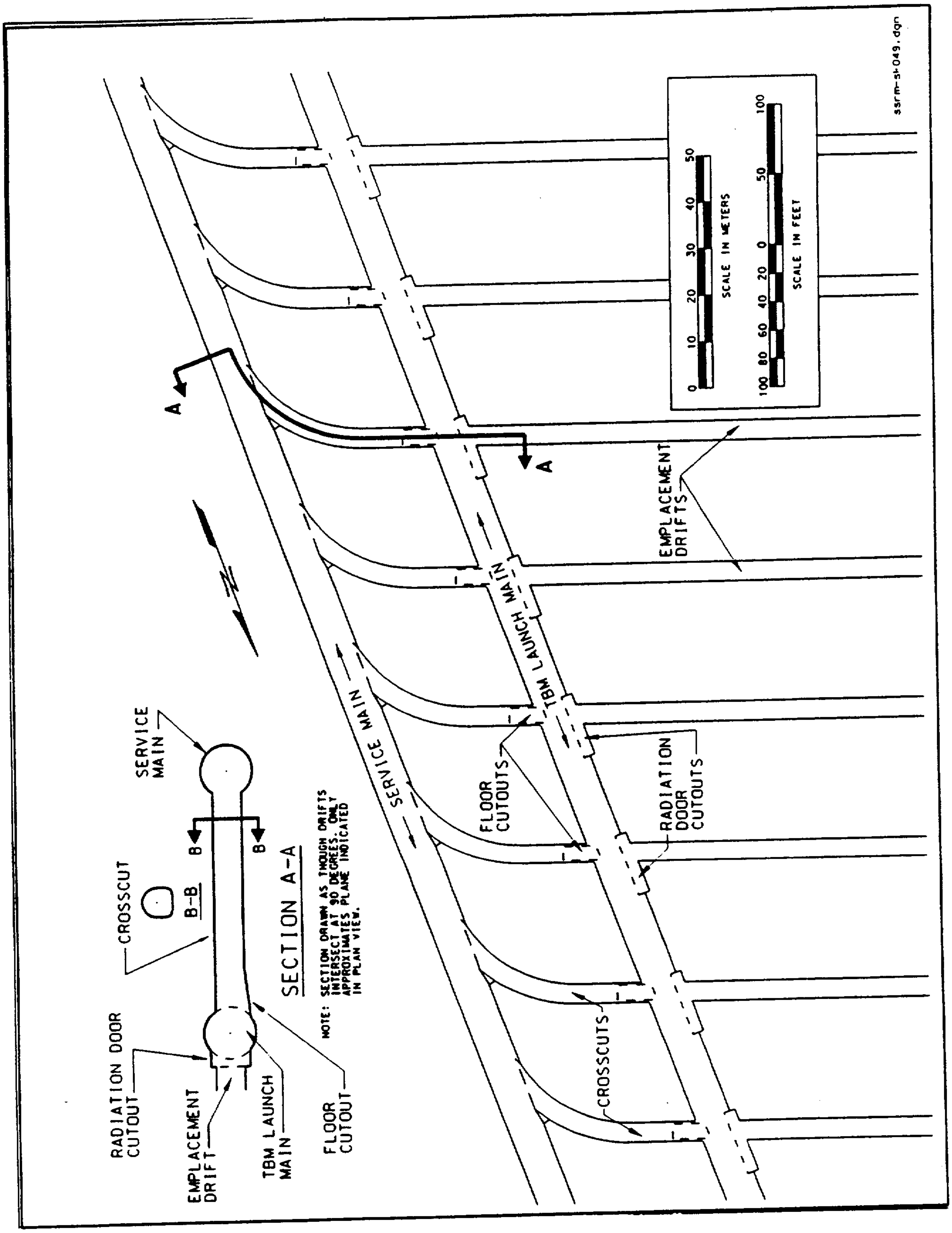


Figure 5-12 Detailed Layout of Drifting in Service/Launch Mains Area

time, by the alcove miner immediately following removal of the TBM as it completes each emplacement drift. This will permit utilization of the ventilation duct system already hung in the drift, for exhausting dusty air generated during excavation.

A single alcove miner/roadheading operation should provide sufficient coverage of crosscut and radiation door cut-out excavation to stay ahead of two TBMs performing emplacement drift excavation. When a TBM is brought into the launch main to begin excavation of another emplacement drift, the alcove miner, roadheader and various support equipment would be temporarily moved into a crosscut to permit the TBM carrier to pass.

Construction of an emplacement drift involves several successive stages as follows:

1. Launch TBM.

2. Excavate emplacement drift with TBM, installing precast concrete invert segments, rail, utilities and permanent ground support as the machine advances.

3. Following completion of drift excavation, install any additional ground support deemed necessary and construct a cast-in-place concrete invert to support a permanent rail system used to facilitate waste emplacement, while removing utilities and other materials originally installed to sustain excavation process. (Utilities and other materials that are removed would be reused in other emplacement drifts that are being excavated at the same time.) This work would be performed on a retreat basis, i.e., from the far end of the emplacement drift, back toward the service main.

4. Install permanent rail and supports or trackway for remote video monitoring, instrumentation equipment or similar devices in the emplacement drift.

5. Construct radiation doors at the ends of the emplacement drift.

In order to permit all of the work outlined above to be performed concurrently, it is necessary to provide construction access to at least five emplacement drifts at any given time. In reality, probably twice that number would be needed, i.e., access to ten emplacement drifts might be desirable in order to permit adequate flexibility during development operations.

To accommodate access to multiple emplacement drifts in varying stages of construction, a switching or service platform as depicted on Figures 5-13, 5-14, 5-15, and 5-16 would be utilized. This platform would be designed and fabricated to include the following attributes:

1. The platform would be fabricated in sections ten to fifteen meters (30 to 50 ft) long to facilitate transportation into the subsurface and to permit repositioning of the platform one or two sections at a time, if necessary. Adjacent sections would be joined using simple pin connections.

2. Each section would be outfitted with steel wheels to facilitate moving the platform in individual or multiple sections along rail attached to precast concrete segments in the

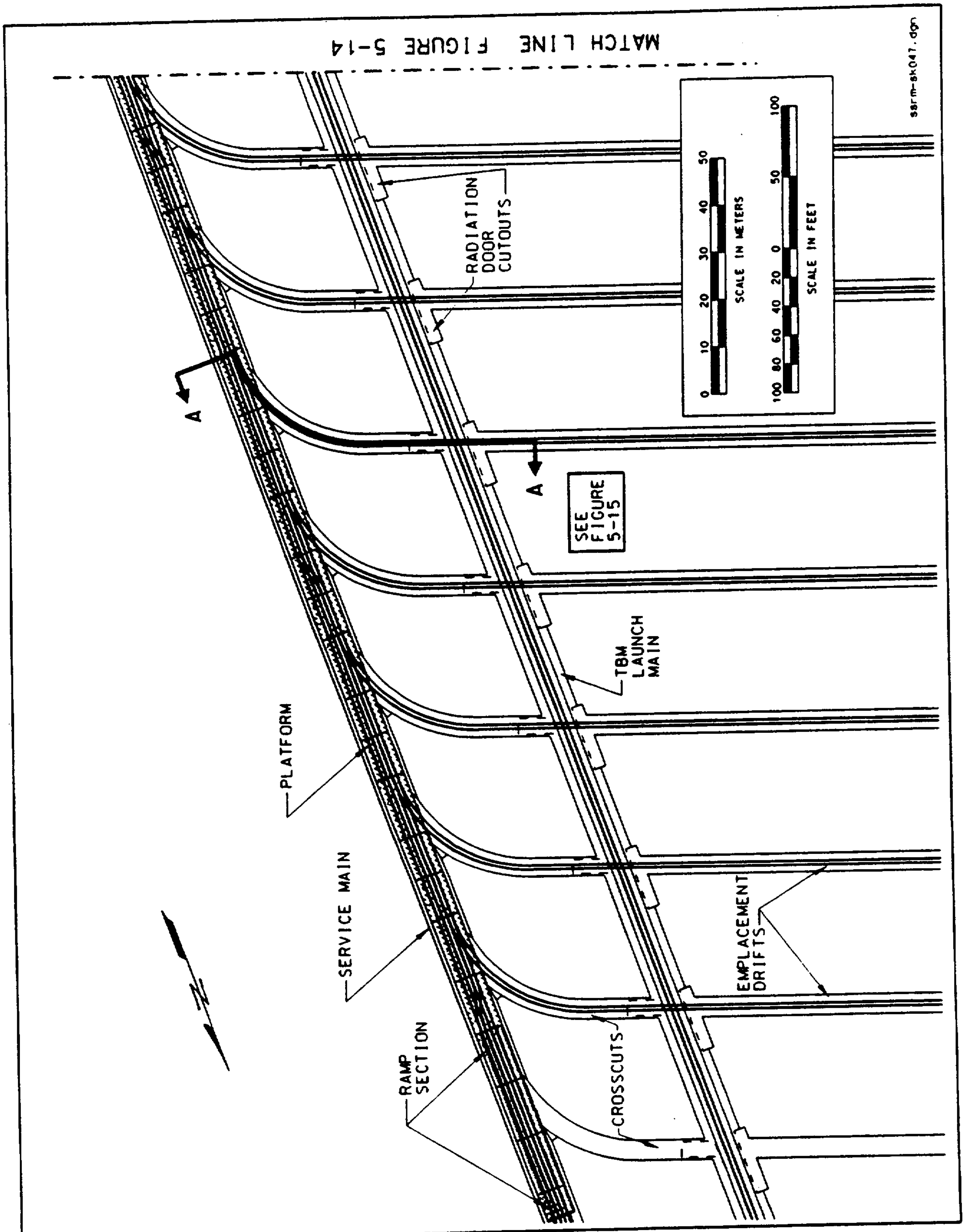


Figure 5-13 Service Platform - North End

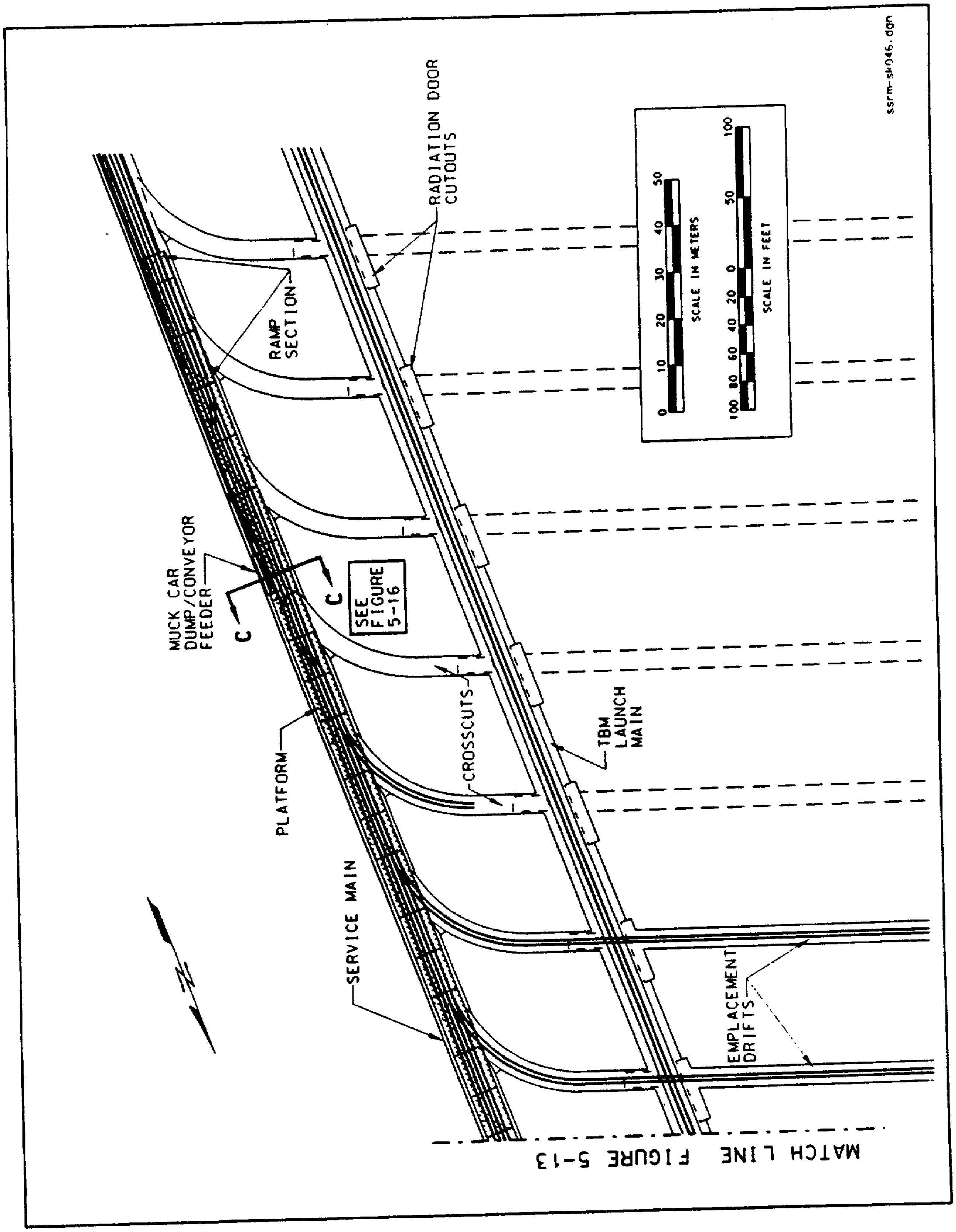


Figure 5-14 Service Platform - South End

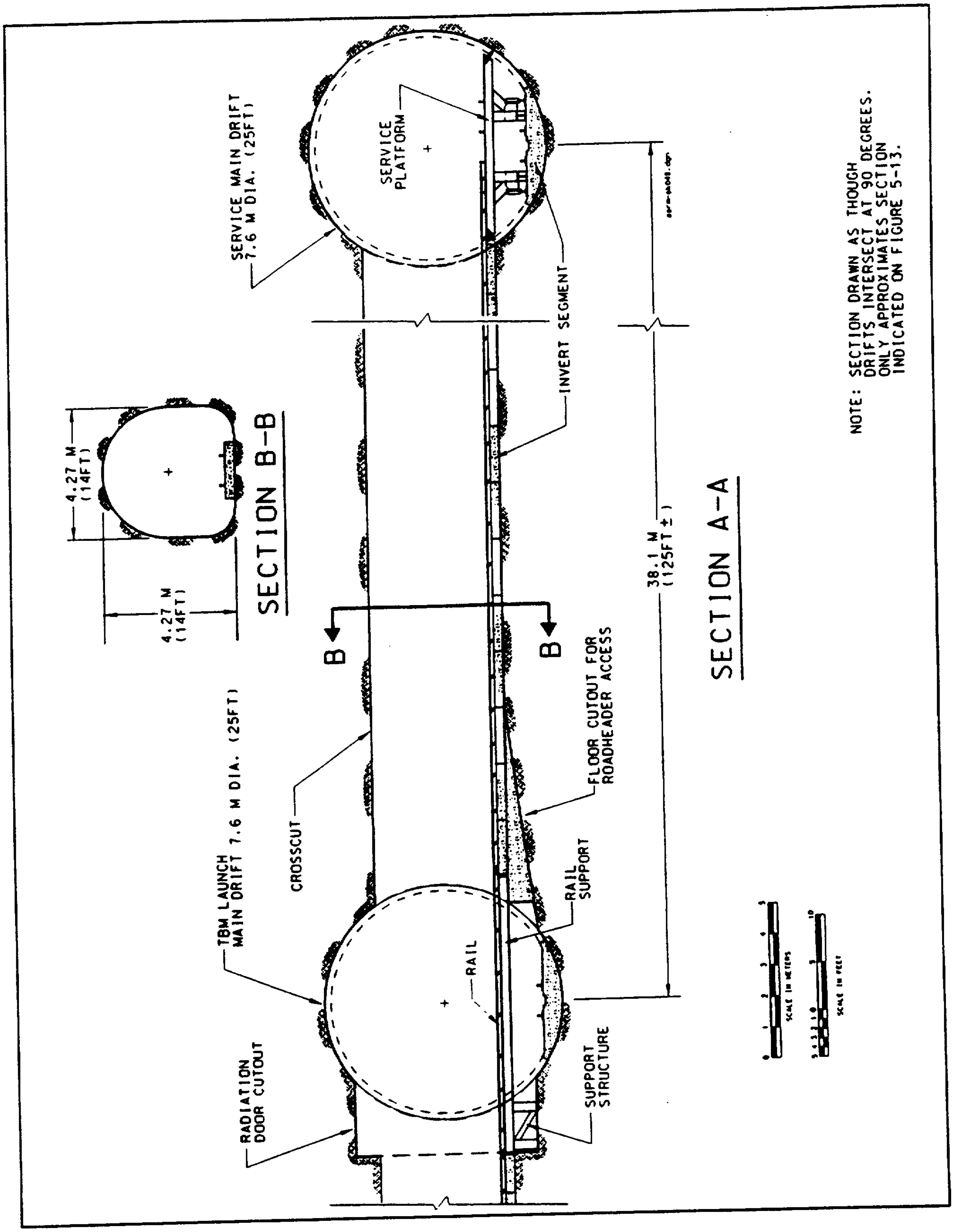


Figure 5-15 Service Platform - Section Through Crosscut

service main invert.

3. Sections would be equipped with lifting and anchoring systems which allow the platform to be lifted up and supported by its wheels for relocating or repositioning, then set down on adjustable, fixed supports that relieve wheel loads and accommodate temporary anchoring of the platform to the invert and walls of the tunnel to provide stable working conditions.

4. The top of the platform would be decked with expanded metal or a similar, non-skid surface and would have two sets of rail trackway installed. Rail switches would be installed on one track, spaced to coincide with the centerline spacing of the crosscuts and emplacement drifts. Crossover switches would be installed to permit access from one trackway to the other.

5. Racks or similar devices would be mounted along various sections of the platform to accommodate temporary storage of pipe, rail, fanline and other utilities or materials used in construction of the emplacement drifts.

6. A train dump and conveyor feeder station would be located at the south end of the platform to facilitate offloading of excavated muck from the emplacement drifts and crosscut excavation onto a conveyor system for transport out of the tunnel.

7. Each end of the platform would terminate in a ramp section which allows trains to transition from the permanent rail system attached to the tunnel invert, to the elevated railway attached to the top of the platform.

Figures 5-13 and 5-14 show the platform situated to provide access to ten crosscuts and their adjoining emplacement drifts at one time. Four or five of these drifts would be in various phases of construction following excavation. The remainder would either be in the process of being excavated or are next in line for excavation. The southernmost crosscut accessed by the platform would be used by the roadheading operation for muck and materials haulage.
Post-excavation construction in the emplacement drifts would be scheduled such that it keeps pace with the rate of TBM excavation of the drifts. When excavation of the last emplacement drift accessible from the platform is completed, the platform would be moved to the south and repositioned so that drifts requiring post-excavation construction are accessed from the north end of the platform, while the south end is situated to permit access to four or five more drifts to be excavated. The platform would be moved periodically toward the south in this manner throughout most of the repository operational period, until construction of the emplacement drifts is completed.

As mentioned above, actual emplacement drift construction begins with "launching" the TBM. Traditionally, this task has been accomplished by excavating a short starter tunnel or "launch chamber" beforehand using non-TBM methods, then constructing gripper pads made of concrete or timber to provide reaction points for the grippers so they, in turn, can react the thrust necessary to propel the machine forward. For most tunnels this is a one-time operation; a more mechanized approach is not warranted.

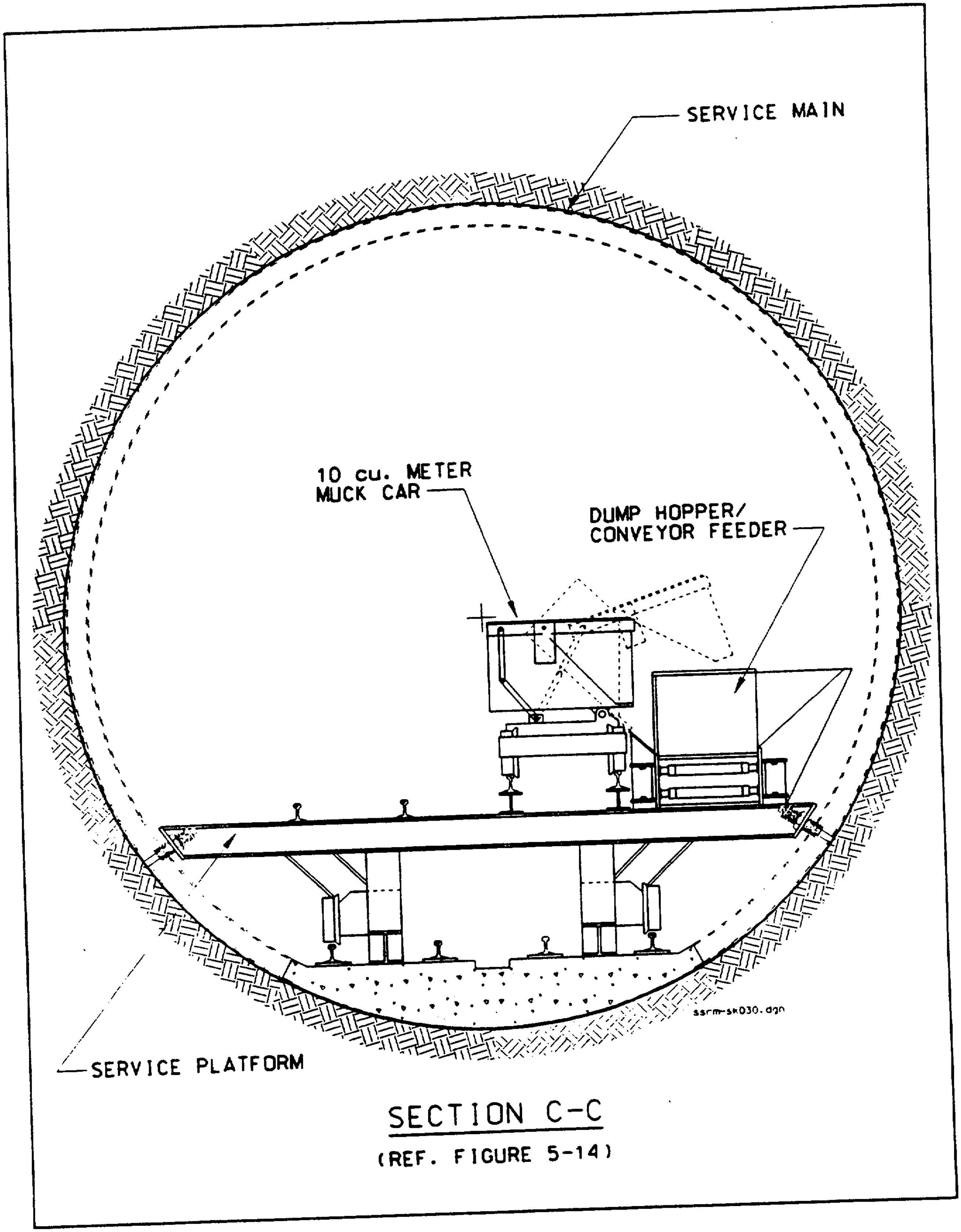


Figure 5-16 Service Platform - Muck Car Dump Point

The Option I layout, however, requires numerous launchings of the emplacement drift TBMs. In order to simplify these launchings without having to perform costly and time consuming starter tunnel excavation, emplacement drift TBMs for the Option I layout would be designed with a relatively small length to diameter aspect ratio, on the order of 1.25 : 1.0, not including the machine conveyor and tail shield sections, which can be designed to permit easy removal and reinstallation. (The aspect ratio for the 7.62 meter diameter TBM being built for the ESF program is even smaller, approximately 1.05 : 1.0, with tail shield and machine conveyor removed.) This criteria would permit the 4.3 meter (14 ft) diameter emplacement drift TBMs to be rotated in the 7.6 meter (25 ft) diameter launch main without the need for additional excavations. Given a relatively short TBM, all that is needed to facilitate launching is some sort of frame that will stabilize the machine and provide a reaction for thrust as it bores away from the larger diameter opening. A mechanized approach for accomplishing this task in a relatively short period of time is depicted on Figures 5-17, 5-18, and 5-19. A typical launch would be performed as follows:

1. The TBM would be moved to the launch site inside a steel cylinder called a "launch tube". While moving, the machine and tube would remain in longitudinal alignment with the various access drifts along the transportation route. The launch tube would be attached to a turntable mounted on top of a specially designed rail carrier. The machine would be positioned inside the tube such that the center of gravity for the TBM coincides with the center of the turntable bearing. This permits stable rotation of the TBM/launch tube assembly on the carrier at the launch site.

2. Prior to moving the TBM into the launch area, a short cylindrical steel section called a "transition tube" would be positioned on a flat, concrete, "grade slab" placed beforehand along the bottom of the radiation door cut-out excavation. The base of the transition tube would be flat and would be outfitted with three hydraulic, vertical positioning jacks. The transition tube would be aligned to the proper line and grade for the emplacement drift.

