GOLDER ASSOCIATES

Review of Y/OWI/TM-36 Repository Design
Performance in Salt, Granite, Shale or
Basalt

MASTER

DISCLAIMER

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

REVIEW OF Y/OWI/TM-36
REPOSITORY DESIGN PERFORMANCE
IN
SALT, GRANITE, SHALE OR BASALT

Richard Talbot

Oscar B. Nair

Golder Associates, Inc.
1658 Cole Boulevard
Golden, Colorado 80401

PO #8770903

Distribution:

- 5 copies - Lawrence Livermore Laboratory
- 3 copies - Golder Associates

MASTER

77308D

D/51

September 1979

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Golder Associates

TABLE OF CONTENTS

	<u>Page No.</u>
1.0 SUMMARY	1
2.0 REPOSITORY DESIGN EVALUATION	5
2.1 REPOSITORY DESIGN FEATURES	8
2.1.1 Repository Construction Features	8
2.1.2 Nuclear Waste Handling Features	9
2.1.3 Natural Features	9
3.0 REPOSITORY CONSTRUCTION	11
3.1 SURFACE FACILITIES	11
3.1.1 Hoists and Headframes	11
a. Men and Materials (M & M)	11
b. Low Level Waste (LLW)	12
c. Canistered Waste Shaft	13
3.1.2 Radwaste Storage at Stations	15
3.1.3 Main Power Supply	15
3.1.4 Fans	16
3.1.5 Air and Water Lines	16
3.2 SHAFT SYSTEM	16
3.2.1 Excavation	16
a. Concrete Quality	17
b. Rock Fracture	17
c. Water Control Techniques	18
d. Bunton Fastenings	19
3.3 REPOSITORY EXCAVATION	19
3.3.1 Layout Design	19
a. Salt	19
b. Granite	21
c. Shale	22
d. Basalt	22
3.3.2 Excavation Sequence	23
3.3.3 Geological Investigation	26
3.3.4 Full Scale Pilot Test	27
3.4 MINE EXCAVATION AND TRANSPORTATION SYSTEMS	28
3.5 VENTILATION SYSTEM	28
3.5.1 Airway Maintenance	31
3.5.2 Airflow in Shafts and Main Corridors	31
3.5.3 Air Heating and Cooling	32

3.6	DRAINAGE AND PUMPING	32
3.7	POWER SUPPLY	34
3.8	COMMUNICATIONS AND CONTROLS	34
3.9	EMERGENCY ESCAPE	35
3.10	BACKFILLING AND DECOMMISSIONING	35
4.0	NUCLEAR WASTE HANDLING	38
4.1	HOISTING	38
4.1.1	Loading and Unloading	38
	a. Low Level Waste	38
	b. Canistered Waste	39
4.2	TRANSPORT ON REPOSITORY LEVEL	39
4.2.1	Low Level Waste	39
4.2.2	Canistered Waste	40
4.3	EMPLACEMENT	40
4.3.1	Low Level Waste	40
4.3.2	Canistered Waste	41
4.3.3	Alternative Canister Emplacement Schemes	42
4.4	RETRIEVAL	43
4.4.1	Low Level Waste	43
4.4.2	Canistered Waste	44
4.4.3	Sleeve Corrosion	45
5.0	SYSTEMS ANALYSIS	46
6.0	DESIGN SAFETY FEATURES	47
7.0	DATA BASE	48
7.1	GEOLOGY	48
7.2	BASELINE ROCK PROPERTIES	48
7.3	GROUNDWATER MOVEMENT AND NUCLIDE TRANSPORT	49
7.4	THERMAL ANALYSES	51
7.4.1	Introduction	51
7.4.2	Thermal Modeling	52
	a. Quantitative Models	53
	b. Waste Forms and Packaging	54

7.4.3	Near Field Calculations	47
	a. Results	48
	b. Thermal Criteria	48
7.4.4	Far Field Calculations	51
7.4.5	Convective Heat Removal in Salt	52
7.5	THERMO-MECHANICAL STRESS ANALYSIS	53
7.6	FACILITY CONSTRUCTION FEASIBILITY AND COSTS	54

As part of the ongoing work by the Lawrence Livermore Laboratory to evaluate repository design performance, this memorandum presents a review of the preconceptual repository design described in Y/OWI/TM-36, "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations," April, 1978.