3. As the launch tube encasing the TBM approaches the launch area, it would be rotated and moved into alignment with the transition tube. Hydraulic outrigger jacks on the launch tube carrier would be used to stabilize and support the weight of the TBM and launch tube. The transition tube and launch tube would then be joined using bolts or clamps and short, five to ten centimeter (2 to 4 inch) spacers between the mating ends of the tubes. (The gap occupied by the spacers allows positioning of the launch tube without disturbing the alignment of the transition tube.)

4. A hydraulic cylinder is used to extend a primary thrust reaction shoe against the wall of the 7.6 meter diameter launch main. The shoe support is locked into position on the slide along which it travels. The two horizontal clamp cylinders are then rotated from their transport position and attached to the transition tube using steel links and pins. The clamp cylinders are then extended against the face of the radiation door cut-out.

5. The launch structure is now clamped in place and is supported by the seven vertical support jacks. The machine conveyor and trailing floor sections are brought in through

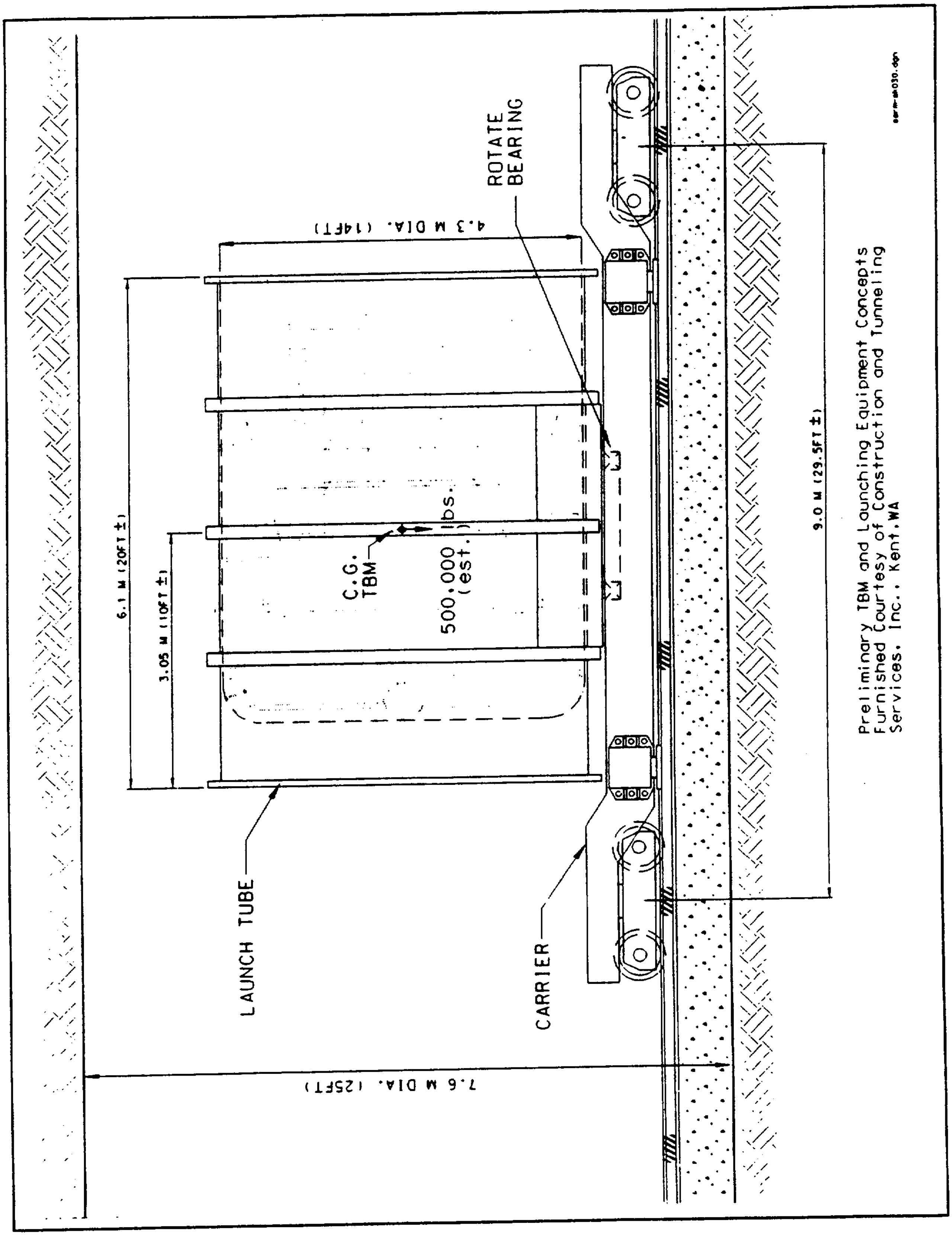


Figure 5-17 TBM/Launch Tube Carrier

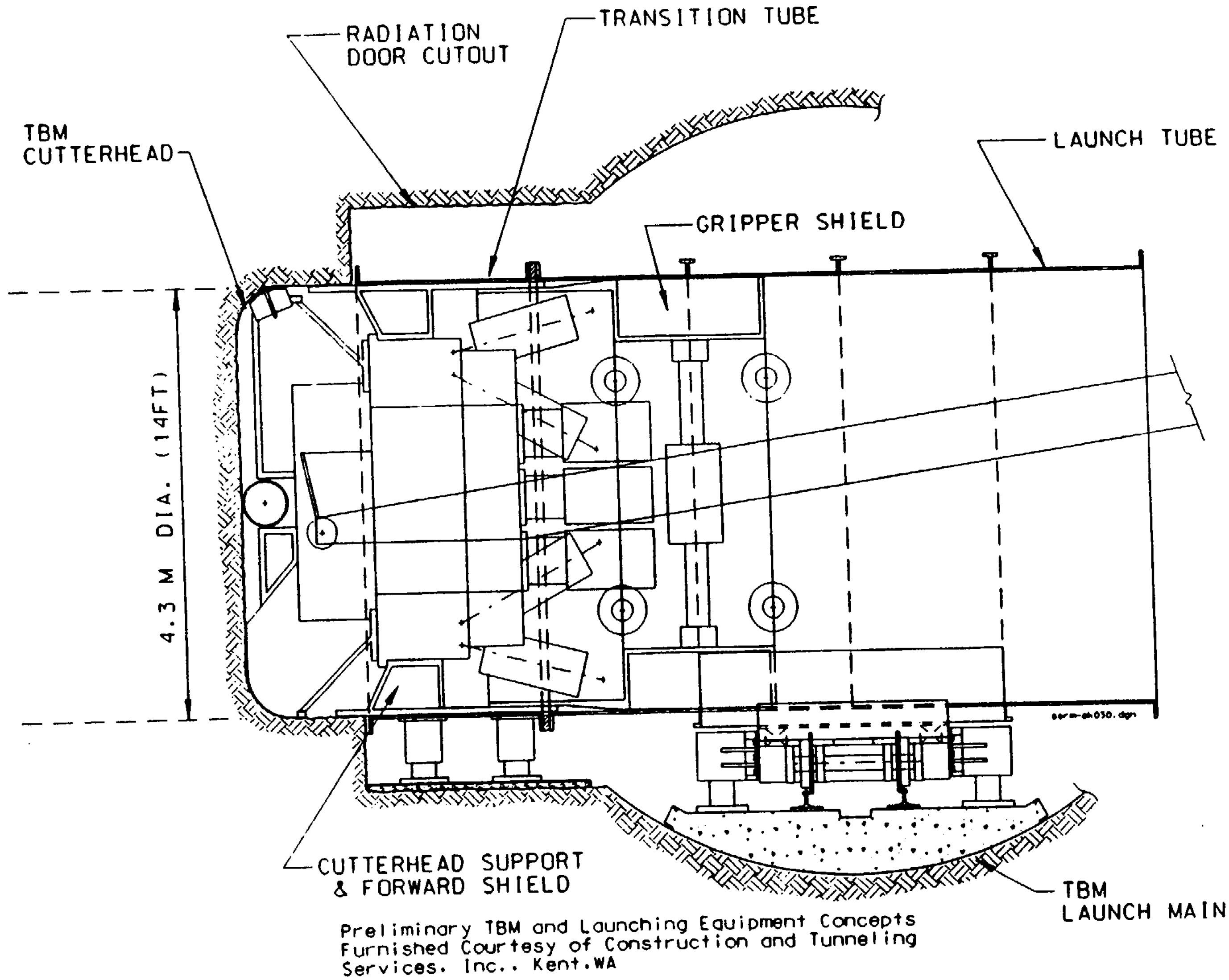


Figure 5-18 TBM Launch - Side View

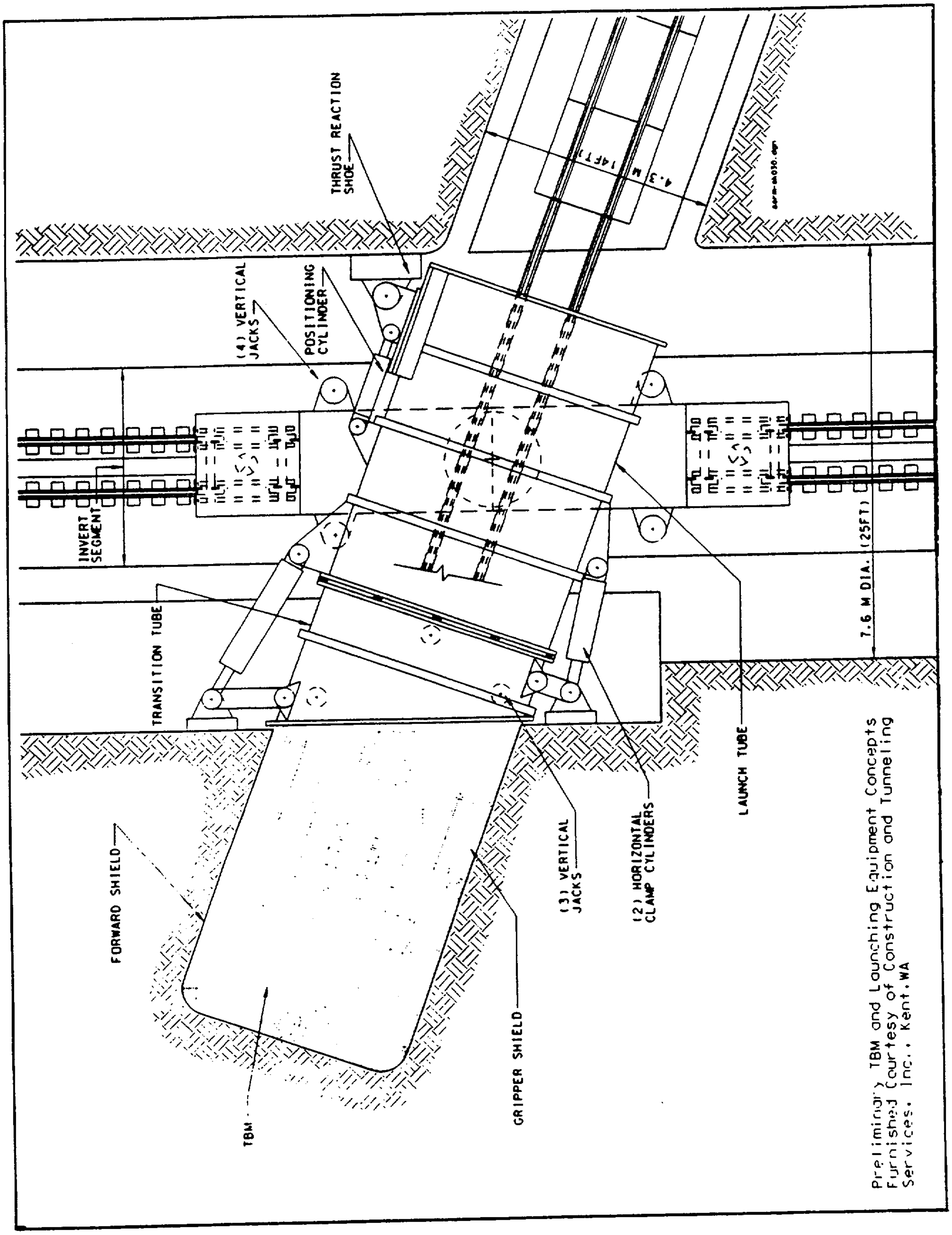


Figure 5-19 TBM Launch - Plan View

the crosscut and connected to the TBM.

6. The TBM is advanced to the face by lightly gripping the launch tube, but when boring begins, the cutterhead thrust would be reacted by retractable "chock" mechanisms mounted in the tubes. When the TBM grippers pass beyond the end of the transition tube, extensible struts would be used between the grippers and the last set of chocks until the machine has advanced far enough beyond the initial face to allow pressuring up the grippers without fear of breaking the rock at the corners of the cut-out.

7. The trailing floor rides on rail temporarily laid through the launch and transition tubes. When the trailing floor sections are fully in the emplacement drift, the launch structure is disassembled. The transition tube is moved to the next emplacement drift location and the launch tube is moved back into the perimeter main, ready to retrieve the next TBM. A simple support bridge is installed across the launch main to facilitate installation of rail for train traffic in and out of the emplacement drift.

8. As a TBM completes its drive across the emplacement block, it will "hole-out" at the perimeter ventilation main. As soon as the cutterhead is fully into the larger diameter opening, the machine would be backed up slightly, muck would be cleared away from the intersection, and the launch tube would be brought into position on its carrier to retrieve the TBM. A short transition piece would be installed to bridge the bottom of the gap between the end of the emplacement drift and the launch tube, and the TBM would advance into the tube. The tail shield and the machine conveyor would be removed from the TBM and placed back in the emplacement drift. The launch tube/TBM assembly would be rotated into longitudinal alignment with the perimeter main and would be moved back to the launch main to begin a new drift. The TBM conveyor, tail shield and the trailing floor cars would be pulled out of the drift and moved out of the way until the TBM is ready to resume boring.

Excavation of the Option I emplacement drifts with the TBMs would be performed in typical, hard rock tunnelling fashion. Muck haulage out of the 1000 to 1400 meter (3300 to 4600 ft) long emplacement drifts would be performed using conventional muck trains. Two muck trains would support each TBM operation. Considering the short drift length, and the problems associated with positioning a conveyor belt storage magazine and transfer conveyors in the crosscuts and/or service main, use of a continuous conveyor system to move the muck out of the drifts is considered impractical.

It is envisioned that the muck trains would consist of a locomotive, four each 8 to 10 cubic meter (10 to 13 cubic yard) muck cars, and supply cars as needed. In a commercial tunnel, the locomotives would probably be diesel powered. Electric trolley, or even battery locomotives could be used in this layout since the emplacement drifts are flat-lying and the one-way haul distance is relatively short. A "California switch" (a raised, wheeled platform containing two sets of parallel track, with ramps and switches located at each end) would be maintained in close proximity to the end of the trailing floor in order to minimize TBM downtime that results when a loaded train leaves the trailing floor and an empty one takes its place.

As the TBM advances, most elements of the permanent ground support would be installed immediately behind the machine, unless a shotcrete or concrete lining is determined to be necessary. Utilities necessary to support the tunneling operation would also be installed on advance. These would include ventilation duct; electrical power and communications cables; a process water pipeline; and a compressed air pipeline.

After the TBM "holes" into the perimeter main, and both it and the trailing floor are removed from the emplacement drift, the cut-out for the radiation door at the end of the drift would be excavated as described earlier. The ventilation duct would then be removed from the drift, since "flow-through" ventilation is available.

Post-excavation construction in the drift could commence following removal of the duct. This work would involve removal of utilities and the excavation rail system, cleanup of the invert, and construction of a cast-in-place concrete floor. It may also include installation of additional ground support or lining. These tasks would be performed in a retreat mode, i.e., in short, distinct reaches in order to maintain the availability of utilities and access rail to the work location, leaving an essentially finished product behind. When the work has been completed back to the service main, an emplacement rail system would be installed on top of the finished concrete. Installation of various supports, brackets, trackways, or other fixtures necessary to accommodate remote monitoring and instrumentation devices, as well as those items that might be needed to facilitate backfilling or sealing, would then be performed. The drift would be cleaned as necessary, radiation doors would be constructed at each end, and the drift would enter a stand-by mode until turned over to the emplacement operations side of the repository.

Separation of the development and emplacement sides of the repository would be accomplished by erecting "substantial stoppings" that seal against air movement and obstruct equipment passage in the perimeter main, the launch main, the service main and the potential waste handling main. (It may be desirable to provide for personnel passage through these stoppings to allow an alternate means of escape in case of a fire or other emergency condition.) When a new group of emplacement drifts is to be turned over to emplacement operations, new stoppings would be constructed at the appropriate location by crews on the development side, then the old stopping would be dismantled by crews on the emplacement side. In this manner, compliance with the separate ventilation systems requirement is maintained.

Inherent in the Option I layout is a great deal of flexibility regarding scheduling the turnover of completed emplacement drifts to the emplacement operations side. The panel concept utilized in past work (DOE, 1988) required, as a minimum, that development of an entire panel, containing numerous emplacement drifts, be completed before any of the individual drifts inside the panel could be turned over to emplacement operations. The Option I layout, on the other hand, could turn over a single drift if necessary-- although it may not be very cost effective to do so because of the work associated with moving the location of the substantial stoppings.

As a general note, it should be pointed out that a key feature that lends credibility to the Option I layout is the use of large diameter access drifts, or mains, in conjunction with small diameter emplacement drifts. This concept not only facilitates mechanization of the launching process for starting TBM excavation of the emplacement drifts, it also affords a means of recovering the

TBM when the drift is completed and provides a route for moving the machine basically intact to the starting location for the next drift. It is conceivable that, with practice, development crews could accomplish the recover-move-launch task inside of a week, given this relative difference in drift sizes and the mechanized launch process described above. But, layout concepts which do not provide ample space to perform these tasks could require dismantling the TBMs at the end of each drive, moving individual components to the new launch location, and reassembling the machines in larger diameter openings that have been constructed beforehand by other means. This work could require several months to complete--even if the distance moved is only a few hundred meters.

Another key aspect of the Option I layout is the flexibility afforded by the parallel service and launch mains. These work together to provide a system that can vary the productivity required of development operations in response to changes in the waste receipt schedule. Additional TBMs can be brought on line if necessary without causing major disruptions to the development scheme.

While it lacks certain optimizations, the Option I repository development scheme described above is considered to be a realistic scenario, sufficiently flexible to be constructed and operated in an efficient, productive manner.

5.1.7.4.2 Subsurface Emplacement Operations

Section 5.1.6.2 described the ISDOR emplacement mode concept, which was adopted for use in the development of the Option I layout. This in-drift emplacement concept consists of a 1.95 meter (6.4 ft) diameter waste package permanently mounted on a wheeled cart that rolls on rail laid in the invert of a 3.4 meter (14 ft) diameter emplacement drift. To reiterate the point made in Section 5.1.6.2, the size of waste package adopted for purposes of this discussion in no way reflects any conclusion or recommendation of the ongoing waste package ACD effort. The size is, however, considered to be representative of a conservative case for purposes of this report. Based on data provided in Table 5-6, this 21 assembly package would be approximately 5 meters (16.5 ft) in length and would weigh about 85 tonnes (94 tons).

It is assumed that the waste package would be mounted on its emplacement cart in a hot cell located in the waste handling building on the surface, and that the waste package/cart assembly would be inserted into a transport cask before being moved away from the waste handling building. The transport cask would be designed to reduce surface dose radiation exposure to "stand-beside" limits.

Figure 5-20 portrays the steel cask concept that is envisioned. It would be outfitted with an outer set of steel wheels that facilitate loading the cask onto a transport carrier and offloading of the cask onto an emplacement platform situated at the mouth of an emplacement drift. The interior of the cask would be equipped with a device to secure the waste package/cart during transport and a self-contained mechanism capable of offloading the waste package/cart assembly into one end of an emplacement drift.

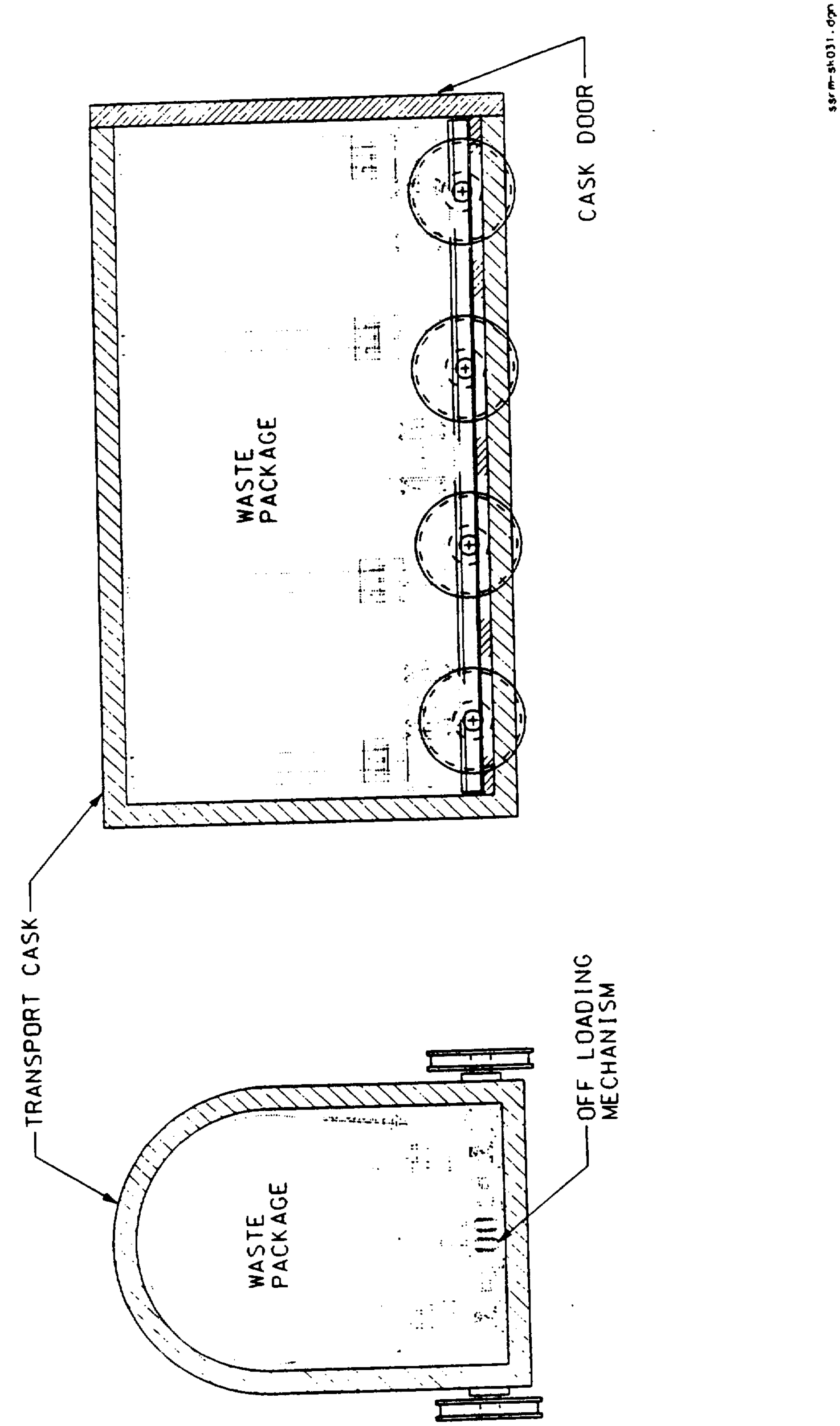


Figure 5-20 Subsurface Transport Cask Concept

The transport cask would be moved to the subsurface on a specially designed, but relatively simple rail carrier. The carrier would be coupled to a locomotive and the pair would travel down the north ramp to the waste handling main. As mentioned in section 5.1.7.3.4, the waste handling main could be either a main drift excavated specifically to accommodate the waste emplacement function, or it could be that portion of the TBM launch main that is located on the emplacement operations side of the repository. For purposes of figures and discussions included in this report section, we will assume that the TBM launch main serves the waste handling and emplacement function.

An emplacement platform would be used to facilitate offloading of the transport cask and insertion of the waste package into an emplacement drift. The locomotive would back the transport cask carrier against the edge of this platform. Hydraulic outrigger jacks and a sliding carriage on the carrier would then be used to position the cask in such a manner that it could be pulled off of the carrier and onto the platform. A turntable mounted in the emplacement platform would then rotate the cask into alignment with the emplacement drift as shown on Figure 5-21.

Up to this point, all operations could be conducted without unusual concerns for worker radiation exposure, so long as the transport cask has been designed to "stand-beside" standards. The actual opening of the cask, and insertion of the waste package into the emplacement drift, would result in exposure risks for anyone positioned in-line with either the drift or cask openings. Therefore, workers and operators would position themselves ten to twenty meters (30 to 60 ft) away from the emplacement platform, probably inside of a portable, shielded enclosure (shielded for purposes of offering an additional level of protection beyond that afforded by being located out of line with the radiation sources) prior to opening either the cask or the sliding radiation door situated across the mouth of the emplacement drift. All operations involved with the actual emplacement of the waste package would be conducted remotely from within the shielded enclosure.

The remotely guided, video monitored steps involved with conducting the actual emplacement operation are envisioned as follows:

1. With the transport cask centered on the emplacement platform, the radiation door on the emplacement drift would slide open. As the door assumes its full open position, it pulls into position a structural transition piece that is used to bridge the gap between the platform and the invert rail situated just inside the emplacement drift.

2. The transport cask would be moved toward the drift, on the emplacement platform, until resting its forward wheels fully on the transition piece. The door on the cask would then be opened, as it is now in an overlapping position with the end of the open drift door, and thereby afforded a substitute layer of shielding.

3. With its door open, the transport cask would be moved forward once again, pushing a short section of sliding rail on top of the transition piece forward until mated firmly with the rail in the emplacement drift and the rail inside of the cask. The cask would then be secured to prevent further movement. Figure 5-22 presents the concept at this stage of operations.

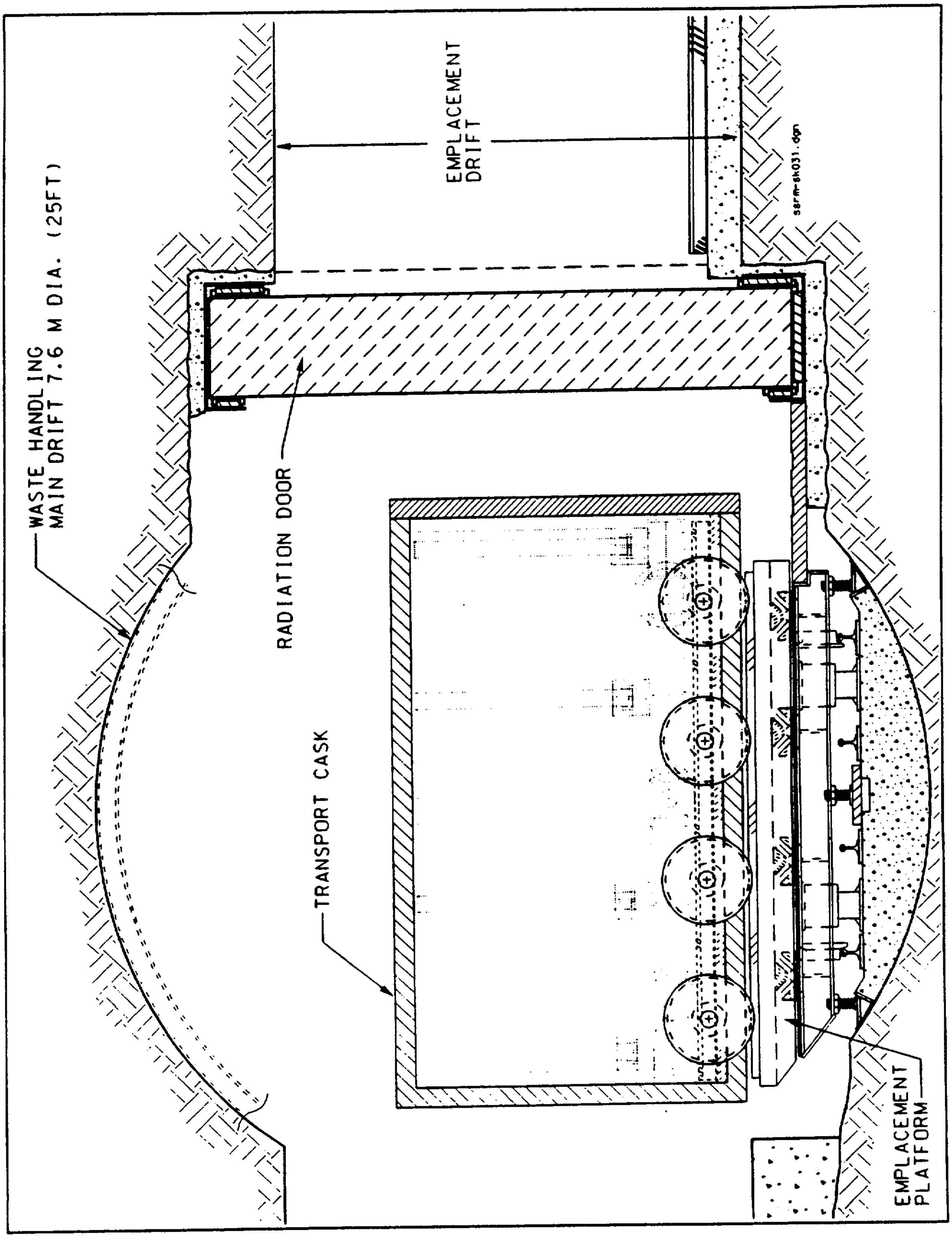


Figure 5-21 Cask Aligned with Emplacement Drift

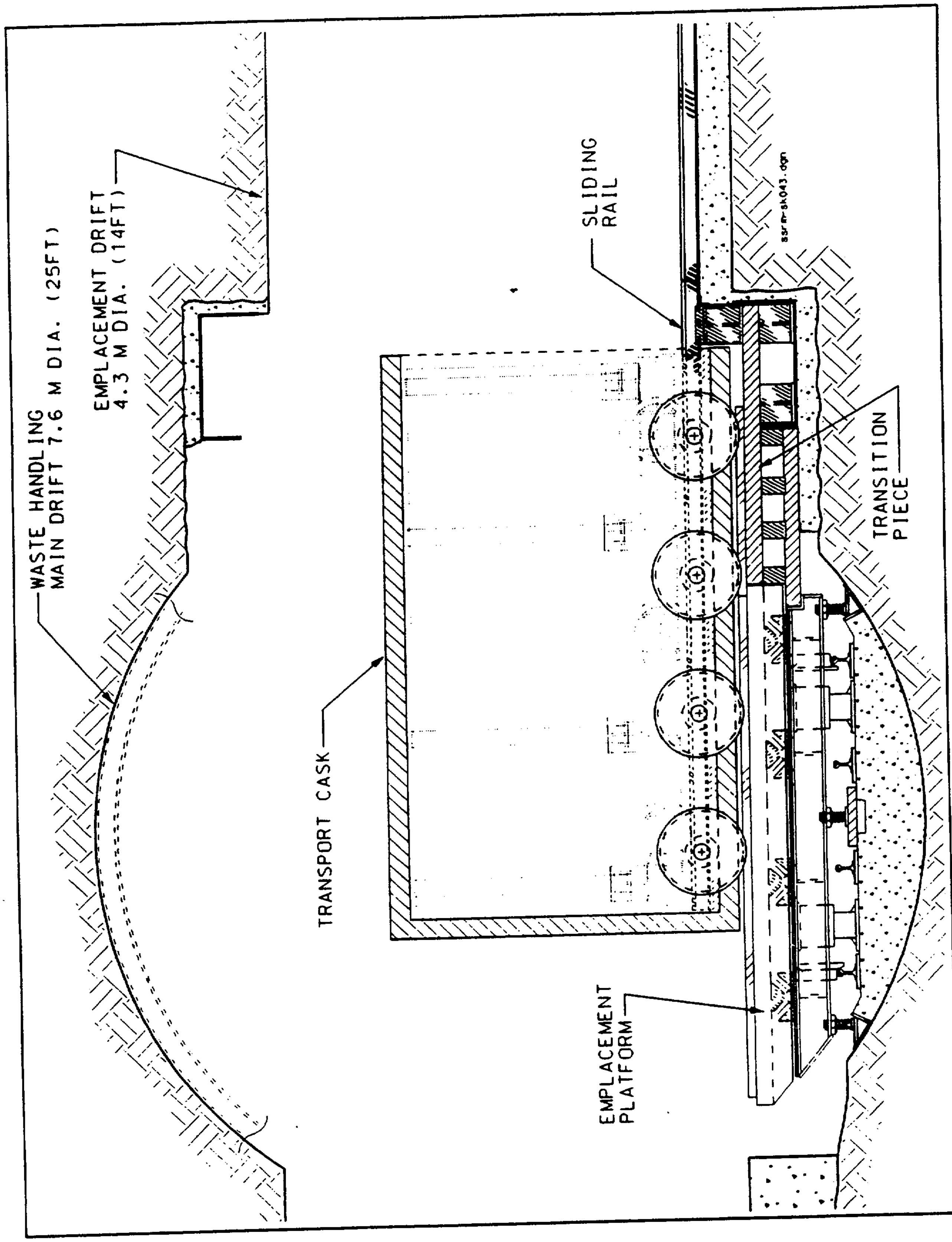


Figure 5-22 Open Cask Mated with Rail in Emplacement Drift

4. The self-contained mechanism inside of the cask used for moving the waste package into the drift would then be activated. This device would be capable of pushing the package fully into the end of the drift and would activate a "stop" or brake on the emplacement cart to hold it in position. The mechanism would also be designed to pull packages into the cask, if necessary, for performance confirmation, retrieval, or other purposes. After pushing the waste package into the drift, the mechanism would be withdrawn into the cask.

5. With the waste package "parked" just a meter or so inside of the drift, the cask would be withdrawn fully onto the emplacement platform, pulling the sliding rail on top of the transition piece back into a retracted position.

6. The radiation door on the emplacement drift would then be closed, allowing workers to resume non-remote operations. The door on the cask would be closed and the cask would be rotated on the platform into longitudinal alignment with the main drift as shown on Figure 5-23. The cask would then be loaded back onto the rail carrier. The carrier would lower itself back onto the rail and the locomotive would pull the empty cask back to the surface to pick-up another waste package.

7. A remotely operated, battery-powered locomotive used for pushing the waste package to its emplacement position in the drift would then be readied for operation. This locomotive would be parked in a stand-by position on a non-rotating extension of the emplacement platform located opposite from the cask delivery area. The locomotive would be mounted on a fixture that resembles the floor of the transport cask in order to properly fix the vertical position of the locomotive wheels relative to the rail in the emplacement drift. Using the same mechanism designed for moving the transport cask on and off of the platform, the locomotive would be positioned on the platform turntable and would be rotated into alignment with the emplacement drift. Workers would re-enter their remote enclosure and the drift door would be re-opened.

8. By completing the same basic movements on the platform as described above for the transport cask, the locomotive would be directed into the drift and would couple to the waste package. The emplacement cart stop mechanism would be deactivated and the locomotive would push the waste package/cart to its intended emplacement location in the drift. Electronic distance meters would be one way to remotely monitor the position of the package to a high degree of accuracy as it travels through the drift. Upon reaching the emplacement position, the locomotive would activate the stop mechanism on the cart and would decouple from it. The locomotive would then return to the emplacement platform and the radiation door on the drift would close.

9. The emplacement crew would resume non-remote operations in the main drift to prepare for the next waste package. The emplacement locomotive would be repositioned in its stand-by location on the emplacement platform.

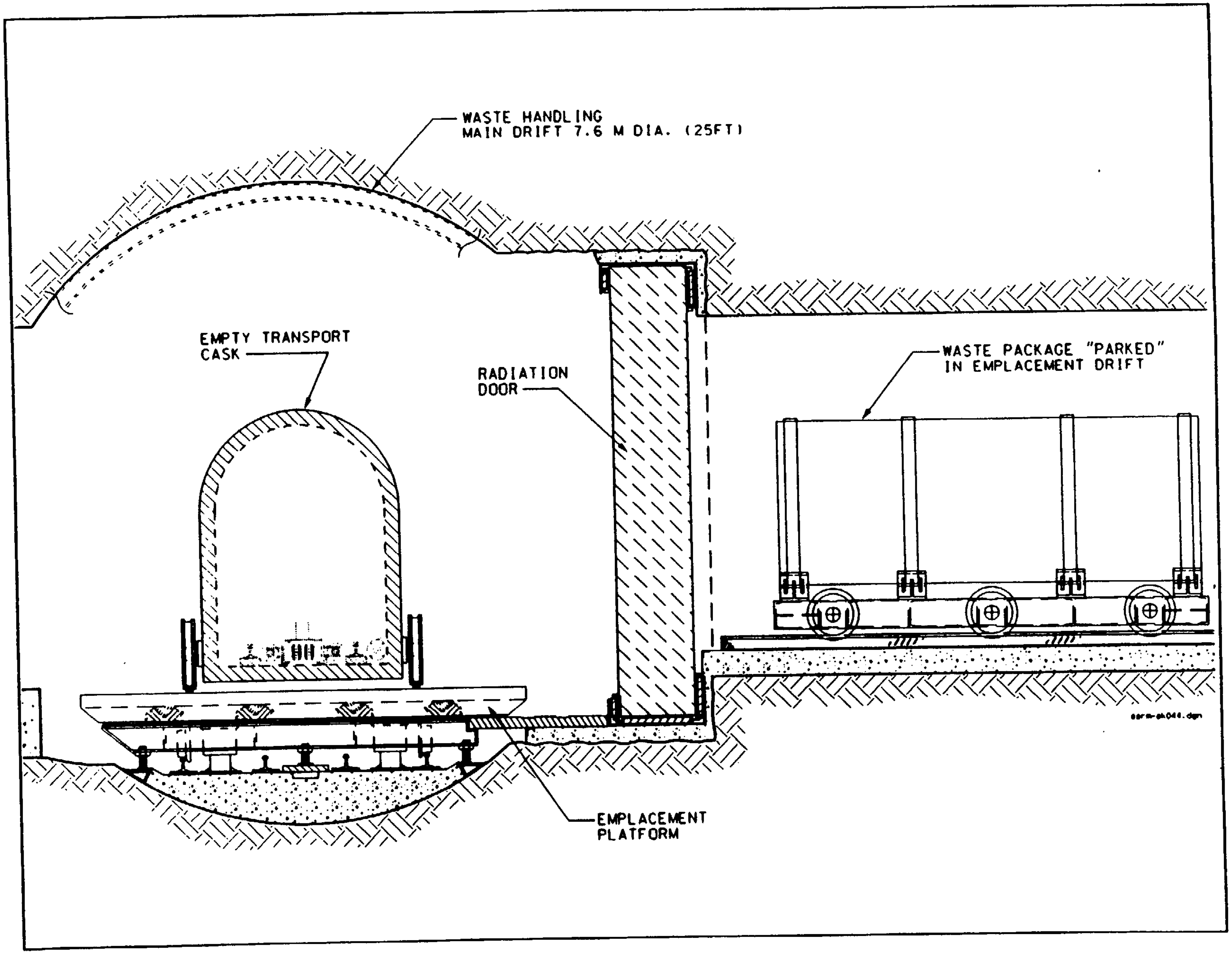


Figure 5-23 Empty Cask Rotated for Return Trip to Surface

For efficiency of operations, it is envisioned that the emplacement platform would be positioned only one time for each emplacement drift, and that emplacement of all of the packages for that drift would be completed before moving the platform to the next drift location. This concept is not mandatory but would eliminate the downtime that would result from numerous platform relocations.

Moving of the emplacement platform would be accomplished by lowering the vertical positioning jacks so that the weight of the platform is transferred onto steel wheels that are attached, and that would roll on rail laid in the invert of the main drift. The platform would be towed to the next emplacement drift in line and would be repositioned, using survey index points established during construction of the emplacement drift, as a reference base. These points would allow the platform to be located at the precise location necessary for horizontal and vertical control of the emplacement operation. The vertical positioning jacks would be used to establish the precise elevation necessary, then the platform would be mechanically fixed in position to relieve the hydraulic pressure in the cylinders. The transition piece mentioned above would be utilized once again, but would probably require a slight amount of height adjustment, using metal shims or similar methods, to allow the platform, cask, and locomotive to be properly mated with the rail in the emplacement drift. The portable shield enclosure and the device used to open and close the radiation door would be moved ahead prior to moving the platform.

Emplacement operations under the Option I concept would proceed sequentially, drift by drift, from the north end of the layout toward the south. If more than a single emplacement operation is needed in order to sustain the waste receipt schedule, and if the emplacement end of the TBM launch main is utilized for waste emplacement operations, then some of the crosscuts connecting the service and launch mains would be excavated to a larger profile during development in order to provide additional points of access from the service main for the waste transport vehicles. Alternatively, if a dedicated waste handling main were excavated as discussed in section 5.1.7.3.5, and more than one emplacement operation is needed, then an additional waste handling main, aligned parallel to the other, would probably be required. These adjustments to the basic concept would be necessary because the emplacement platform blocks access to that portion of the main drift that is located south of the emplacement operation.

Chances are good, however, that a single emplacement system designed to operate more or less as described above, could maintain a sufficient rate of emplacement if the larger capacity packages under consideration were to be used, due to the lower total number of packages that would result. A key aspect of the concept that would allow the system to work with a minimum number of transport vehicles is the "divorcing" of the transport function from the actual emplacement function. This allows the cycle times for the transport and emplacement operations to overlap, and simplifies the range of functions that each piece of equipment must be capable of performing.

5.1.7.5 Subsurface Ventilation, Option I

Ventilation is the control of air movement, its amount, quality and direction. This section is intended to provide a preliminary discussion of air distribution concepts and potential airflow requirements for the Option I layout concept. It does not address a detailed ventilation network design analysis of the potential repository.

The strategy of airflow distribution for a ventilation system is governed by factors including safety, cost, flexibility and development sequence. The principal concern is safety. The repository design requirement stipulated by 10CFR60.133(g)(3) dictates that the underground facility ventilation system shall separate the ventilation of excavation and waste emplacement areas. Although specific definition of what constitutes separation is not given in the CFR, the main purpose of the requirement is to limit the potential for radiation exposure. To meet this requirement, proper arrangement of the primary air intake and exhaust airways for development and emplacement areas needs to be considered. The Repository Underground Ventilation Concepts study (M&O, 1993e) analyzed several alternatives regarding separate ventilation. It indicated that planning two entirely independent ventilation systems is a favored scheme insofar as safety is concerned.

The subsurface repository ventilation network for the Option I layout is arranged to maintain two separate airflow systems; one system provides air for the development of the repository while the other provides air for waste emplacement operations. Each system has its own primary intake and exhaust openings to the surface for the supply of fresh air and exhaust of return air. Connections between the two ventilation systems are sealed with substantial bulk-heads or "air stoppings." Alternatively, air locks (double air doors) could also be considered at the required locations.

The two completely independent ventilation systems have no operational impacts upon one another. It is expected that efforts related to balancing the separate ventilation networks, fan coordination, and design and construction of the necessary ventilation control devices would be simpler for the separated systems than for a single, combined system. The pressure difference of the ventilating air between the two systems would be designed in such way that unavoidable air leakage always moves from the development side of operations toward the emplacement area. Each system would be designed to function normally when accident conditions occur in the other. For example, if an upset condition were to occur in one system due to a fire or similar emergency, the other system could remain unchanged and its operations would not be affected. More importantly, personnel under such an emergency would have an additional choice of potential escape routes by entering the other system through strategically placed air locks. A potential disadvantage of this scheme is that simultaneous development and emplacement operations are possible only after the four major access openings to the surface are available.

Figure 5-24 shows (diagrammatically) the general method that is envisioned for air flow distribution in the Option I repository layout concept. The configuration of the ventilation network for other layout concepts would vary according to the specific layout that is used and the development and emplacement operational scenarios that might be employed.

In addition to the two main ramps constructed during site characterization, two vertical shafts would be constructed, one north and one south, in order to establish the two independent ventilation systems necessary for simultaneous development and emplacement operations. The bottoms of these shafts would be connected to the perimeter main at the north and south ends

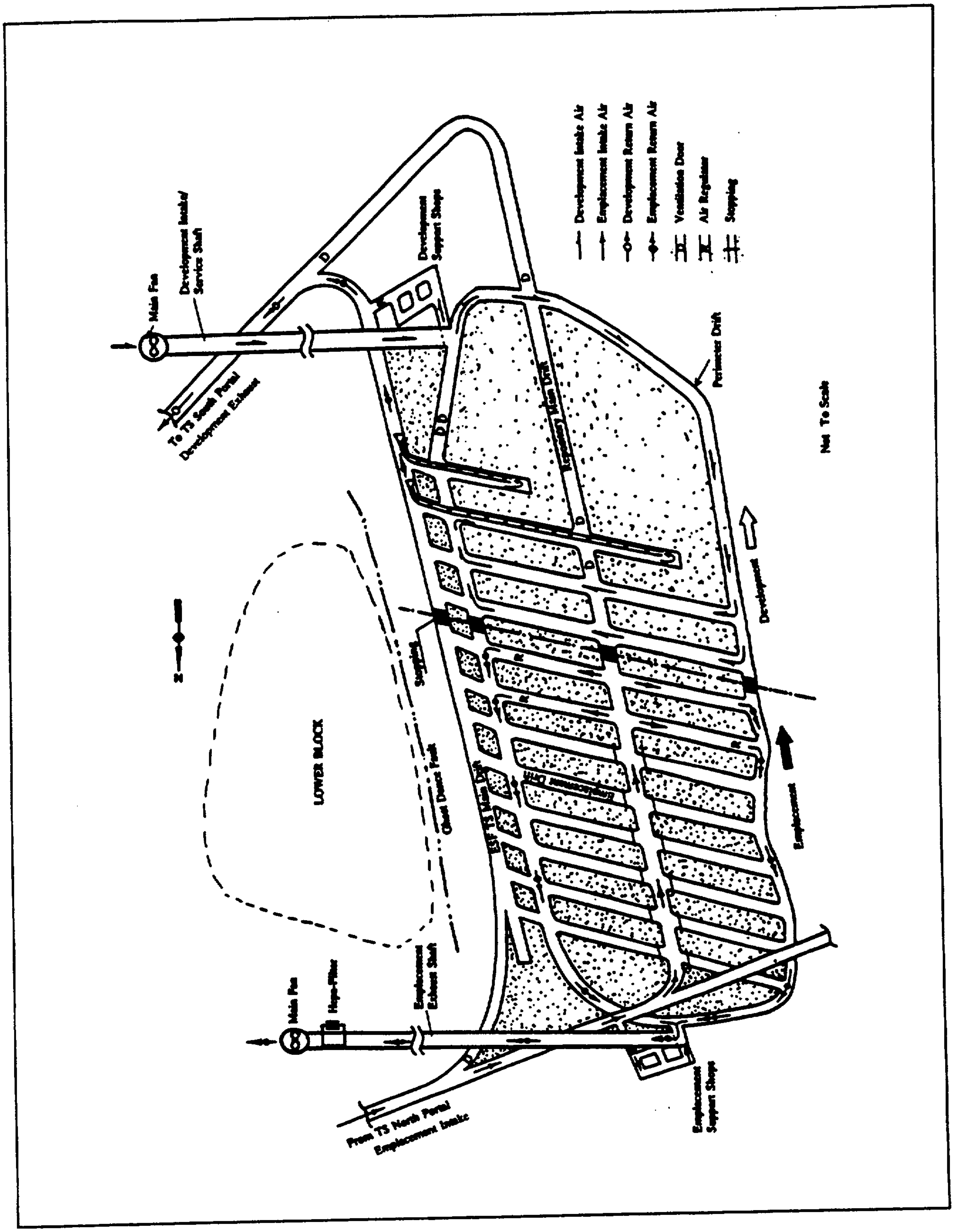


Figure 5-24 Air Flow Distribution in Option I Layout with Dedicated Waste Handling Main

of the layout. After completion of construction for the shafts and main drifts, development of the emplacement drifts would begin, advancing from north to south, followed by emplacement.

The intake air for the development side of operations would be brought through the development intake shaft, through the west side perimeter main, and into two or more completed emplacement drifts (awaiting turnover to emplacement operations) that deliver the fresh air to the launch and service main drifts. Fresh air for active emplacement drift headings being excavated by the TBMs is drawn into the ends of these drifts from the service and/or launch mains by auxiliary fans and duct that extend to the TBM cutterhead and that operate in an exhausting, or negative pressure mode. Dusty air from the TBM cutting zone is routed through dust scrubbers and directly into the ventilation duct which exhausts into the service main, thereby allowing personnel in the drift to always work in fresh intake air. Return air in the service main exits via the south ramp to the surface. Crosscut development headings would also be ventilated using auxiliary fans and duct and would exhaust through portable dust scrubbers into the TBM launch main. A relatively small quantity of air would be split from near the bottom of the intake shaft to ventilate potential development support shops that might be needed in the subsurface; the used air from the shops would then be directed into the main return airway to surface.

Ventilation intake air for the emplacement side of operations is supplied via the waste ramp, then directed to the active emplacement area through either a dedicated waste handling main as shown on Figure 5-24, or through the emplacement operations end of the TBM launch main as shown on Figure 5-25 if the dedicated main is determined to be unnecessary (see section 5.1.7.3.5). Return air is directed through open emplacement drifts that have not yet received waste, into the perimeter drift, and then exhausted through the emplacement exhaust shaft. If an accident were to result in the release of radionuclides, the return air would be routed through a bank of HEPA filters before being discharged to the atmosphere.

The ventilation system would be designed so that all air leakage between the two systems is from the development area to the emplacement area. This pressure differential is created by using a primary forcing, or positive pressure main fan(s) on the collar of the development intake shaft and using exhausting, or negative pressure main fan(s) installed at the collar of the emplacement exhaust shaft. With this type of arrangement, the pressure differential forcing air leakage from the development area to the emplacement area always exists, even if the ventilation pressure supplied by one of the systems is interrupted.

Preliminary air flow requirements estimated for development and emplacement areas are shown in Tables 5-12 and 5-13. These air quantities were determined by the need to control heat, dust, and potential diesel exhaust gas emissions in the repository and are based on results obtained from the Repository Underground Ventilation Concepts study (M&O, 1993e), which was prepared using a layout similar to the Option I concept.