The purpose of this review is:

- To assess the adequacy of the design procedures and assumptions;
- To identify inappropriate or unsubstantiated design issues;
- To identify areas where additional numerical analyses may be required;
- To develop data for inclusion in a reference repository design.

The preconceptual repository design is presented in the form of 23 volumes of data base, analyses, and design layouts for four rock types: bedded salt, shale, granite and basalt. This memorandum reviews all four repository designs.

The preconceptual repository designs for salt, granite, shale and basalt are stated to be based on "more than two decades of analysis and in situ experimentation" (1). This data base is neither adequately presented in TM-36, nor is it explicitly referenced. The depth to which we have been able to review the structural design aspects of the repository is therefore limited and our comments are based largely on the limited work done previously by Golder Associates in this area.

The repository design presented is prepared for a generic site and, in those aspects that would normally involve consideration of specific geological and hydrological features, the description and discussion of necessity tends to become rather vague. In contrast, for some other aspects of the design, such as the surface treatment facilities, ventilation systems, security, etc., much more detail is provided. It is noted, however, that the limitations and uncertainties in the data and analysis are generally brought to the readers attention. Our review has been concerned with the major deficiencies that we have noted, either in technical procedure or logic, rather than the reiteration of the already noted problem areas.

A major deficiency in the design of the repository in granite and basalt is that the inherent structural characteristics of the host rock have not been taken into consideration. The design of a mine in hard rock is substantially different from that in salt. Where, by the nature of the formation, a repository in bedded salt is confined to a single level, a repository in massive granite need not be. The long term stability of large rooms in granite are well known. Transportation could be by track systems - either conventional or suspended on roof-mounted tracks; manually operated or remote controlled. Rooms could be in the traditional orthogonal pattern as presented or they could take on different configurations. The alternative repository layout possibilities in granite or basalt are not addressed in TM-36. It is our opinion that a properly designed repository in granite or basalt that took advantage of the structural strength of the host rock, its good hydrological properties and its low maintenance requirements, would be an attractive alternative to a repository in sedimentary formations.

Other significant deficiencies of TM-36 may be summarized as follows:

- There is no iterative redesign called for due to the possibility of significant escape of radionuclides via groundwater;
- There is no defense-in-depth of the multi-barrier concept of waste containment;
- No attempt is made to evaluate the performance of the proposed design with respect to the design objectives;
- The problems associated with retrievability and decommissioning have been ignored;
- No provision has been made to adjust layout and other design where adverse features are encountered;
- No provision has been made to prove or disprove assumptions of rock mass behavior prior to commissioning of the repository.

In general, we consider that the design procedure used for the preconceptual repository is not clear and lacks a logical, consistent argument. There is relatively little attempt made to evaluate the design, either in part or in total, in terms of the risks associated with nuclear waste storage, particularly the long-term containment aspects. It is frequently difficult to judge, therefore, the adequacy of the proposed design measures and safety features.

Chapter 2 presents a brief discussion of the repository evaluation requirements and the major features that are later reviewed. Chapters 3 and 4 provide review comments on the repository construction and nuclear waste handling facilities, including the structural design of the repository. Chapter 5 discusses a systems study that is lacking in TM-36 and that should be a requirement of any preconceptual design. Chapter 6 derives specific safety features not covered elsewhere and Chapter 7 includes a discussion of the data base used to prepare the design.

REFERENCE (1) TM-36, Volume 1, P. viii, "Executive Summary".

2.0

REPOSITORY DESIGN EVALUATION

A geologic repository for waste storage must serve two purposes.

Provide secure, short-term storage, with provision for waste retrieval, for a period of several tens of years. The minimum retrieval requirement for design verification is estimated to be five years.* For SURF waste (Spent Unreprocessed Reactor Fuel), a period of 25 years is considered necessary to allow for possible waste reprocessing at a later date. The rate of retrieval required is considered to be comparable to the rate of burial.