As mentioned in Section 5.1.7.4.1, access to ten emplacement drifts might be desirable in order to permit adequate flexibility during development operations; two of which would be active TBM headings, with the remainder in various stages of post-excavation construction. Air quantities for these drifts are estimated and included in Table 5-12. A minimum air velocity of 0.3 m/s (60 ft/min) was used to determine air flow quantities for construction in the post-excavation drifts

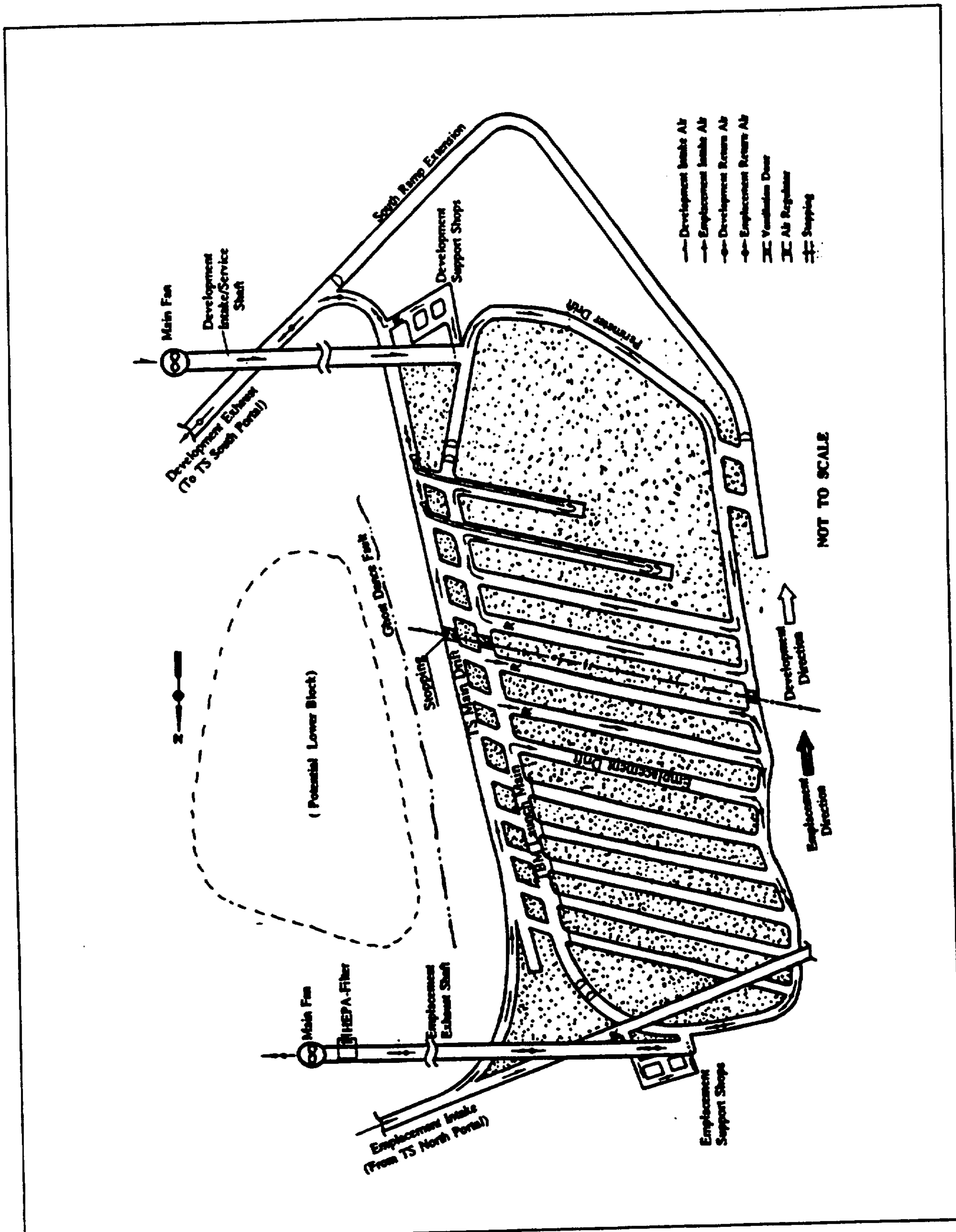


Fig. 5-25 Air Flow Distribution in Option I Layout without Dedicated Waste Handling Main

because no mining or other significant dust producing operations are expected in these areas.

For the typical ranges of air quantity requirements and the general concepts of air flow distribution presented herein for the Option I layout concept, the ventilation equipment and devices are expected to be similar to those used in conventional underground mining facilities, including main and auxiliary fans, bulkheads (or stoppings), air regulators, air doors, air locks, ventilation duct or tubing, air quality monitoring devices and dust collectors. More in-depth evaluation of these facilities will be addressed in future repository ACD ventilation studies.

Table 5-12 Estimated Air Quantity for Development Operations

Development Area	Required Air Quantity m^3/s	Required Air Quantity (ft^3/min)	Design Air Quantity* m^3/s	Design Air Quantity* (ft^3/min)
Emplacement Drift (TBM Heading #1)	31.94	(67678)	39.93	(84600)
Emplacement Drift (TBM Heading #2)	31.94	(67678)	39.93	(84600)
Emplacement Drift (Post-excavation Construction, 8 Drifts)	34.37	(72827)	42.96	(91000)
Crosscut (D&B**)	36.54	(77430)	45.68	(96800)
Crosscut (Roadheader)	15.71	(33288)	19.64	(41600)
Maintenance Shop	25.96	(55000)	32.45	(68800)
		Total	220.60	(467500)

* Includes 20% for leakage/ uncertainty allowance.
** Drill and blast development option

Table 5-13 Estimated Air Quantity for Emplacement Operations

Emplacement Area	Required Air Quantity m³/s	(ft³/min)		Design Air Quantity* m³/s	(ft³/min)
Emplacement Drift #1	35.00	(75000)		43.75	(92700)
Emplacement Drift #2	35.00	(75000)		43.75	(92700)
Maintenance Shops	25.96	(55000)		32.45	(68800)
Standby Drift #1	14.00	(30000)		17.50	(37100)
Standby Drift #1	14.00	(30000)		17.50	(37100)
			Total	150.00	(318000)

* Includes 20% for leakage/ uncertainty allowance.

5.1.7.6 Subsurface Drainage, Option I

The Option I layout is designed to drain any water seeping into the main drift openings toward a sump located at the emplacement exhaust shaft. Figure 5-26 provides approximate elevations at key points and the general gradient of the layout block. As noted in section 5.1.7.3.7, the emplacement drifts in this layout are flat-lying, and the design would be adjusted later to facilitate drainage out of these drifts if the concept undergoes further refinement. The emplacement drifts would then drain into one of the main drifts, and on toward the emplacement exhaust shaft as described above.

The substantial stoppings described in Section 5.1.7.4.1, which physically separate the development and emplacement sides of the repository, present a problem for drainage in that they block the flowpath in the main drifts. Water encountered on the development side of the repository would flow toward these stoppings. There it would be collected in a sump at each stopping location and either pumped through the stopping to the emplacement side, or would be pumped to the surface through discharge pipelines hung in the service and perimeter mains. Any leakage through the stoppings would be from the development to the emplacement side, similar to ventilation air leakage at these locations.

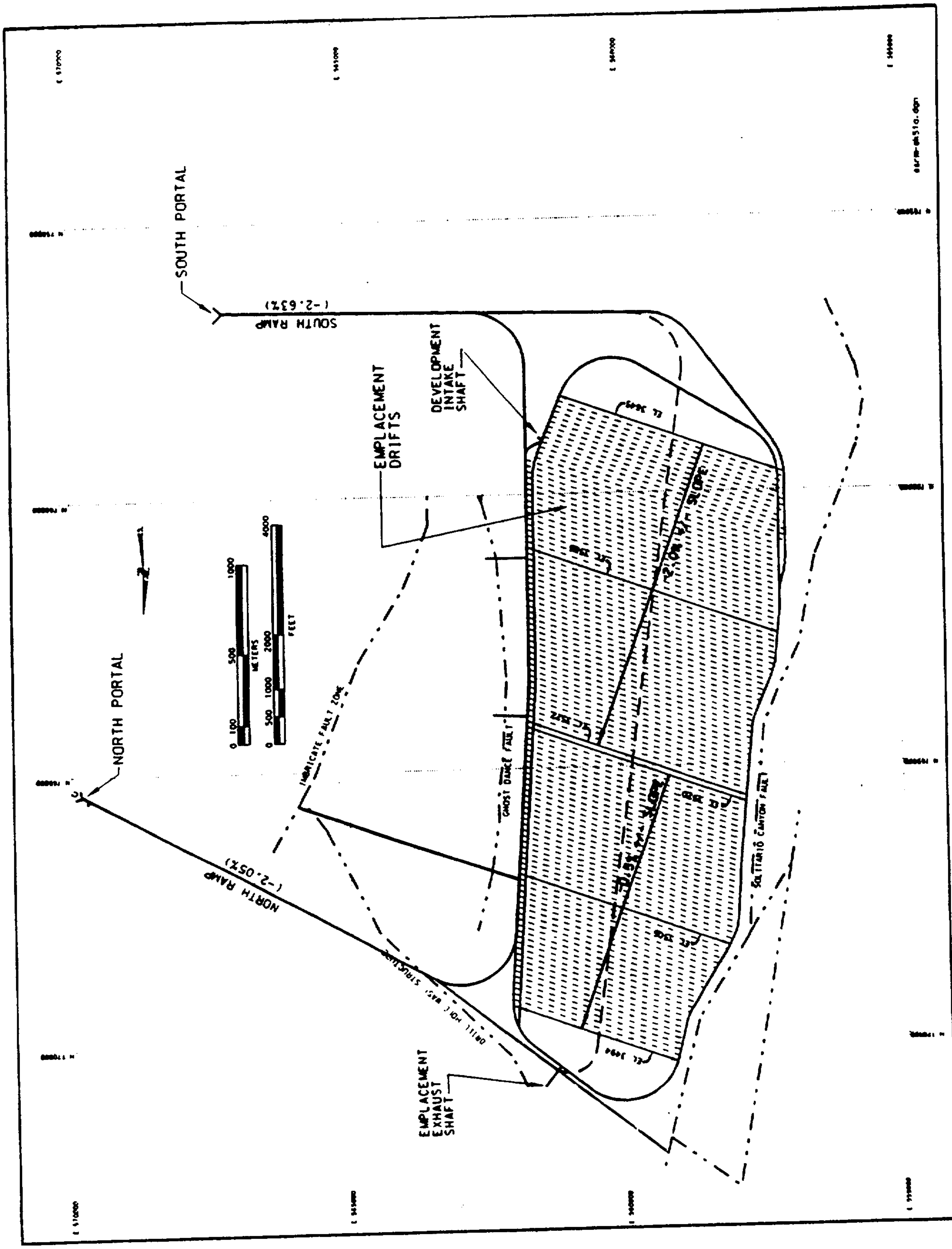


Figure 5-26 Elevation and Grade Data - Option I Layout

5.1.7.7 Thermal Capacity and Expansion Considerations, Option I

The Mission Plan (DOE, 1985) targets the first nuclear waste repository for a storage capacity of 70,000 MTU. Depending upon the average age and burnup rate of fuel that is delivered, this equates to a total heat output at the time of emplacement of approximately 65,000 kW from spent fuel, and an additional 3200 kW from DHLW (Mansure and Petney, 1991). Definition of a thermal loading that is appropriate for Yucca Mountain is the subject of numerous, ongoing studies at this time. Whether or not the Option I layout can actually accommodate this much waste depends, to a large extent, on the maximum thermal loading that is determined to be allowable. Other factors that may limit the potential for storing all of the waste within the confines of the layout include the possible presence of undesirable geologic conditions in some areas.

Figures 5-27 and 5-28 present the storage capacity of the Option I layout with, and without the potential waste handling main, respectively. Ignoring the possibility that geologic conditions might preclude waste emplacement in certain zones, the darkened portions of the layout on these figures represents the area over which the waste could be emplaced on a regular pattern. Or, using terminology defined in Section 5.1.4.2, the dark areas represent thermal conditions that can be characterized as conforming to an LAPD. Based on the darkened areas shown on the figures, the Option I layout block could accommodate the total waste inventory at a LAPD of 19.5 W/m^2 (79 kW/acre) or higher, with the inclusion of the potential waste handling main, or 18.1 W/m^2 (73 kW/acre) or higher, without the additional main-- assuming geologic conditions are favorable throughout the entire area. Although they are slightly higher, these LAPDs are relatively close to the 17.3 W/m^2 (70 kW/acre) LAPD used in the SCP layout (DOE, 1988).

As explained in Section 5.1.4.2, the number more commonly referred to in the SCP is 14.1 W/m^2 (57 kW/acre), which represents the power density obtained when panel access drifts, abutment pillars, standoff distances and other areas which surround the emplacement drifts and pillars, but don't contain waste, are included in the thermal density calculation. The Option I concept doesn't include multiple panels or many of the other features included in a calculation of that sort; the LAPD numbers are the best measures for comparison.

The lightly shaded area in the southwest corner of the potential emplacement block represents a zone where the distance between the invert of the emplacement drifts and the underlying TSw3 unit is less than 40 meters (130 ft). The area within this zone of lighter shading is not included in calculations which support the LAPD numbers reported above, as existing thermal criteria limit the maximum temperature allowable in the TSw3 unit, as discussed in section 5.1.4.2. The 40 meter separation used here is an assumed value that takes into consideration the fact that the area is situated at a corner of the emplacement block and should benefit from the resultant edge effect. The lightly shaded area could still be used for low, or non-heat producing waste.

The unshaded portion of the layout between the main drifts and the shading is a 40-meter (130-ft) wide thermal barrier, or standoff zone. Requirements for this feature were discussed in Section - 5.1.4.2; it acts to prevent heat buildup in the main access drifts.

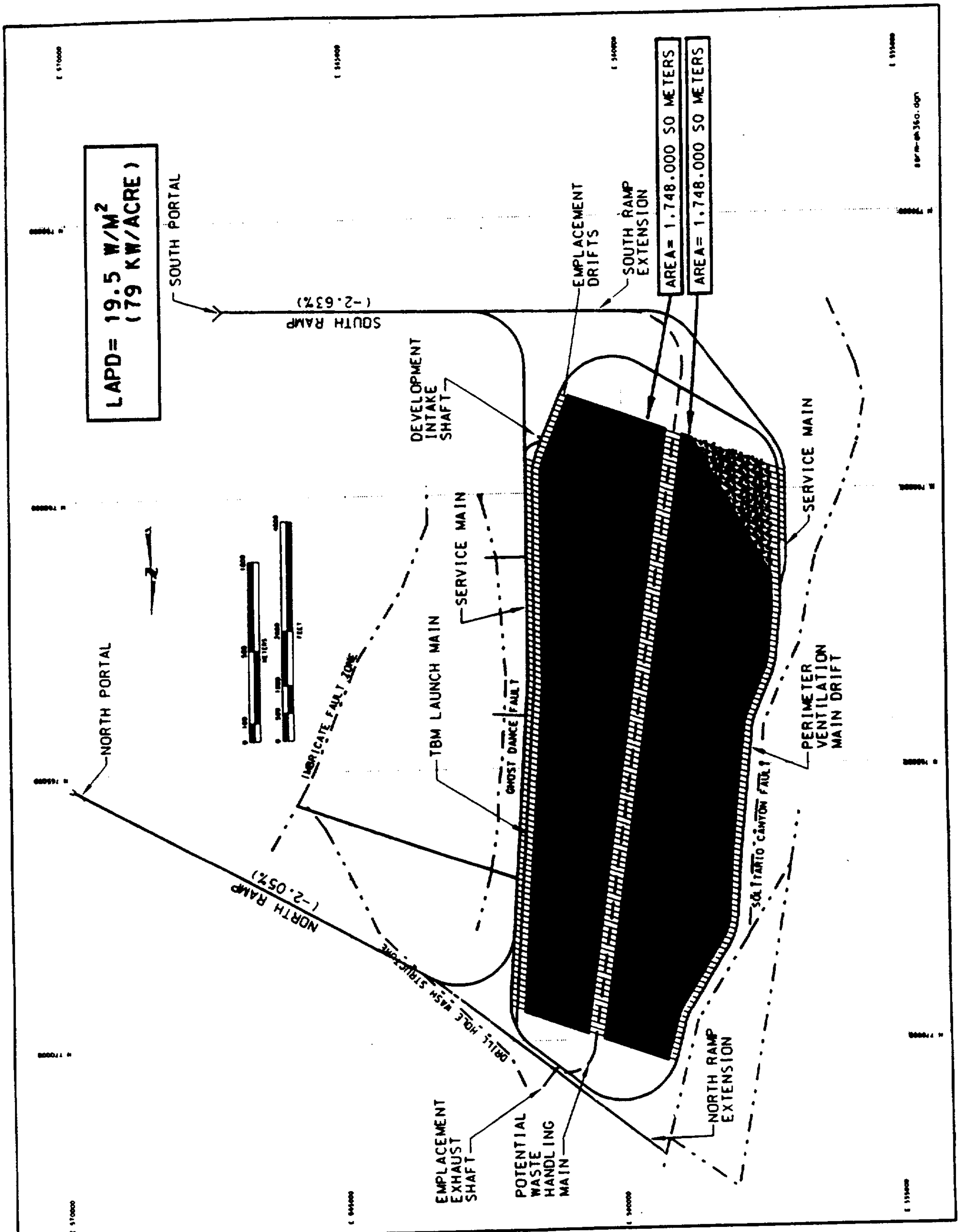


Figure 5-27 Thermal Capacity, Option I, with Dedicated Waste Handling Main

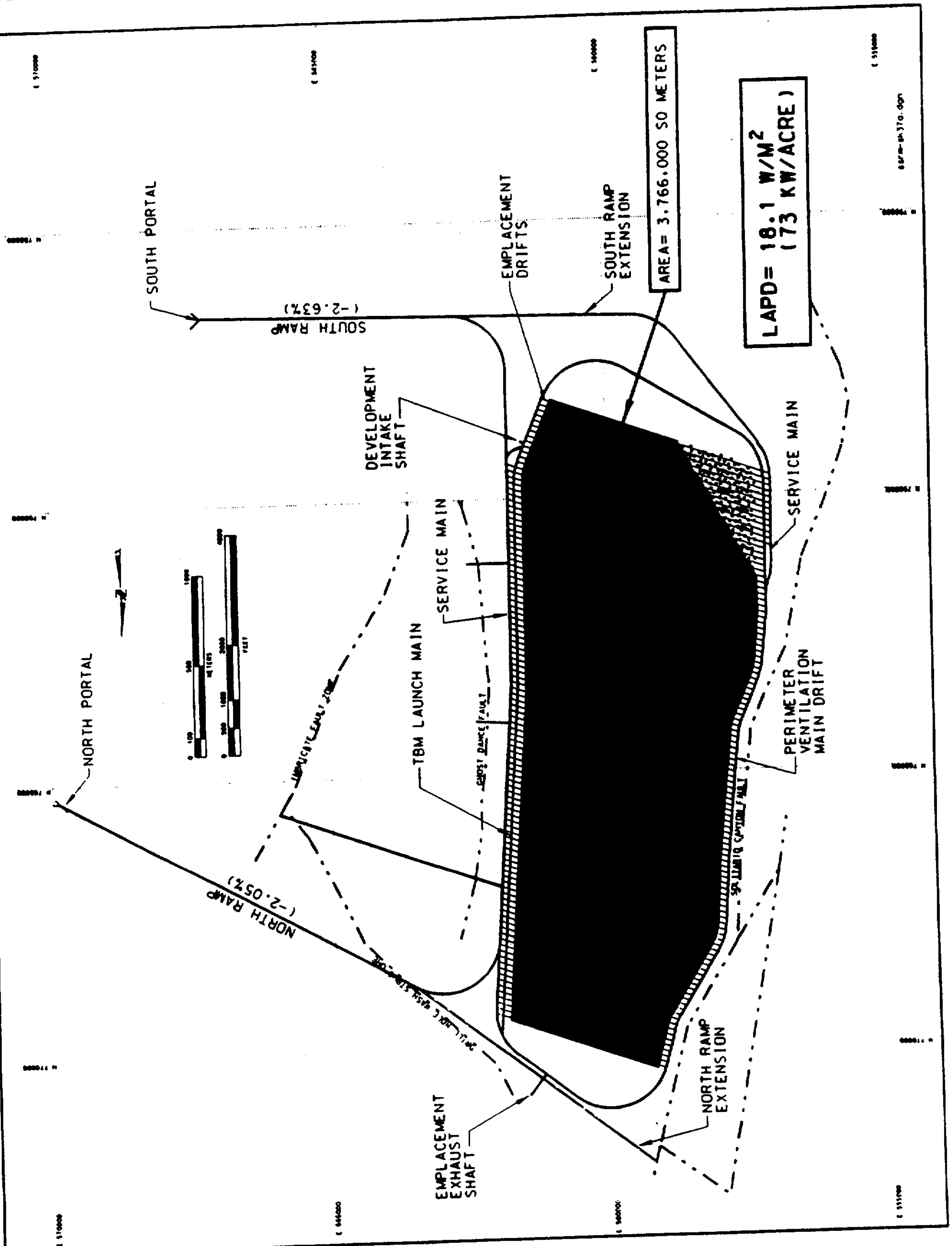


Figure 5-28 Thermal Capacity, Option I, without Dedicated Waste Handling Main

The Option I layout uses essentially all of the area situated between the Ghost Dance and Solitario Canyon faults that could be logically developed using the Option I operational schemes described in earlier sections of the report. If thermal loadings lower than those mentioned above are desirable, or if contingency areas are needed to guard against unforeseen geologic or other conditions, then expansion of the layout is necessary. The following sections address potential expansion of the layout within Area 1 (see Figure 5-9), and alternative expansion areas that have also been considered.

5.1.7.7.1 Expansion Inside of Area 1

One of the design objectives listed for development of the Option I concept was to fit the layout within Area 1. This objective was established in order to provide a common basis for comparison between this, and other layouts that have been developed by others in the past. Figure 5-29 presents an expanded version of the basic Option I concept that utilizes the area situated between the Ghost Dance and Imbricate Fault systems. This area is called the "lower block", because it is situated at an elevation that is approximately 70 meters (230 ft) lower than the primary emplacement block situated to the west.

The lower block was designed using the same objectives that were presented earlier in Section - 5.1.7.2. The objective that specifies flat-lying emplacement drifts was the main "driver" that led to the "step" down from the primary block, due to the eastward dip of the TSw2 unit. This aspect is shown by the cross-section on Figure 5-30. The selected horizon was established by: overlaying surface topography on the structural contours for the TSw1/TSw2 contact; picking a location for the farthest north emplacement drift that would leave adequate space for the ESF Main Test Area (MTA); establishing an elevation for this drift that was near the top of the TSw2 unit while complying with the 200 meters cover requirement; and then iterating through several main drift layouts that satisfied all of the objectives and requirements.

The upper block would be fully emplaced before emplacement operations move to the lower block. Operationally, the development and emplacement schemes in the lower block would work as described earlier for the primary block. Both operations would proceed from north to south, and the functions of the various drifts would be the same.

Access to the lower block would be provided using -3.00% ramps that originate from the lower reaches of those connecting the primary block to the surface. Additionally, the two ventilation shafts would be connected to the lower block emplacement area main drifts. As shown on Figure 5-31, drainage water would flow to the emplacement exhaust shaft as with the primary block. Ventilation circuitry for the combined upper and lower block system is shown diagrammatically on Figure 5-32.

It is envisioned that construction of the ramps and the main drifts for the lower block would be carried out as a more or less independent operation on the development side of the repository during development and emplacement of the upper block. The north access ramp to the lower block would be developed from the bottom up in order to maintain separation of ventilation systems. Both shafts would be sunk to full depth at the time of original construction.

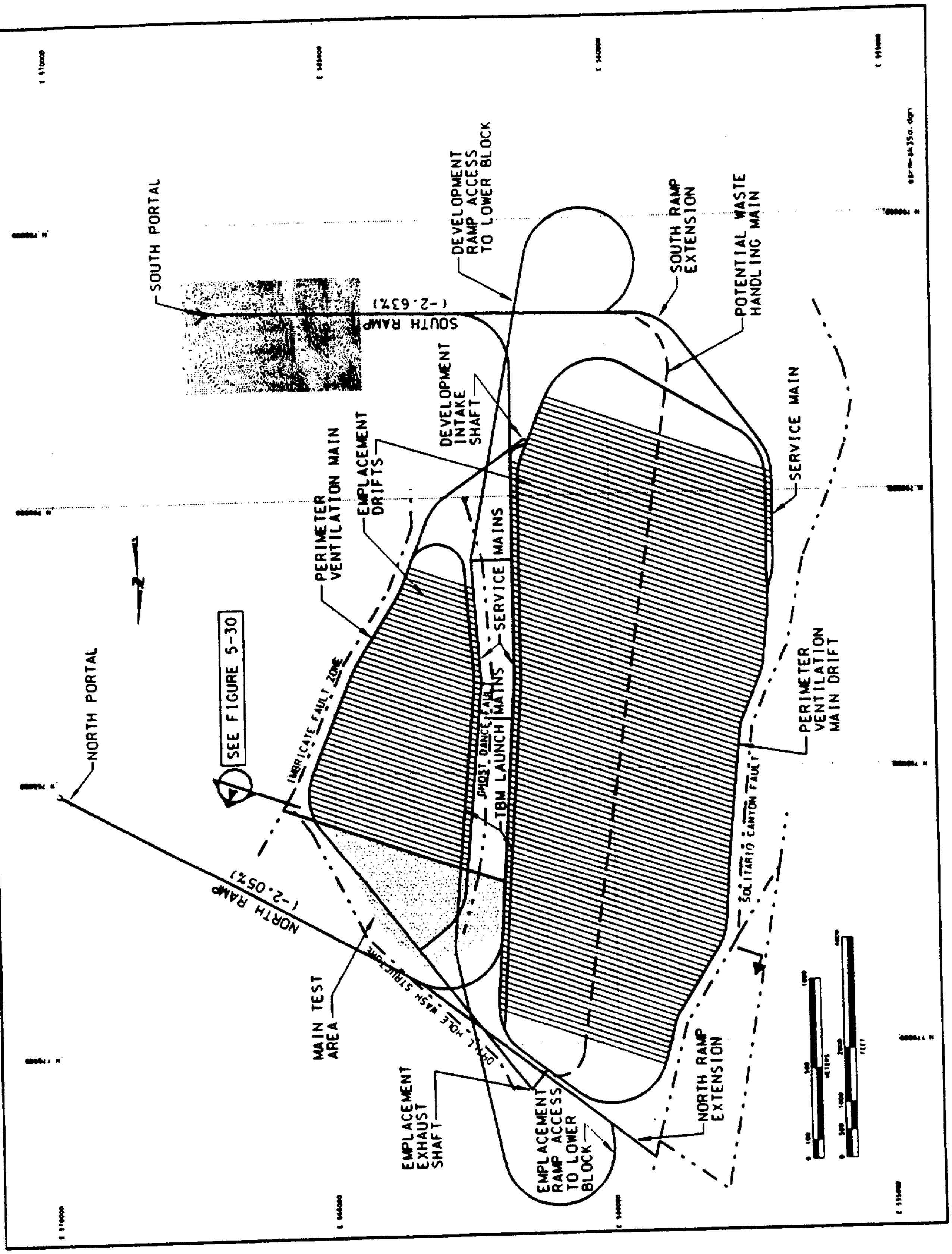


Figure 5-29 Conceptual Repository Layout, Option I - Expanded

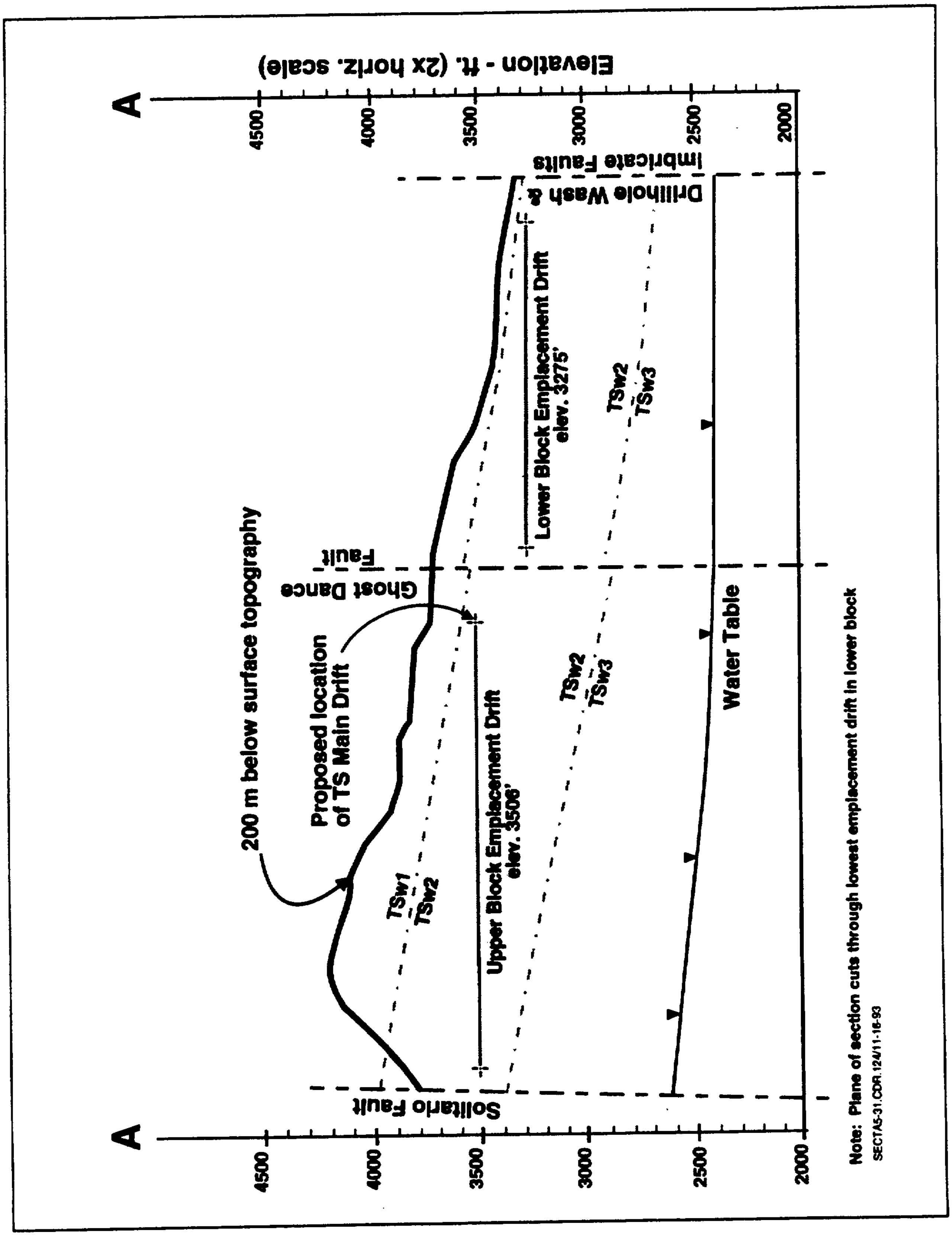


Figure 5-30 Cross-Section Through Expanded Conceptual Repository Layout

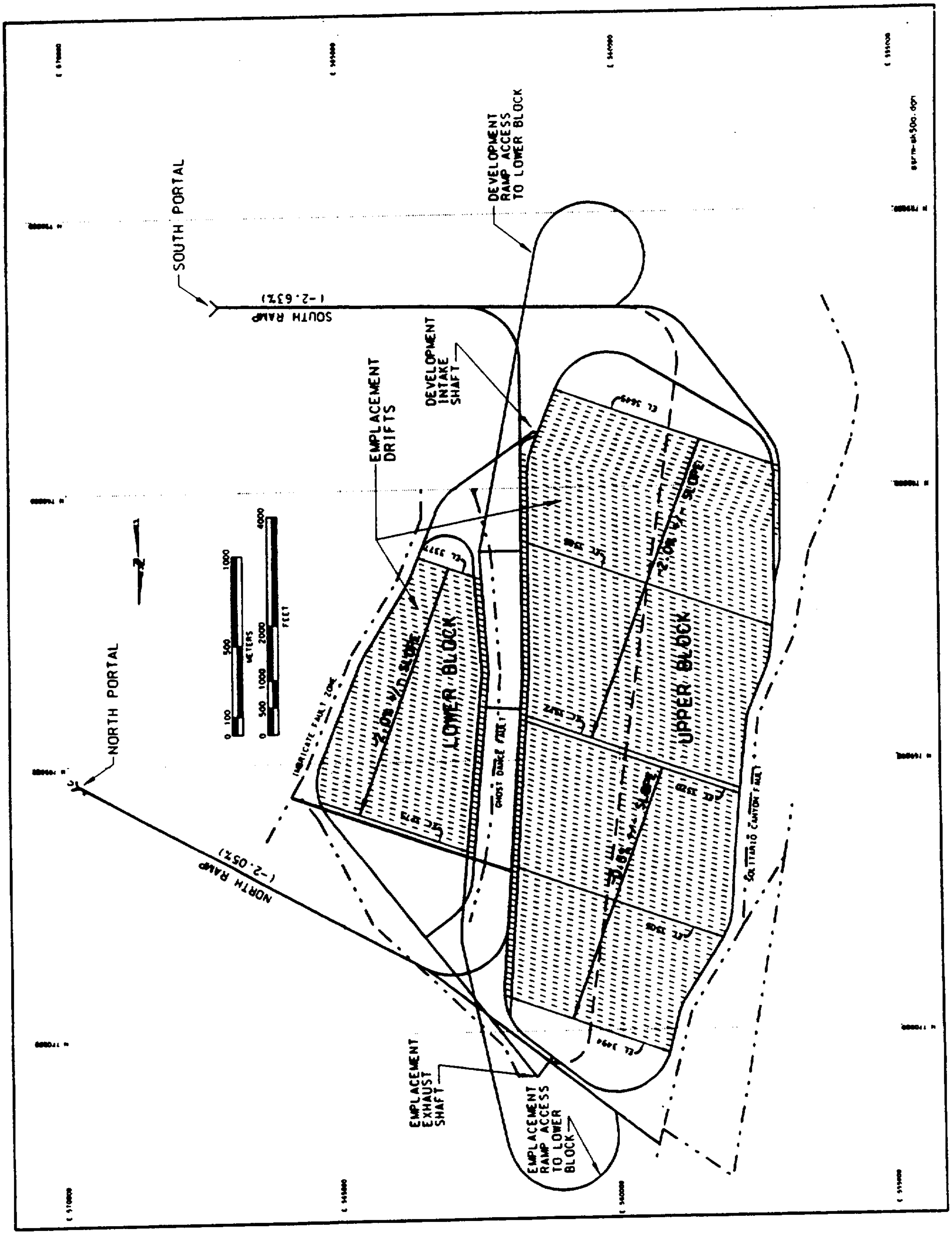


Figure 5-31 Elevation and Grade Data - Expanded Option I Layout

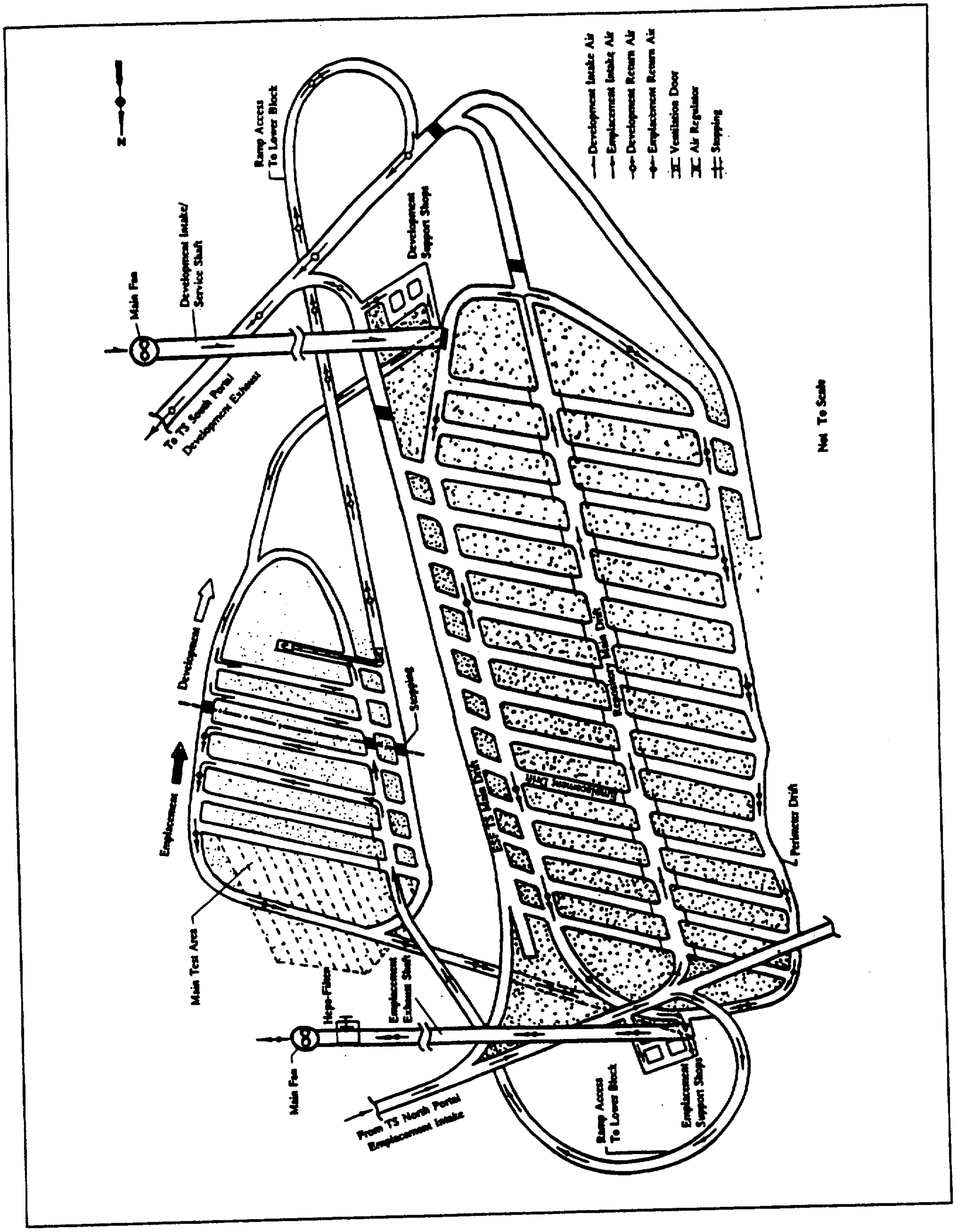


Figure 5-32 Air Flow Distribution in Expanded Option I Layout

Figure 5-33 presents the combined thermal capacity of the primary and lower blocks, using the same sort of analysis as presented earlier for the primary block without a dedicated waste handling main. As shown on the figure, the two blocks could support a LAPD of 14.7 W/m^2 (59 kW/acre) if one neglects losses of area due to potential geologic or other factors.

Depending upon the amount of potential expansion area that may be required, it should be pointed out that development of a separate emplacement block in the area shown may not be the best choice. Access ramps and main drift requirements, in relation to the reduced length and number of emplacement drifts that are provided, could be excessive when compared to other potential expansion areas. Thermal and thermal-hydrological concerns may also exist, due to possible interactions between the upper and lower blocks. The following section addresses other expansion areas that should be considered as potential supplements to the Option I primary block.

5.1.7.7.2 Expansion Outside of Area 1

Expansion outside of the primary area has been given brief consideration in early repository work (Mansure and Ortiz, 1984) as well as in the SCP (DOE, 1988, pp. 8-14 to 8-17). Six potentially useable areas have been previously identified (see Figure 5-9). The primary area, which includes the Option I repository layout discussed in Section 5.1.7.3, is located within the boundary of potentially useable Area 1. It should be noted that the numbering of the potentially useable areas does not reflect any significance in their ranking (Mansure and Ortiz, 1984, p. 10).

As mentioned in Section 5.1.7.7, the basic reasons for consideration of repository expansion include a lower thermal loading than could be accommodated by the primary area, or the potential for undesirable geologic features that could render some areas unusable due to waste isolation or other concerns.

Geologic Data for Expansion Areas

The primary, currently available source of geologic data for the TSw2 thermomechanical rock unit is the IGIS model (see section 5.1.2). Unfortunately, the IGIS model does not extend significantly beyond the limits of potentially useable area 1. To gain a better understanding of the geology beyond the limits of the IGIS model and in the vicinity of the potential expansion areas, available geologic information was examined and manual geologic interpretations were compiled for these areas. It should be noted that these manual interpretations are based upon very few drill holes, most of which were not cored, and on the surface mapping of Scott and Bonk (1984). Consequently, geologic interpretations for the potential expansion areas, as presented in this report, must be considered conceptual and very preliminary.

The primary source of subsurface stratigraphic information in the potential expansion areas is boreholes. These boreholes include USW G-1 and USW G-4 for area 2 expansion and USW H-6 and USW WT-7 for area 4 expansion. Boreholes USW G-1 and USW G-4 were cored and detailed logs are available in Spengler et al (1981) and Spengler and Chornack (1984), respectively. Borehole USW H-6 was drilled open hole for hydrology purposes, but selected intervals through the Topopah were cored. The borehole was logged by cuttings except for the cored intervals. This information is presented in Craig et al (1983). Borehole USW WT-7 was

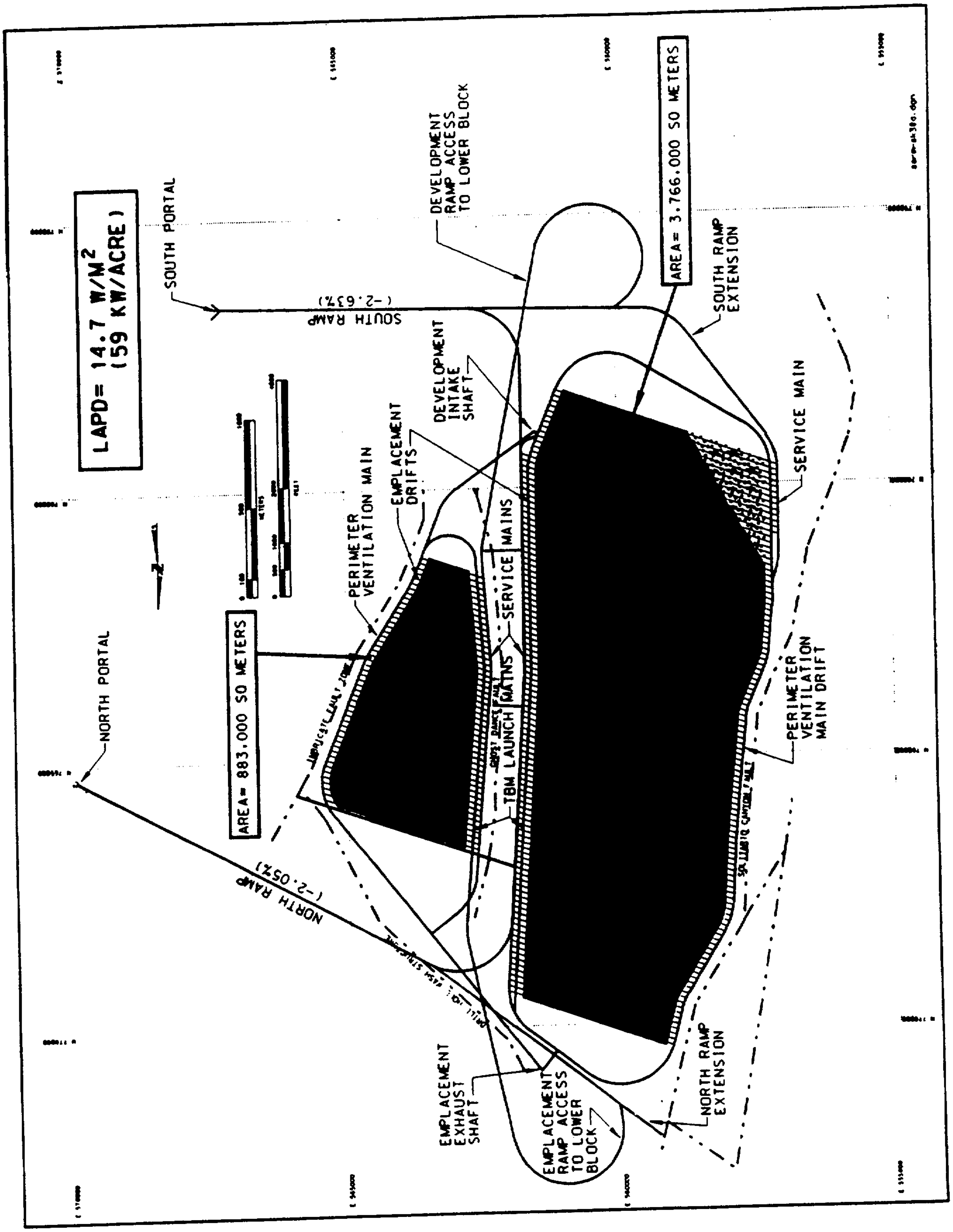


Figure 5-33 Thermal Capacity, Option I-Expanded Layout

rotary drilled without coring, but the hole was geophysically logged and cuttings were sampled and logged. This information is presented in Muller and Kibler (1986).

Surface geologic information was taken from Scott and Bonk (1984). The surface geology was used as a reference datum where borehole information was lacking, as in the northern part of area 4. The elevation of selected contacts shown on the geologic map were identified and unit thicknesses from neighboring boreholes were subtracted from these to locate an assumed elevation for the top and bottom of the TSw1 and TSw2 thermomechanical units. These elevations were then adjusted to reflect reasonable TSw2 thicknesses and surface structures extrapolated from the fringes of the IGIS model.

The surface mapping information from Scott and Bonk (1984) was also used to evaluate geologic structures. The faults shown on this mapping were projected to the general elevation of the repository based on fault plane dips given on the map.

To reiterate what was stated earlier, the geologic interpretation for the potential expansion areas presented in this report is for conceptual scoping purposes only and should be treated as very preliminary. If an expanded repository concept is to be considered, then more complete and detailed geologic investigations are needed to better define the geology of these areas. These investigations, if conducted, could significantly alter the concepts presented herein.

<u>Expanded Repository Layout Objectives</u>

To provide a general indication of the reasonable extent of potential expansion that could be accomplished outside of Area 1, a very preliminary expanded repository layout concept was prepared. The Option I repository layout concepts discussed in Section 5.1.7.3 formed the basis for the preliminary layout.

Following are the primary objectives that were used in developing the preliminary conceptual layout. Many of these objectives are identical to those included for the Option I concept (see section 5.1.7.2), although those dealing with drainage and avoidance of faulting are somewhat more relaxed, due to the extent of the areas considered and to the lack of large, contiguous areas that do not exhibit some form of pronounced fracturing identifiable on the surface.

a) Maintain ramp access to disposal horizons at gradients of 3 percent or less and main drifts within the disposal horizons at 2 percent or less. Maintain emplacement drifts on a flat/horizontal gradient.

b) Provide a realistic layout that provides for logical development and waste emplacement schemes.

c) Provide a layout that is compatible with the Option I layout and the expanded Option I layout presented in Sections 5.1.7.3 and 5.1.7.7.1, respectively.

d) Provide a layout that allows for the separation of the emplacement and development side ventilation systems.

e) Locate the waste emplacement horizon within the TSw2 thermomechanical rock unit, based upon very limited manual geologic interpretations as discussed above.

f) Locate the emplacement horizon at least 200 m below the surface (with the exception of main access ramps)

g) Locate the emplacement horizon above the water table.

h) Locate and orient emplacement areas, to the extent practicable, to avoid major identified faults and major fracture systems which have been identified on the surface, consistent with achieving relatively continuous storage areas and a workable layout.

i) Maintain emplacement drifts at an orientation within the acute angle developed between the bearings N 70° W and S 75° W, which is the preferred drift orientation window described in Section 5.1.2.4.1.

j) Provide a layout in which drainage collection can be accomplished in a few distinct locations.

Expanded Emplacement Areas

Figure 5-34 presents the potential emplacement blocks, designated Optional Areas A through D, that resulted from the preliminary layout work that was performed. The Option I and expanded Option I layouts, situated inside of Area 1, are also included in the figure.

The potential emplacement blocks are included in areas designated as potentially useable areas 2 and 4 by Mansure and Ortiz (1984). The expanded areas are roughly bounded by the Pagany Wash fault on the north side, the Fatigue Wash fault on the west side, and the Solitario fault on the east side. Optional Areas A through D are comprised of four different storage horizons to maintain main drift gradients below 2 percent, emplacement drifts at flat/horizontal gradients, and to stay within the TSw2 unit. The potential storage horizon with the highest elevation is Area B, followed by C, A, and D.

Thermal Capacity of Potential Expansion Areas

The thermal capacity (defined as the lowest LAPD attainable) of a repository which incorporates the Option I layout, together with one or more of the potential expansion areas shown on Figure 5-34, is provided in Table 5-14. (A discussion of thermal loading can be found in Section 5.1.4.1). Local areal power densities (LAPDs) of between 6.3 and 18.1 W/m^2 (25 to 73 kw/Acre) are preliminary estimates of the range of LAPD which could be achieved using various combinations of expansion areas, and neglecting losses of area which could occur if undesirable geologic features are discovered.

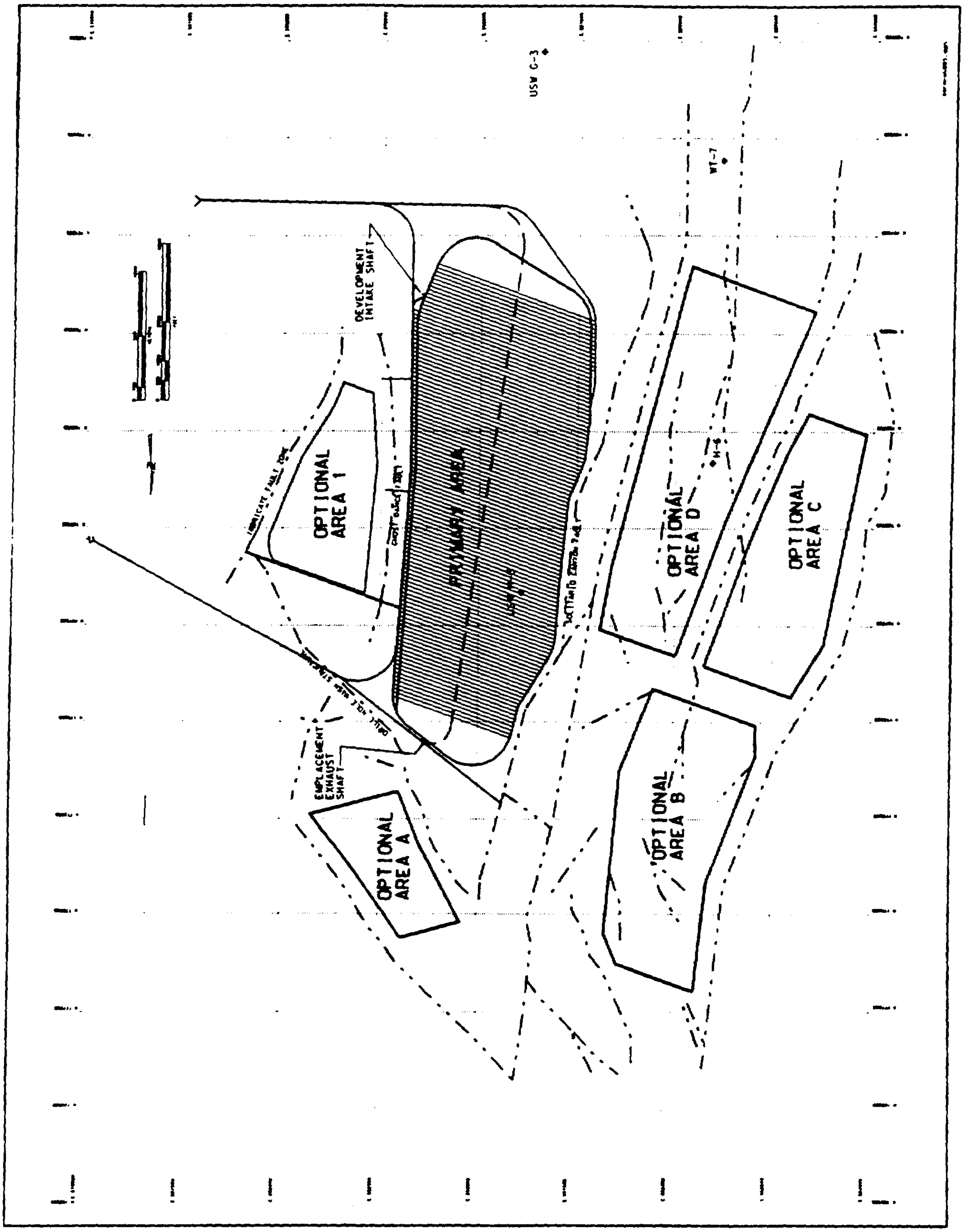


Figure 5-34 Potential Repository Expansion Areas

Table 5-14 Local Areal Power Density for Preliminary Expansion Areas

Repository Storage Area	Preliminary Effective Storage Area	Cumulative Effective Storage Area	Local Areal Power Density (LAPD)[a]	Cumulative Local Areal Power Density[a]	
	(m^2)	(m^2)	(W/m^2)	(W/m^2)	*(kW/Acre)*
Primary Area	3,766,000	3,766,000	18.1	18.1	73
Optional Area 1	883,000	4,649,000		14.7	59
Primary Area	3,766,000	3,766,000	18.1	18.1	73
Optional Area A	634,000	4,400,000		15.5	63
Primary Area	3,766,000	3,766,000	18.1	18.1	73
Optional Area B	1,777,000	5,543,000		12.3	50
Optional Area C	1,467,000	7,010,000		9.7	39
Optional Area D	2,369,000	9,379,000		7.3	29
Primary Area	3,766,000	3,766,000	18.1	18.1	73
Optional Area 1	883,000	4,649,000		14.7	59
Optional Area A	634,000	5,283,000		12.9	52
Primary Area	3,766,000	3,766,000	18.1	18.1	73
Optional Area 1	883,000	4,649,000		14.7	59
Optional Area A	634,000	5,283,000		12.9	52
Optional Area B	1,777,000	7,060,000		9.7	39
Optional Area C	1,467,000	8,527,000		8.0	32
Optional Area D	2,369,000	10,896,000		6.3	25

[a] Based upon 68,200 kW total waste heat output.

Development Sequence of Expansion Areas

A preliminary sequence of development for the potential expansion areas is discussed in the following paragraphs, based upon examination of a preliminary expanded repository layout, and consistent with the nomenclature used on Figure 5-34 and Table 5-14. The sequence of development assumes that waste is emplaced in a general northerly to southerly direction, depending upon the main axis orientation for each emplacement area. It also assumes that the Topopah Spring (TS) north ramp is used for waste haulage and emplacement intake ventilation, and the TS south ramp is used for development access and exhaust ventilation.

Optional Area A warrants strong consideration as a stand-alone alternative in place of Optional Area 1, located east of the Ghost Dance Fault in Area 1, if a slightly higher LAPD is acceptable (15.5 versus 14.7 W/m^2, or, 63 kW/acre vs 59 kW/acre). Area A would need to be fully developed prior to emplacement of waste to avoid the potential need for short-lived development ventilation shafts. However, indications are that development of an emplacement block in Optional Area A could be carried out concurrently with development of the primary repository block (Option I layout), potentially shortening the overall pre-emplacement construction schedule. Initial indications are that the total amount of development drifting and ramps needed for Optional Area A would be somewhat less than in Optional Area 1, and that the block could be situated at a greater distance above the water table.

Optional Areas B, C, and D are potentially suitable as stand-alone expansion areas in place of either Optional Areas 1 or A. They could also be used as expansion areas in addition to Optional Areas 1 and/or A. Based on the assumed waste emplacement direction, the assumed waste emplacement access and ventilation corridors, and geologic interpretations which suggest a southeasterly dip direction for the TSw2 unit, the preferable sequence of development would be Optional Area 1 and/or A, followed by Area B, followed by C, followed by D. Waste emplacement could be concurrent with area development for each expansion area. Expansion could also be carried out as Area B only, or Areas B and C, to achieve a desired LAPD. Table 5-14 indicates the incremental LAPDs possible using various approaches. It should be noted that expansion into Areas B, C and D would represent a major commitment for additional ramp extensions off of the main north and south ramps. Initial indications are that a second development intake shaft may also be needed, however, centralized placement of repository shafts between the primary area and Optional Areas B, C, and D, most likely on the top of Yucca Crest, could be an effective means of limiting additional shaft requirements.

Future ACD work will continue to examine and more fully develop alternative layouts, consistent with thermal loadings being considered in other areas of the project.

5.1.7.8 Retrieval Considerations, Option I

A fundamental program requirement listed in 10 CFR 60.111(b) is that the repository design shall include provisions for retrieving the waste from its emplacement location throughout the operational and caretaker periods.

The degree to which one lets the retrieval requirement drive design of the subsurface openings is largely a function of how easy one wants to make the task. Ultimate selection of an emplacement mode must thoroughly consider the retrieval issue. In-drift emplacement, for example, could consider emplacement openings that are designed large enough to allow packages to be accessed individually, without disturbing other packages, or, on the other hand, much smaller emplacement openings that require the sequential removal of all of the packages in the drift could be considered.

The use of small diameter emplacement drifts and the ISDOR emplacement mode as applied in the Option I concept subscribes to a philosophy that, while it lends itself to retrieval of the waste in a straightforward manner, does not make the task any easier than is considered absolutely necessary to maintain full compliance with the requirement. To better maintain the option for retrieval, it would be impractical to install backfill or decommissioning seals in the emplacement drifts until after retrieval of the waste is no longer considered to be a potential course of action.

Retrieval operations under the Option I concept would be carried out in the reverse order of emplacement, using the original emplacement equipment as follows:

1. The emplacement platform would be positioned at the mouth of an emplacement drift.

2. The remotely operated emplacement locomotive would be positioned on the platform.

3. The drift door would open and the locomotive would travel to the first waste package, couple to the emplacement cart, release the stop mechanism and return to the mouth of the drift, parking the waste package just inside the drift door location.

4. The locomotive would exit the drift.

5. The drift door would close and the locomotive would return to its standby position.

6. The transport cask would be positioned on the platform; the drift door would re-open and the cask would be repositioned on the transition piece.

7. The internal mechanism in the cask would draw the waste package and cart into the cask.

8. The cask door would be closed and the cask would move back into a centered position on the platform.

9. The drift radiation door would close.

10. The cask would be rotated and loaded onto the rail carrier for transport to the surface.

Although it may require an additional suite of equipment, retrieval of all of the packages in the time period mandated by the requirement should be easily achieved using this concept.

Obvious design considerations that must be examined include anti-corrosion provisions for the emplacement cart wheel axles and bushings or bearings, and for the cart's stop mechanism. Materials for the frame and package supports must also be addressed. Other retrieval design factors include the types of materials used in ground support, e.g., perhaps the use of stainless steel rock bolts and liner plate, or similar protective measures would be warranted depending upon the amount of seepage water that is present. In properly supported openings, the chances of a significant rock fall would be extremely remote, but access is available at either end of the emplacement drift so cleanup and maintenance could be managed from two directions if necessary, using special procedures and equipment as required.

Because the normal base of operations for retrieval is in the waste handling main drift and all actual waste package interfaces are conducted from this remote location, personnel would not be required to enter the emplacement drift except in off-normal situations. Since this main also functions as the primary ventilation intake airway, temperatures there should remain cool throughout all phases of repository operations. In the event that an off-normal condition requires that someone physically enter the emplacement drift, then blast cooling of the drift with relatively large quantities of air would be carried out beforehand. Workers would enter the drift inside of a shielded vehicle equipped with robotics features that allow manipulation of various waste package or drift support elements as necessary.

Ventilation is perhaps the most effective method to provide acceptable climate conditions for support of the retrieval activities. Primary ventilation concepts that can be considered for temperature control include: 1) continuously ventilating all of the emplacement drifts, beginning at the time of emplacement and continuing throughout the pre-closure period (ventilation fixtures could be incorporated into the radiation doors to facilitate ventilation while maintaining shielding); and 2) cooling of previously unventilated emplacement drifts with large quantities of ambient air just prior to the time that reentry is necessary.

The Repository Underground Ventilation Concepts study (M&O, 1993e) analyzed the feasibility of both types of cooling by ventilation, and performed some preliminary calculations using a layout similar to the Option I repository concept. The following discussions of ventilation for retrieval of emplaced waste are based primarily on that study and use an assumed air temperature of 50 °C as representative of acceptable working conditions during the retrieval process.

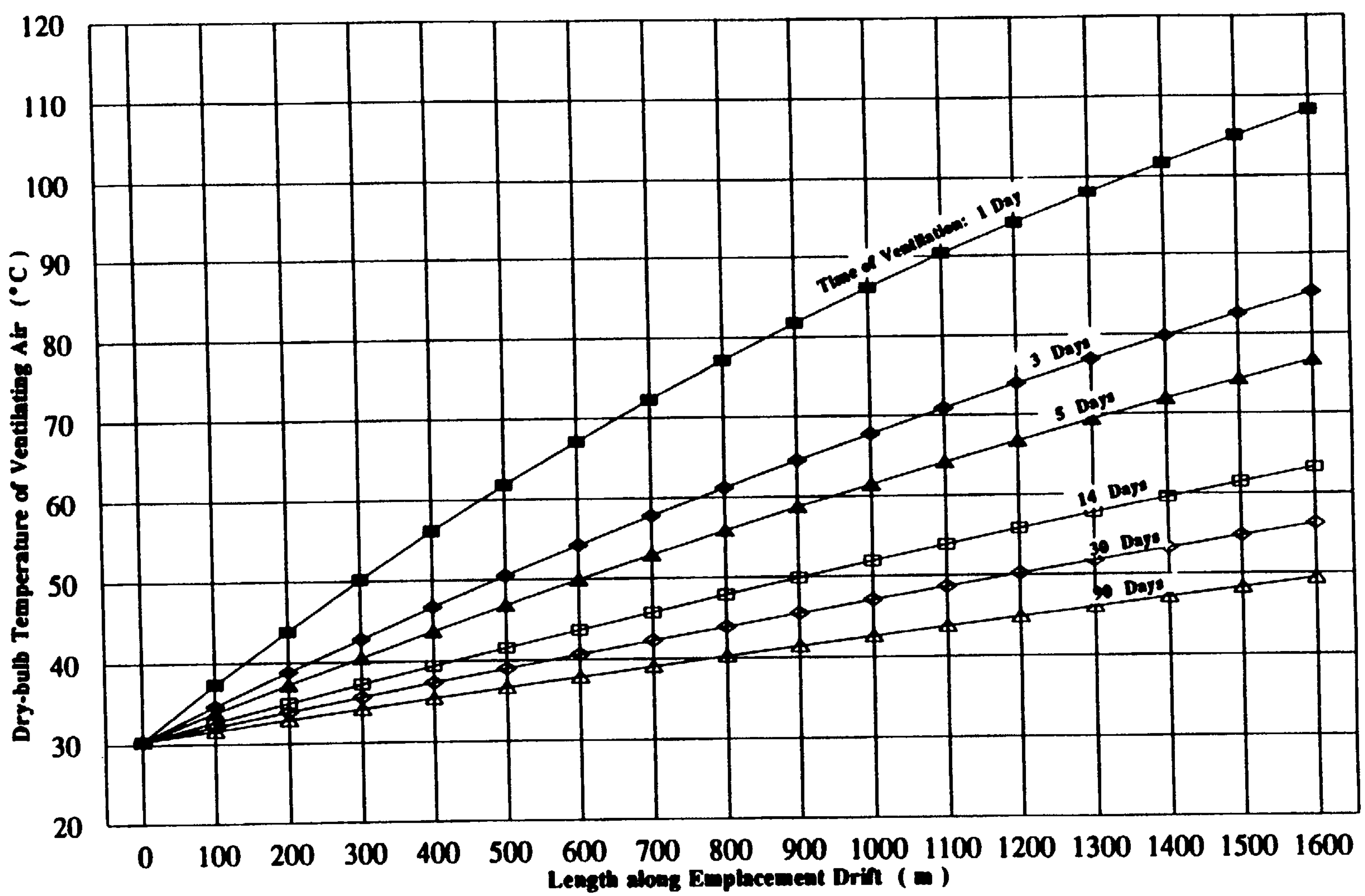
Continuous ventilation removes heat from the repository from the beginning of the heat transfer processes, thus a relatively low drift temperature is expected, in comparison to an unventilated drift. However, this approach requires an extremely large total air quantity because all of the emplacement drifts are ventilated simultaneously. Calculated examples for the Option I layout show that to maintain the temperature of ventilating air in an emplacement drift below 50 °C, using intake air at a temperature of 26 °C, the air flow rates required are about 8.26 m^3/s (17,500 ft^3/min) for a 640 m long drift, or 19.36 m^3/s (41,000 ft^3/min) for a 1500 m long drift. This illustrates that ventilation air flowing in what could be considered a normal range would be capable of continuously removing the desired amount of heat from a single emplacement drift without exceeding the 50 °C temperature. However, simultaneously ventilating all emplacement drifts requires a very large total air quantity, consequently, excessive costs for ventilation related construction and operation could be expected and additional shafts might be needed. Further study of the continuous ventilation concept is recommended before seriously considering it as a viable option.

When a drift emplaced with waste is closed for an extended period such as 50 years, the heat transfer from the waste to the surrounding rock, mainly through conductive and radiative processes, will cause a large scale increase in rock and drift wall temperatures because almost all of the energy released from the waste is transferred to its surroundings. Cooling of an emplacement drift under these circumstances within a reasonable period of time requires a relatively large quantity of air for a single drift when compared to the continuous ventilation case, due to increased drift wall and rock mantle temperatures, but the total air quantity required is substantially reduced because the number of drifts undergoing cooling at a given time would be reduced. The maximum initial rock temperature at the beginning of cooling depends on factors including areal power density, emplacement mode and drift size. For a given initial rock temperature, the quantity of ventilation air becomes the predominant factor in temperature control. Transient state calculations and analysis (M&O, 1993e) show that it is possible to regain access to an emplacement drift that has been closed for an extended period (such as 50 years), by ventilating the drift with large quantities of ambient air.

Figure 5-35 provides an example of the temperature distributions along an emplacement drift and their variation as a function of the time of cooling. A typical air quantity of 94.39 m^3/s (200000 ft^3/min) was selected to illustrate a complete emplacement drift cooling process to a temperature of 50 °C. As shown on the figure, the air temperature steadily increases while passing through the drift, due to the high initial rock temperature. The highest air temperature always occurs at the airway exit. Based on the parameters stated on the plot, it takes about a week to reduce the air temperature to 50 °C for a drift 640 meters (2100 ft) in length, or about 8 weeks of ventilation for a 1500 meter (4900 ft) long drift.

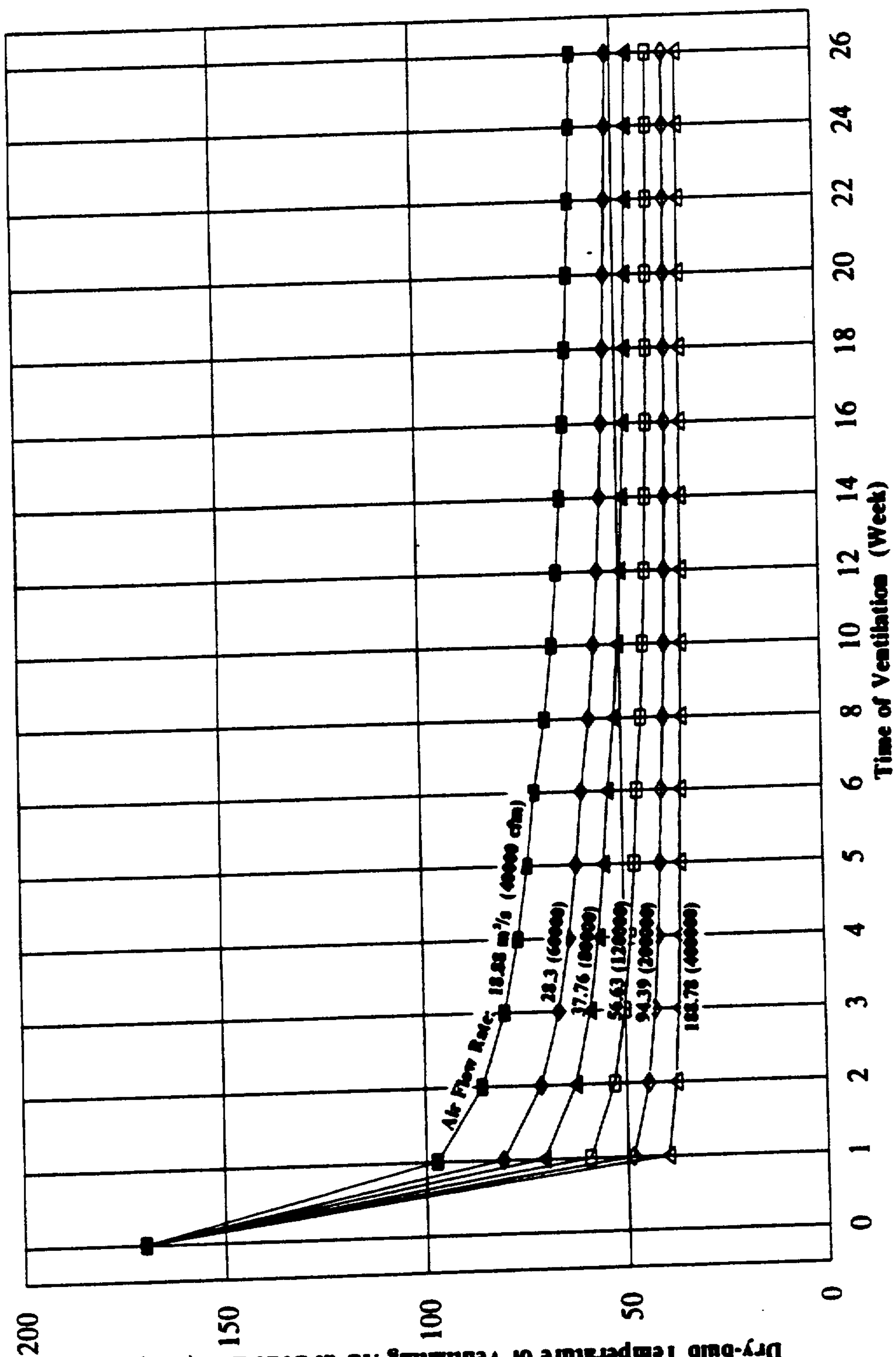
The highest temperature profile in the initial stage of cooling indicates that the highest heat load on the air flow occurs at the beginning of the cooling. During the period of ventilation, the heat load on the airflow is reduced at a decreasing rate. This type of behavior reveals the importance of the initial air quantity at the beginning of drift cooling. It would be advantageous to provide very high air flow quantities initially for rapid and effective cooling. After the heat generation rate is reduced, a lower air quantity could be used to maintain the desirable drift temperature. This suggests the possibility of using a staged approach for concurrently cooling additional drifts in order to reduce the total air quantity requirement.

Figure 5-36 presents the calculated temperatures of cooling air exiting emplacement drifts before reentry, based on various air quantities and cooling times. Based on a 640 m long drift and other parameters as shown, this figure demonstrates that an air quantity of 94.39 m^3/s (200,000 ft^3/min) can reduce the temperature of air exiting the drift to below 50 °C after one week of ventilation. If a higher air quantity of 188.78 m^3/s (400,000 ft^3/min) is used, reentry is possible within the



* *An example calculated for conditions of: 1) In-drift emplacement mode, 2) Airflow rate 94.39 m^3/s, 3) Drift diameter 4.27 m, 4) Waste package diameter of 2.4 m, 5) Intake air temperature 30.3 °C, and 6) initial rock temperature of 170 °C at beginning of ventilation.*

Figure 5-35 Temperature of Ventilating Air along an Emplacement Drift



* *An example calculated for conditions of: 1) LAPD 17.3 W/m² (70 kW/acre), 2) Airflow rate 94.39 m³/s, 3) Drift diameter 4.27 m, 4) Waste package diameter of 2.4 m, 5) Intake air temperature 30.3 °C, and 6) initial rock temperature of 170 °C at beginning of ventilation.*

Figure 5-36 Air Temperature Variation During the Cooling Period first week. For air flows equal to or lower than 28.3 m^3/s (60,000 ft^3/min), it is impossible to achieve the 50 °C air temperature for re-entry within 26 weeks.

5.1.7.9 Backfilling, Sealing and Decommissioning Considerations, Option I

5.1.7.9.1 Backfilling and Sealing of Emplacement Drifts

As with any in-drift emplacement concept, backfilling and sealing of the Option I layout emplacement drifts poses special problems inherent to the emplacement mode, which are perhaps more pronounced with the ISDOR mode due to the limited amount of working space in the drift. While an absolute need for placement of backfill throughout the entire drift has yet to be established in the repository program, a potential need to perform this task must be addressed. As mentioned in the preceding section, it would be impractical to install backfill or decommissioning seals in the emplacement drifts until after retrieval of the waste is no longer considered to be a potential course of action.

Waste packages emplaced in-drift must be able to shed the heat generated by the spent nuclear fuel in order to prevent breakdown of the cladding and other materials forming portions of the engineered barrier system. This is the first issue that must be addressed when considering backfilling the emplacement drift, because air voids inherent in crushed tuff or other, inexpensive and easily accessible dry materials would tend to insulate the packages if placed around them in the drift. Pumped, lean concrete, or a high-density "paste" backfill composed of finely crushed tuff and cement, with bentonite, flyash, or other admixtures may be a better solution, if the water that isn't consumed by hydration, or the cementitious materials and admixtures used in the mix, don't pose unsurmountable performance issues. It may be that radionuclide absorbing materials could be added to provide an additional, or mitigating barrier.

At any rate, pumped backfill containing admixtures to increase workability is considered to be the only material that could realistically be placed around the waste packages using the ISDOR emplacement mode. Without the centrally located, potential waste handling main discussed in section 5.1.7.3.5, maximum pumping distances of approximately 1400 meters (2300 ft) could be expected, by pumping from each end of the emplacement drift. This is within the range of currently available concrete pumping equipment but requires a specially designed mix.

Backfill pumping operations would utilize a 15 to 20 cm (6 to 8 inch) diameter slickline positioned near the crown of the emplacement drift to deliver the material to the active backfill location. The slickline would be made from sections of plain-end steel pipe welded together to form a continuous run. It would lay in a U-shaped trough that would be installed in the crown of the opening during drift construction. The trough would have 60% to 80% of its sides cut away to allow the backfill to spill out around the packages, while still allowing the slickline to be pushed into, or be pulled out of, the drift. Backfilling would begin at the approximate midpoint of the drift and would retreat back toward the main drift, by removing sections of slickline as the placement progresses. All operations associated with the handling of the slickline would have to be performed remotely due to the exposure risk associated with working in-line with the emplacement drift. The drift may have to be cooled prior to beginning backfill operations, using large quantities of ventilation air as discussed in the previous section.

It is not expected that the drift could be completely filled due to the remote nature of the approach, but an adequate quantity of backfill could be delivered to greatly increase the long-term stability of the opening. Thus, while backfilling of in-drift waste packages may be more difficult in the smaller emplacement drifts used in the Option I concept, the need to backfill for long term opening stability is less of an issue when compared to much larger, more accessible drift diameters. The cost of a backfilling operation as described here would be high; it could approach the total cost of constructing the emplacement drifts.

Sealing the ends of the emplacement drifts would be considerably easier than backfilling of the entire drift. A detailed analysis of the requirements for sealing of these drifts is beyond the scope of this study, however, the following is offered as one potential method of installing seals at each end of the emplacement drifts:

Those operations that must be conducted within the drift would be carried out remotely. A bulkhead would be erected in the standoff zone of the emplacement drift using robotics or similar techniques to form a containment for the concrete or other seal material that might be used. A second bulkhead might then be erected at an appropriate distance from the first to further contain the sealing material. The seal material would then be placed between the two bulkheads and checked for adequacy of the installation. Then the space in the drift between the second bulkhead and the door at the mouth of the drift could also be filled if necessary.

5.1.7.9.2 Decommissioning

Examination of various details regarding decommissioning of the subsurface and installation of permanent seals in the ramps and shafts was beyond the scope of the effort presented in this study. A general note that should be considered in future work, however, has to do with the use of precast concrete invert segments in the subsurface openings.

Specifications for the recently awarded TBM manufacturing contract (RSN,1992) for the ESF include strict requirements which address elimination or mitigation of potential fluid leaks and spills from the machine. The stated design and operational goal is for zero events involving contact of the organic fluids with the surrounding rock. The primary concern is that introduction of hydrocarbons into the subsurface matrix could, in some way, support migration of radionuclides into the accessible environment.

Many of the figures presented in this report show rail mounted on top of precast concrete segments in the invert of the various openings. These are normally used in tunnels that traverse through ground that is relatively soft in terms of bearing capacity, or that might become soft or disturbed if it comes into contact with seepage water in the tunnel. Neither of these conditions are expected in the proposed repository horizon. However, if one observes the invert in frequently traveled areas of underground mines or tunnels, many times a "trail" of oil or grease formed by small leaks and seeps from the haulage equipment can be seen. Besides creating a stable roadway that can be constructed immediately to the rear of a TBM without impeding its progress, use of the segments is considered beneficial from the standpoint of containing minor leaks of hydraulic fluid, grease, or gear oil from various items of equipment that will be used in the repository. (Major leaks or spills could require temporary removal of segments, cleanup of the spilled fluid and invert, and reinstallation of the segments in the affected area.)

An aggressive preventative maintenance program can accomplish a great deal in terms of minimizing the occurrence of occasional drips or leaks, but it cannot totally preclude their occurrence. The segments provide a removable containment "vessel" for capturing minor fluid leaks without forcing manufacturers of the underground equipment into new, or cumbersome designs, in an attempt to mitigate the fluid leaks issue.

The segments would remain in place until the repository is ready to be decommissioned. Removal of the segments, if deemed to be necessary at that time, could be effected in a relatively straightforward manner as one of the major decommissioning tasks.

5.1.8 Repository Subsurface Layouts-Options II

5.1.8.1 Alternative Layout Features

Several alternative layouts were investigated in an effort to establish a range of possible patterns that could stimulate layouts to meet evolving hydrothermal considerations related to post closure performance. In considering the alternatives, several primary goals were set forth as follows:

- Attempt to create a pattern that would be as circular as possible, avoiding sharp corners in plan view of the areal emplacement scheme.
- Minimize the number of TBM launch setups so that a machine can have as much operating time as possible.
- Investigate the possible variations for in-drift emplacement, while maintaining the flexibility to combine emplacement modes and custom design thermal loading through physical layout and the practicality of waste package emplacement, relocation, and retrieval.

The concept of "extended hot" repository uses an idealized thermal umbrella being developed over a repository to move the dry front away from the emplacement area for a period of thousands of years. A layout which may result in such a thermal umbrella could be a circular repository consisting of a series of concentric drifts which should promote an even distribution of heat from the emplaced waste and that would, theoretically, allow the possibility of rearranging waste packages as time passes to manage the heat load.

The concept may not be applicable in its idealized form to the Yucca Mountain site because of the geology such as faults, fracture pattern and programmatic issues. However, layouts can effectively be adjusted to avoid "sharp corners", and approach the idealized circular configuration.

The alternative idealized layout concepts presented in this section tried to provide as much continuous excavation as possible without the need for stopping and re-launch of the machine. For this exercise, a rule-of-thumb figure of approximately 15 km (50,000 ft) was selected as an interval for major rebuild of the TBM, and layouts that could be naturally subdivided into this length afford a convenient break for both machine repair and changeover from development to emplacement for that area.

The concepts presented in this section offer variations of the in-drift emplacement mode. Some combine the concept of emplacement in access drifts as well as in specially excavated emplacement crosscuts of differing size and length. These layouts consider co-mingling of emplacement modes using different waste package sizes in an attempt to manage thermal loading. All configurations striving toward this goal consider proven technology for equipment to be used in excavation, but some specialized equipment may need to be developed utilizing that technology to achieve selected results.

5.1.8.2 General Design Goals, Alternative Options II

The design objectives outlined in Section 5.1.7.2 of this report for the Option I layout case are, for the most part, valid for the development of the Option II layouts presented in this section. However, in order to develop a set of alternatives, some design flexibility was allowed while creating the initial patterns. The main objective was to investigate various patterns and permutations of design which could, potentially, be refined later into acceptable layouts or sub-layouts where deemed appropriate. Concepts that provided flexibility for the alternatives are as follows:

- Curve radius for TBM work was kept to a nominal 90 m , although in some instances a 60 m radius was allowed. It is assumed that if a pattern needing this tight of radius is truly preferable, equipment can be custom built to achieve these parameters.

- Center to center spacing of emplacement drifts were kept at a minimum of 30 m while main access drifts generally were kept to a minimum 90 m center to center spacing.

- In order to achieve separation of development and emplacement ventilation, it was allowed that a ventilation level could be developed below the emplacement level. As an example, a level could be constructed 25 to 30 m below the emplacement drifts, and be connected by a series of raises.

- Emplacement drifts of relatively short length were deemed to be worthy of consideration for the lower heat output waste packages. For example, mains on 30 m centers could be connected by crosscuts excavated by custom mechanical excavators utilizing various, small diameter boring concepts as described in Section 5.1.5.5.

- Equipment used for emplacement, retrieval and relocation of waste packages can be a combination of rail and trackless transportation systems, depending on the desired task.

It should be noted that, for the purpose of developing these idealized concepts, many details were intentionally not addressed and are assumed to be addressable in future studies. These details include such features as: detailed operational logistics; radiological safety issues; set back distances from emplaced waste packages to the access drifts; cooling requirements of drifts during retrieval; corner/intersection stability; precise location of mains and emplacement drifts; final size of openings; desired extraction ratios; and actual location of geologic features such as faults, stratigraphic contacts, mineral content or structural anomalies.

5.1.8.3 Option II Layout Descriptions

Following are descriptions of the Option II layouts that were developed. The layouts were constrained by the same general lateral boundaries used in the Option I layout for this report. Hence, only development of the large upper western block and the smaller lower eastern block were considered in developing each pattern. Each pattern is adaptable to larger or smaller areas, but all are limited in smaller blocks by the turning radii assumed for the equipment, and the spacing assumed for main and emplacement drifts. In all cases, the layouts were not allowed to cross the Ghost Dance fault, but were confined to the two blocks mentioned.

In considering the various options, it is necessary to make sure that the emplacement and development activities can be separated to accommodate separate ventilation systems. This can be done using various ventilation control devices. In addition to the basic scheme, an additional ventilation level can be constructed either above or below the emplacement horizon, for example at 20 to 30 m elevation difference. The two levels can then be connected by a number of strategically located raises, thereby isolating the two activity areas. Each of the options considered below can effectively utilize the multi-level ventilation system.

5.1.8.3.1 Option II-A Description

The layout of option II-A (Figure 5-37) is an attempt to fit a purely circular pattern into the blocks available for emplacement. The concept that was first envisioned covered the entire underground area of both blocks, crossing the Ghost Dance, Imbricate, Solitario and Drill Hole Wash faults with concentrically circular drifting. However, this pattern would violate overburden constraints, cross the fault zones, and would result in variable sloping drifts of up to five per cent.

Option II-A envisions a circular drift pattern that is subdivided into sections that allow a full circle pattern to be developed in each section. The sections are then connected by curved drift patterns in an attempt to maintain as round a configuration as possible. The emplacement sections are accessed by a main through the center of the large block, and by crosscuts from the main to perimeter drifting. Development of the sections can be theoretically accomplished using one TBM launch, and proceeding with the concentric pattern by veering to the adjacent drift location at a predetermined point. The connecting, or "fill in" pattern between the circular sections would be driven using roadheaders or other specially designed TBM equipment.

Drifts are spaced at a nominal 30 m spacing center to center, and curve radii are kept to 90 m minimum. Although not shown on the figure, each intersection can be configured to allow either rail or trackless access. All openings are of sufficient dimension to allow in-drift emplacement of waste.

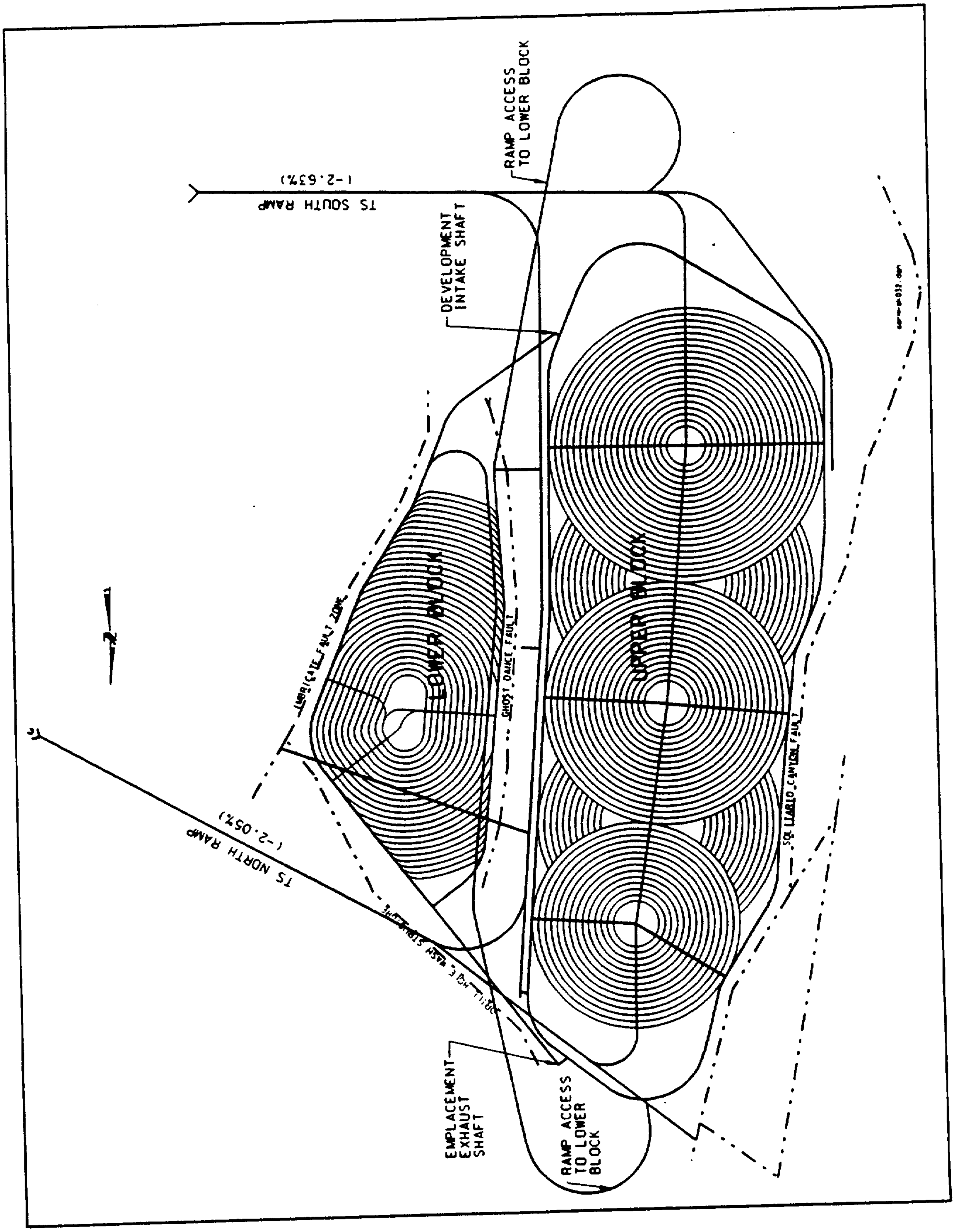


Figure 5-37 Conceptual Repository Layout, Option II-A

If development proceeds from north to south, each section can be released for emplacement as it is finished, allowing a separation of activities into distinct districts. This concept also coincides with proper ventilation application, which can use the same primary airways as the Option I case described in this report.

In general, advantages of this layout include the elimination of square or tight corners, few TBM setups, and a logical partitioning of the emplacement area to separate the development and emplacement activities. Coincidentally, each section as shown approximates 15 km of excavation, which provides a logical timing for major rebuild of the TBM.

Disadvantages include complications in muck haulage, difficulty in setup to excavate the connecting drifts between sections, and complicated air flow patterns for ventilation.

5.1.8.3.2 Option II-B Description

Option II-B shown in Figure 5-38 is similar to Option II-A in that it attempts to maintain a relatively circular pattern, but allows straight runs along the boundaries while curving only at the corners. The block is subdivided into three general areas, each involving approximately 15 km of TBM development. Turning radius is kept to a minimum 90 m and drift spacing is 30 m center to center. Development is done in each section by a single TBM launch, with the machine proceeding on a continuous inward or outward spiral as specified in design.

Access is through a main extending the length of the block from north to south, and through crosscuts from the main to peripheral access drifts. Access drifting patterns are generalized for this exercise, and are totally flexible in their location. Ventilation is achieved in the same manner as that described for the Option II-A case, but may be altered to accept a separate ventilation level that can be used for both development and exhaust as described earlier.

Option II-B improves on the Option II-A concept by avoiding complicated curved connecting drifts between the subsections of the block, maximizes the utilization of available area by allowing the geometry of the pattern to conform to the boundaries, theoretically provides for only one TBM set up per subsection, and allows easier definition of separate areas for the emplacement/development functions.

Disadvantages could include difficulty in muck haulage, and inconsistent spacing of the emplacement drifts in the corner areas.

5.1.8.3.3 Option II-C Description

Option II-C (Figure 5-39) shows a layout for the upper block that utilizes two TBMs for development of access drifts spaced approximately 300 m center to center, oriented on a general north/south bearing. Crosscuts are then driven between the accesses on 30 m centers. The size of main accesses are the same as for Option I, while the size of horizontal crosscuts can be designed as needed for the lower heat output waste packages. It is the preliminary concept that these small diameter crosscuts will be driven using micro-tunneling technology, which is based on combining TBM concepts with fast efficient setups permitted by the smaller machines. These

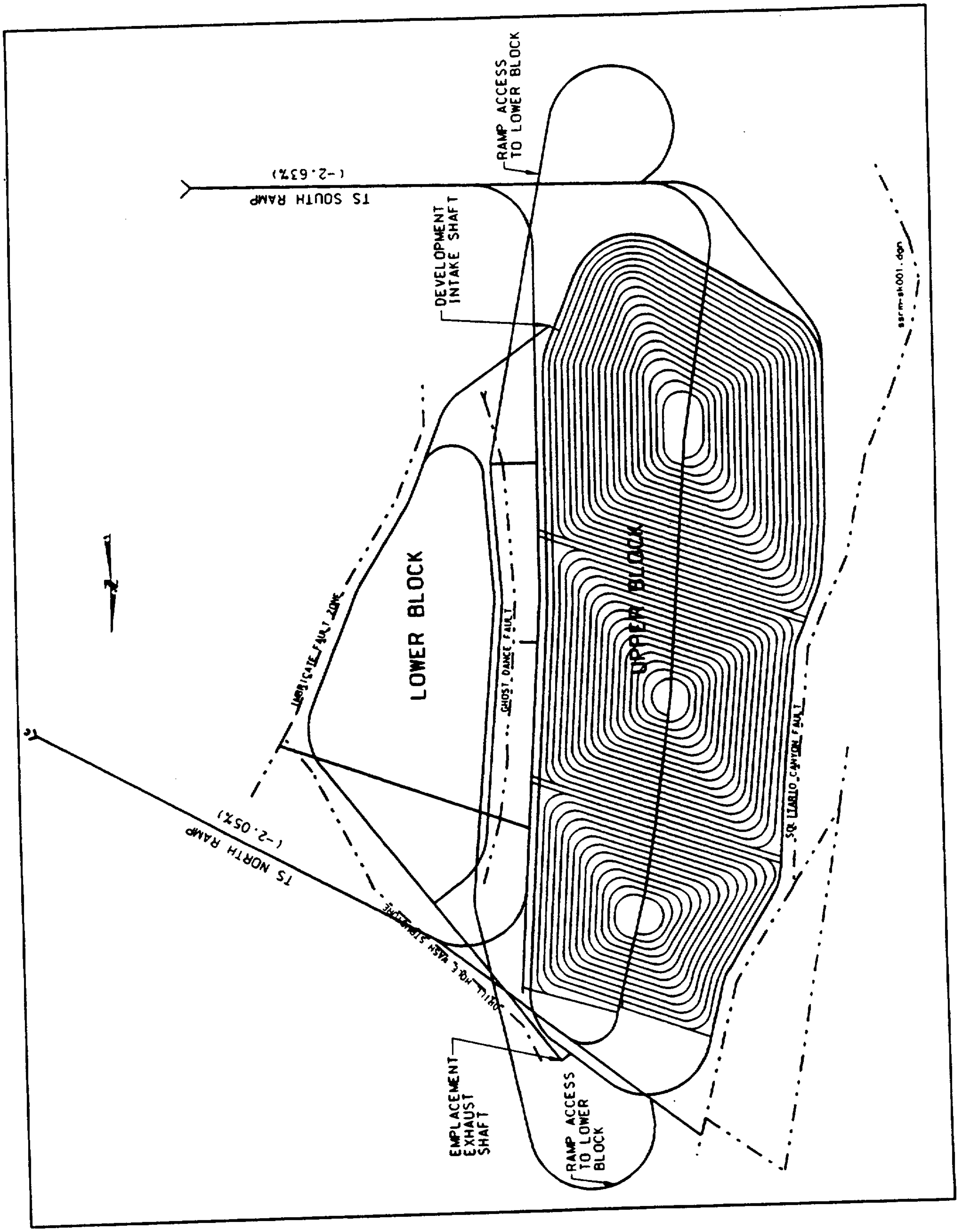


Figure 5-38 Conceptual Repository Layout - Option II-B

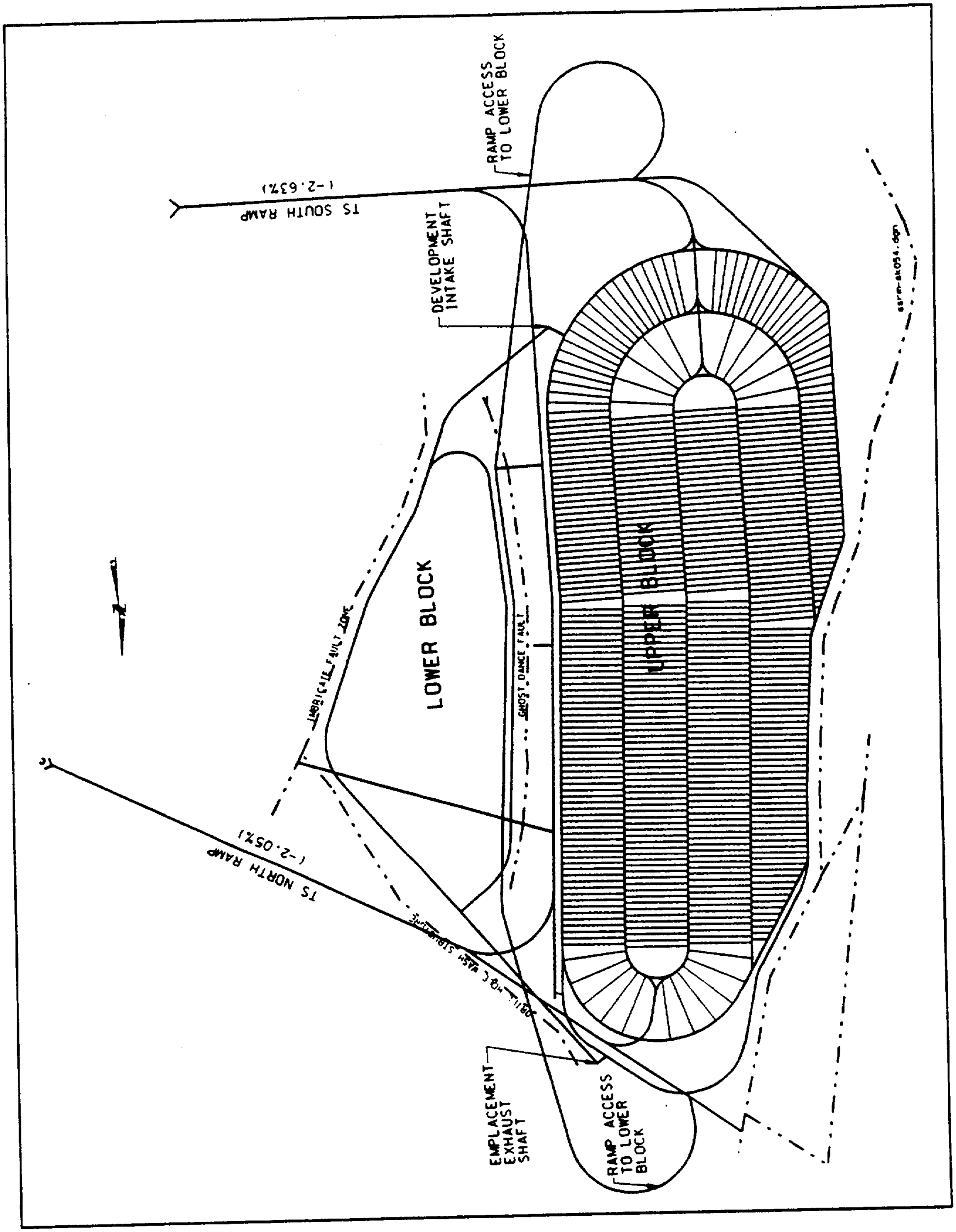


Figure 5-39 Conceptual Repository Layout, Option II-C

machines have the flexibility to incorporate disc cutters from 12.7 cm diameter to 43.2 cm diameter, remote muck removal systems, and self-launch capabilities.

The excavation sequence of development includes the two distinct operations of main drift excavation and crosscut excavation. Parallel excavation of the mains is followed by the crosscut development, utilizing the same main muck removal system (assumed to be conveyor for this section). Development starts on the west edge of the block toward the south, makes a 180 degree arc to the north, proceeds to the north end of the block making another 180 degree turn on that end, and proceeds to completion near the center of the block. Services are supplied through interim connections provided by the crosscuts.

While not divided into distinct subsections as in Options II-A and II-B, this option can provide sequential release of area to the emplacement activity, but not as early as the other options. Again, ventilation is accomplished either on a single or multiple level system as desired, and maintains the flexibility for expansion as necessary.

The advantages of this pattern lie in its long continuous TBM runs needing only two initial launches, and the geometric smoothing of the emplacement area corners. The emplacement crosscuts can be custom designed for size and spacing to accommodate the low heat output waste packages. The crosscuts can be selectively loaded and ventilated and provide a relatively short total length for consideration of retrieval and waste package relocation. The system can utilize multiple emplacement modes in one layout, can ultimately use the mains for in-drift storage, and can facilitate the backfilling process by providing shorter emplacement openings.

Disadvantages of the layout include the apparent inability to emplace waste until later in the development stage and the increased spacing of the emplacement drift centers on the outside of the radial pattern at each end of the block. Ventilation during the development phase would be difficult to control with multiple crosscuts, and stoppings would be needed to systematically control the flow. This system tends to lose some of the advantages of long TBM runs when applied to the lower eastern block, and therefor may have to be combined with another option when being evaluated.

5.1.8.3.4 Option II-D Description

Option II-D (Figure 5-40) combines many of the advantages of the other Option II layouts, featuring long TBM runs, subdivision of the main block into three sections, crosscuts developed for managed emplacement configurations, and efficiency of access and ventilation. The pattern is also applicable to any block size and geometric configuration, and maintains the initial goal to avoid sharp corners relative to thermal loading.

The option subdivides the upper block into three subsections, each containing main access drifts at 90 m spacing center to center. Starting on the north end, a TBM excavates the first east-west main 1a, then moves to the east-west main labelled 1b, then back to 1c, 2a, 2b, 3a, 3b, etc. The TBM continues in a circular pattern, excavating sequentially advancing mains from north to south until the first sub-block is complete. Between each east-west excavation run, the TBM must relocate by being partially dismantled and then moved through the east and west peripheral drifts

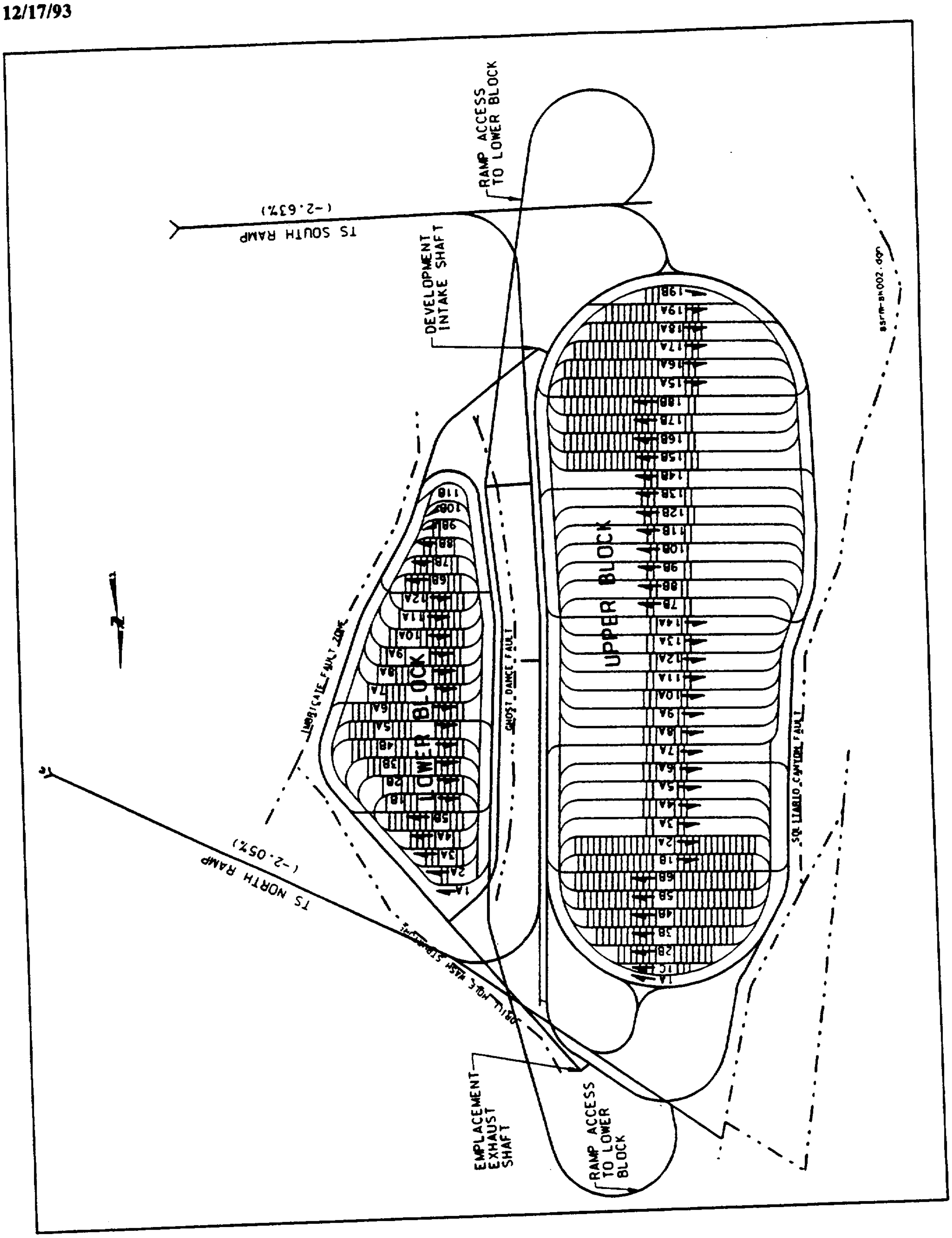


Figure 5-40 Conceptual Repository Layout, Option II-D

into an assembly chamber at the new location. A TBM can start a new turnout by using a set of top and bottom grippers and then proceed forward. Crosscuts are excavated between the mains at 30 m centers, sized accordingly for in-drift emplacement of low heat output waste packages. As one subsection is complete, the block is turned over to the emplacement activity, while the development spread (of equipment) is moved to the next block.

This pattern is applicable to variations in emplacement modes and is flexible in terms of waste package retrieval and relocation due to the relatively short emplacement drift length. The spacing of the mains and the emplacement drifts is flexible to the extent that a 90 m turning radius is currently assumed to be the minimum for TBM excavation. Crosscuts development can use the same range of equipment mentioned in Option II-C. Ventilation can be accommodated in either a single or multiple level scenario.

Advantages of Option II-D include:

- Minimum number of TBM launches at one per sub-block.
- Long TBM runs for development
- The upper block is subdivided into three subsections for logical division of development and emplacement activities. However, emplacement does not have to wait for one subsection to be entirely developed before emplacement can begin.
- The original "rounded" heat load concept is somewhat achieved by eliminating the corner effect in all locations of the block.
- Combinations of emplacement modes for differing waste package configurations are achievable.
- Ventilation is accommodated using either single level or multiple level schemes.
- The system is flexible for use on all sizes and configurations of emplacement blocks.

Disadvantages include:

- The TBM must be partially dismantled, moved through the peripheral mains, and reassembled before excavating the next east-west access drift.
- The spacing of mains is somewhat limited by the TBM turning radius.
- Potentially high excavation cost.
- Emplacement crosscuts alignment outside of favorable drift orientation window.

5.2 ESF/REPOSITORY INTERFACE

The Mission Plan (DOE, 1985) establishes the requirement to integrate the ESF with the GROA, and is consistent with 10 CFR 60.15(c)(3) which stipulates that: "to the extent practical, the exploratory boreholes and shafts should be located where shafts are planned for underground facility construction and operation, or where large unexcavated pillars for the geologic repository are planned...." The word "shafts" has since been interpreted by the NRC to also include ramps (NRC, 1991).

Work performed during FY93 by the repository subsurface ACD group, in conjunction with members of the ESF subsurface design and project engineering teams, and ESF testing personnel, resulted in proposed revisions to the layout and gradient of ESF ramps and drifts. Documentation and supporting logic for the proposed changes are included in a design analysis (M&O, 1993d) that has been submitted to the M&O Change Control Board (CCB) for baselining. The basic Option I repository layout concept, including the expanded version showing a lower block situated to the east of the Ghost Dance Fault, was presented in the design analysis as a potential GROA design that would interface well with the proposed revisions to the ESF configuration.

Minor refinements exist in the Option I layout as presented herein which were not included in the layout as it was shown on figures included in the design analysis mentioned above. Changes were made as follows:

1) The repository perimeter main at the north end of the GROA layout was moved to the south slightly. Figures included in the design analysis located this drift beneath, and on the north side of the north ramp extension, while figures in this report show it moved south of the extension. Also, at the northernmost end of the emplacement block, two east-west cross drifts, one extending from the service main to the potential waste handling main, the other extending from the service main all the way to the perimeter main on the west side of the layout were deleted as a result of moving the northern perimeter main to the south. These changes were made to eliminate potential ESF interference and to retain more flexibility with respect to future repository design efforts.

2) Figures included in the design analysis showed a waste handling main bisecting the emplacement drifts through the center of the potential repository block. Figures presented in this report locate this drift slightly farther west to better balance the emplacement areas on each side of this potential main.

3) Connecting drifts at each end of the service and launch mains on the east side of the layout, and in the southwest corner, are included in the Option I layout in this report to provide access between these drifts by routes other than the crosscuts located at each intersection of the emplacement drifts with the TBM launch main. These drifts were not shown on the figures included in the design analysis.

These refinements were made in the interest of creating a more workable concept and to better support future design efforts in terms of maintaining flexibility. They do not change any of the text in the design analysis, or any of the horizontal or vertical survey control proposed therein for the main ESF drifts or ramps.

5.2.1 Interface Requirements and Considerations

Among the various documents that address the integration of an ESF and a potential, collocated repository, NUREG-1439 (NRC, 1991) probably goes the farthest toward defining the primary areas of interface that are important to waste isolation. As stated on page 10 of that document, "Optimum ESF drift orientation and length may not necessarily coincide with the preferred GROA layout. A careful balancing of site characterization needs with geologic repository performance objectives will be essential." This quotation captures one of the primary objectives that guided development of the proposed ESF layout presented in the design analysis mentioned above and how that layout interfaces with the Option I repository layout concept presented herein.

Major areas of interface discussed in NUREG-1439 include the waste emplacement depth; the underground facility boundary; the location, number, and size of shafts or ramps; excavation methods; drainage design; and, sealing methods. With the exception of sealing methods, each of these areas of interface have been addressed by the integrated design and detailed description of the Option I layout concept presented in Section 5.1.7 of this report and the proposed ESF design presented in the design analysis. Other areas of interface which are also addressed by these two documents include potential waste transportation systems, how selection of a system is influenced by the gradient of various ramps and drifts, and the need for an ESF layout that does not compromise flexibility with respect to alternative repository layout concepts that may be developed in the future.

The flexibility offered by the proposed ESF layout should help future efforts directed toward compliance with 10 CFR 60.21(c)(1)(ii)(D) in terms of allowing suitable time to further evaluate major design features that are important to waste isolation for the Option I layout, and for other repository layout alternatives. This is because the ESF layout "draws a box" around three sides of the potential repository block, rather than cutting through the heart of it before more knowledge is gained regarding actual conditions in the proposed repository horizon. While the Option I layout interfaces well with the proposed ESF reconfiguration and should be able to provide support in terms of program guidance until something better comes along, the revised ESF layout could work with numerous other repository layout alternatives as well.

5.2.2 ESF/Repository Interface Configuration

Listed below are potential repository subsurface openings identified in the Option I layout that would be excavated during ESF construction and are, therefore, the primary realms of interface between the two areas.

NORTH RAMP (including PORTAL)

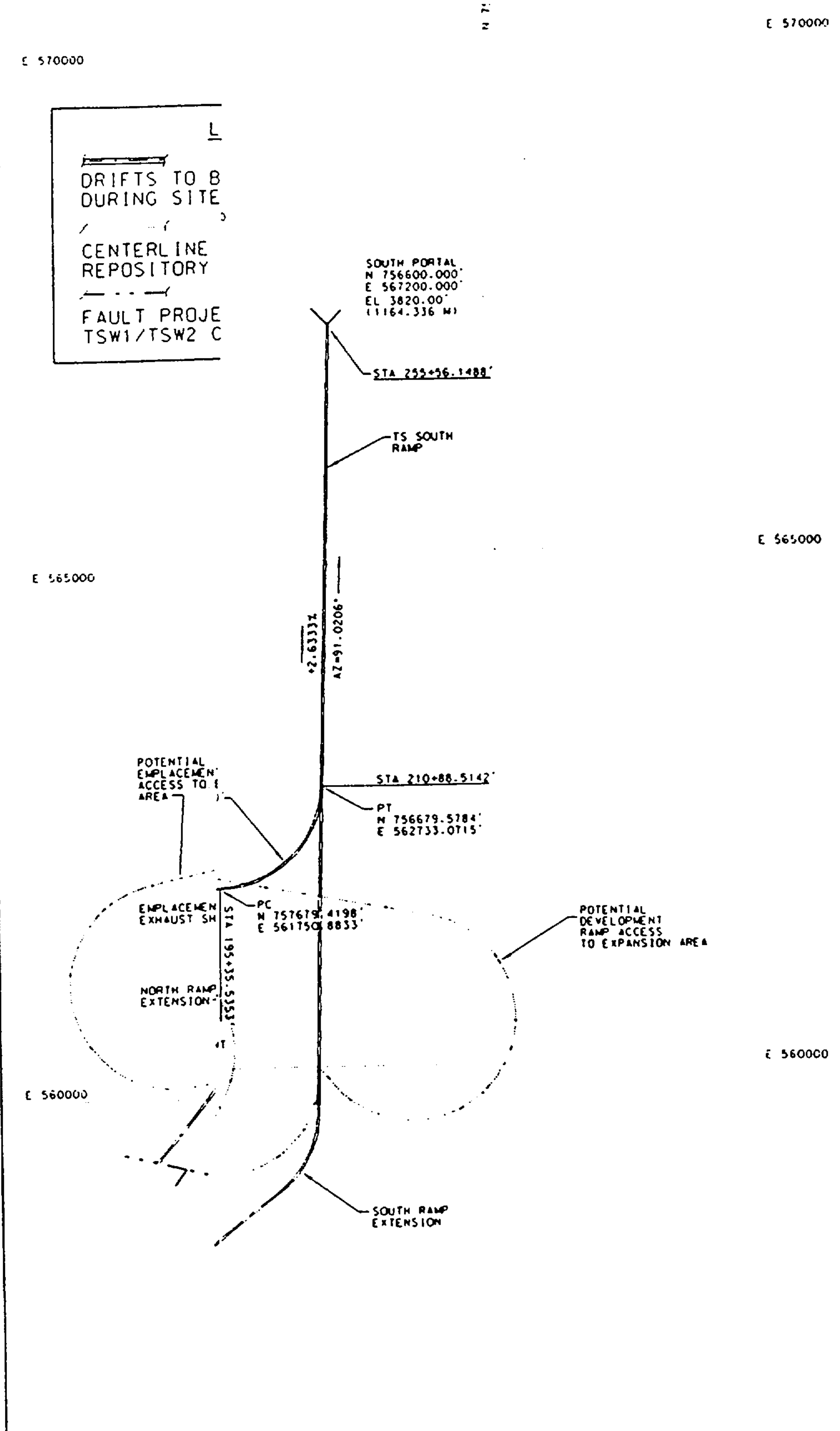
NORTH RAMP EXTENSION

TS MAIN DRIFT (REPOSITORY SERVICE MAIN)

SOUTH RAMP (including PORTAL)

SOUTH RAMP EXTENSION

The function, size, and positioning of each of these openings is discussed in Section 5.1.7.3 of this report. The previously mentioned design analysis (M&O, 1993d) provides additional details regarding proposed ESF functions, as well as the proposed gradients, diameters and lengths of these drifts and justification/rational for the revised ESF layout. Preparation of a complete set of interface drawings was beyond the scope of this report. Figures 5-41 and 5-42 present the integrated layout in plan view without, and with Calico Hills drifting, respectively. Cross sections and other details could be provided in conjunction with FY94 design tasks.



ESF/REPOSITORY INTERFACE
(WITHOUT CALICO HILLS DRIFTING)

FIGURE 5-41

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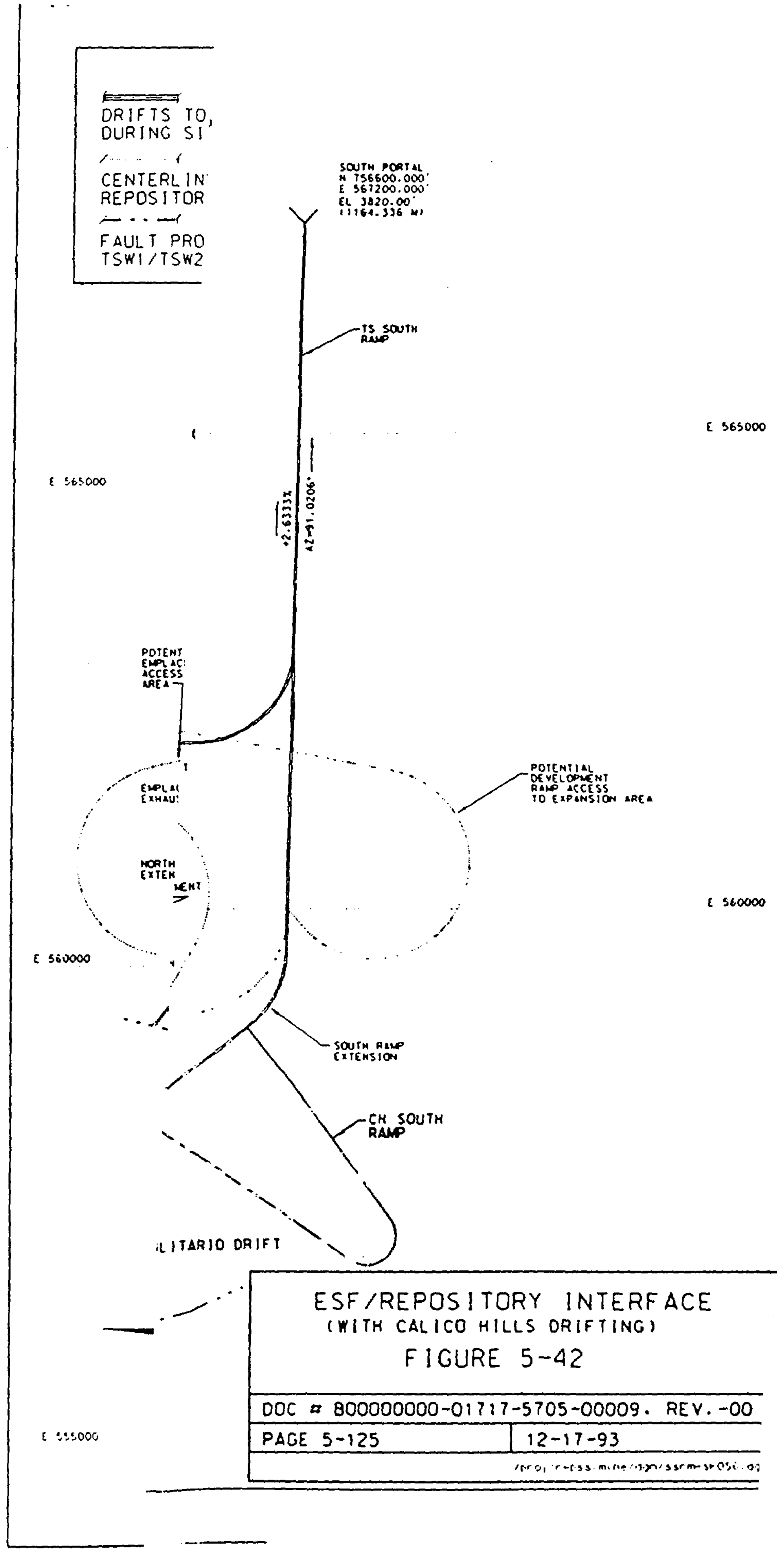

ESF/REPOSITORY INTERFACE
(WITH CALICO HILLS DRIFTING)
FIGURE 5-42

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PAGE 5-125 | 12-17-93

6. CONCLUSIONS AND RECOMMENDATIONS

The primary function of this report is to present various concepts for subsurface repository layouts, one of which, Option I, is described in considerable detail because it interfaces closely with currently proposed ESF concepts. As part of this effort, other layout aspects, including ventilation, potential expansion areas, and various geologic and thermal considerations are included in order to present a better overall understanding of the complexity encompassing the work scope. The conclusions and recommendations developed here center on the findings of this report; they do not present final solutions to the repository ACD effort.

6.1 REPOSITORY LAYOUT

6.1.1 Option I Case

For this report, a subsurface layout for the potential repository was conceptually designed and described in considerable detail. It demonstrates a logical interface with ESF Title II design, the feasibility of using TBMs for the development of a repository, and provides an example of conceptual repository development and emplacement operational systems. The concept presented serves to point out areas of concern for future studies, and offers a basic outline for future studies dealing with alternative layout design concepts.

Although not categorized as conclusions elsewhere in the report, the study establishes some important points to be considered relative to repository layout:

- Based on the IGIS geologic model for Yucca Mountain, it is possible to develop a repository layout concept that utilizes horizontal/flat-lying emplacement drifts, and main drifts that slope at a maximum of 2.0%, all within the upper and lower boundaries of the TSw2 unit, and over large, contiguous areas.

- It is felt that the basic ISDOR concept is a credible and practical solution to many problems associated with emplacement and retrieval operations, and therefore warrants additional study during repository ACD, including radiological safety evaluations.

- The use of large diameter access drifts or mains, in conjunction with smaller diameter emplacement drifts, simplifies launching and recovery of the emplacement drift TBMs, minimizes excavation quantities, and lends itself to the development of straight forward concepts regarding emplacement and retrieval of waste packages.

- The alignment of openings such as the main drifts and ramps, which can be accessed and maintained throughout all phases of the repository program, is considered to be of lower priority than the alignment of emplacement drifts, where heat and radiation pose formidable problems if maintenance is required.

- There is a need to develop specialized mechanical excavation equipment that facilitates fast, efficient TBM relocation and launching, and compatibility with primary muck removal, service systems and access concepts.

- Secondary excavation equipment, such as the TBM type cutting head being worked on by the CSM for adaptation to roadheader machines, needs to be fully developed in order to provide a viable solution for alternative, secondary, non-TBM methods of excavation in the TSw2 unit.

While it lacks certain optimizations, the Option I repository layout is considered to be a realistic scenario, sufficiently flexible to be constructed and operated in an efficient, productive manner.

6.1.2 Option II Layouts

Four optional layout scenarios were presented in section 5.1.8 of the report. These options were not refined to the same level of detail as the Option I case, but do offer generalized examples of possible alternatives that may be worthy of further development. The alternatives that are presented demonstrate differing approaches toward solving issues dealing with:

- The potential desirability of circular emplacement layouts to avoid "cool corners" which may cause an imbalance in the thermal-hydrological performance of the system.

- The possibilities of developing layouts that could accommodate a combination of in-drift and other emplacement modes for differing waste package configurations.

- Ventilation schemes that consider multiple levels as an alternative method for separating development ventilation from emplacement ventilation systems.

- Possibilities of developing layouts that potentially reduce the number of TBM launches that are required.

The Option II layouts are available for future consideration.

6.2 SUBSURFACE VENTILATION

Subsurface ventilation relative to the Option I case was described in section 5.1.7.5 of the report. Descriptions were provided regarding various aspects of ventilation for both the development and emplacement operational systems. Concepts for ventilation system separation between development and emplacement activities were discussed, along with examples of air quantity, quality considerations, cooling features, and retrieval concerns.

Evidence is provided that the Option I case can be adequately ventilated using accepted ventilation engineering practices and concepts. In general, air flow quality and quantity requirements can be satisfied, but more work is necessary to investigate alternative methods of control, isolation, flexibility, and levels of compliance feasibility.

6.3 EMPLACEMENT AREA EXPANSION POSSIBILITIES

The Yucca Mountain area was investigated to determine possible areas for expansion of the emplacement area if lower thermal loadings, adverse geologic features, or other problems require expanded development. Several areas were identified as potentially useable sites, and are roughly bounded by the Pagany Wash fault on the north side, the Fatigue Wash fault on the west side, and the Solitario fault on the east side. The optional areas (A through D) are comprised of four different storage horizons to maintain main drift gradients below 2 per cent, emplacement drifts at flat/horizontal gradients, and to stay within the TSw2 unit.

It should be noted that manual geologic interpretations were necessary to develop the expanded layouts and these were based on a very limited number of drill holes. Consequently, information presented regarding potential expansion areas must be considered very preliminary. The significance, or lack thereof, of identified faults and fractures is difficult to determine based upon the data available for the expansion areas.

Optional Area A warrants strong consideration as a stand-alone option in place of Optional Area 1, if a slightly higher LAPD is acceptable (15.5 vs. 14.7 W/m^2). Area A could be developed concurrently with the primary repository area to potentially shorten the overall construction schedule. Initial indications are that the amount of total development needed for Optional Area A would be somewhat less than Optional Area 1, potentially resulting in a lower pre-emplacement development cost.

Optional Areas B, C and D are potentially suitable as stand-alone expansion areas in place of either Optional Areas 1 or A, and can be used as expansion areas in addition to Optional Areas 1 and/or A. Expansion into Areas B, C and D would represent a major commitment for additional ramp extensions off of the north and south ramps, along with the potential need for a second intake ventilation shaft.

6.4 RECOMMENDATIONS

The recommendations resulting from this study surround the performance of additional work and investigations of underground layout, geologic information and potential expansion areas. Recommendations include:

- Perform additional investigations on area geology, developing an adequate database of information that can be used to construct stratigraphic models and other required input to further ACD investigations.
- Continue to refine and maintain information concerning potential expansion areas for waste emplacement, and periodically evaluate these areas for impacts on current design features and interface potential.
- Perform a study to further investigate potential, alternative repository layout concepts. Evaluate the alternatives, establish rankings and select a preferred option with one

alternate configuration. During development of the alternatives, vital systems and subsystems of each must be worked out in sufficient detail to provide confidence in the final selection process. It should be noted that this recommendation is currently a task identified for ongoing repository ACD work.

- Using a systems analysis type of approach, determine optimum emplacement drift and waste package spacings, considering various drift diameters, package heat outputs, areal thermal loadings, and thermal/thermomechanical goals.

- Evaluate the compatibility of various permanent materials that might be used in emplacement drift construction, in terms of the long term performance implications that must be considered.

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