Provide a long-term containment of nuclides following repository decommissioning. The effectiveness of natural barriers to nuclide movement must be considered as part of the site selection/site suitability evaluation process. The repository design and subsequent construction may in some instances reduce the effectiveness of these natural barriers, particularly in the areas of shafts and borehole sealing, excavation method, thermal cracking and backfilling. Engineered barriers such as waste form and packaging may provide additional containment during the first few hundred years.

The repository must, therefore, be designed to provide both adequate short-term, operational safety, long-term nuclide containment after closure and decommissioning, and an optimum layout with reference to mining and waste handling operations and with respect to occupational health and safety.

* TM-36 Vol. 1. A more realistic design assumption would allow for retrievability during the entire operating life on the repository.

The operational safety of the repository will be determined by such factors as the stability of mined openings, nuclear waste container handling and transportation and other ancillary systems such as ventilation, electric power and communications, fire control, drainage and pumping, etc. Satisfactory design for these factors can probably be made for any potential site in salt, granite, shale or basalt. (2)

Long-term containment will be provided primarily by the site geologic and hydrologic characteristics, depth to the repository horizon and satisfactory entry sealing. These factors are clearly site-dependent. The construction of the repository and its long-term stability may substantially modify these barriers and it may be necessary to demonstrate alternative engineered containment such as waste form and packaging to prove a site specific design.

It is evident that design criteria for these two perspectives will be largely independent. Where common areas exist such as the structural stability of the repository, it is our opinion that criteria for long-term containment will most likely always be more conservative than criteria for operational safety.* The evaluation of repository design criteria must consider both the operational safety and long-term containment issues and in particular, the predicted impact of repository design and construction on long-term containment.

* Radioactive release during the operational phase will not occur unless a canister is physically damaged - an event largely independent of the structural instability of the repository. Release during the long term is a function of groundwater inflows, which may be increased due to structural instability.

Some of the operations in a repository will be functionally similar to parallel operations in nuclear power plant facilities and existing regulatory guides may be applicable. Other excavation related operations may be shown to be independent of the nuclear handling operations, by virtue of the repository design and provided that the means of ensuring independence is regulated by NRC, may be subject only to appropriate mining health and safety regulations. Many of the required nuclear waste handling facilities and procedures will be of novel design, however, and regulations concerning their performance will be required.

The structural design of the repository for the short-term may be evaluated using conventional numerical procedures developed for the design of excavations in rock. In any event, as stated earlier, design criteria will probably be dictated by long-term containment requirements.

For long-term containment evaluation, the impact of structural design must be evaluated by both thermo-mechanical numerical procedures and by nuclide groundwater transport modeling. Because of the dependency of permeability on temperature and stress, coupled models should be used. No such procedure has been adequately developed to date. For containment evaluation in the retrievable term, the different ventilation circuits during the life of the repository need to be modeled and analyzed. There is a similar need for an accident model that could be used to estimate the probability of an event or sequence of events that would lead to the escape of radio nuclides into the mining environment.

2.1 REPOSITORY DESIGN FEATURES

For the purpose of this review, we have attempted to define the major design features that will impact repository performance. The main repository design features are considered to be those systems and components that describe the location, geometry, construction and operation of the repository. To assist in distinguishing between the short-term operation and long-term containment design, we have considered the following three categories:

- Repository construction features
- Nuclear waste handling features
- Natural features.

2.1.1 Repository Construction Features

These design features include the geometric layout of the facilities, excavation systems, fixed installations and other ancillary systems, including:

- Surface facilities
- Shaft system
- Access tunnels and barrier pillars
- Nuclear waste storage areas
- Mine excavation and transportation systems
- Ventilation system
- Ancillary systems including power, drainage and pumping, communications, fire control
- Backfill systems.

2.1.2 Nuclear Waste Handling Features.

This includes all of the operations and equipment directly involved in handling and transporting the nuclear waste containers, and emplacement and retrieval operations in the storage areas, including:

- Temporary shaft storage facilities
- Shaft loading and unloading
- Hoisting
- Transport on repository level
- Emplacement
- Retrieval
- Disposition of equipment and facilities at decommissioning.

There is inevitably some overlap in discussion between nuclear waste handling features and repository construction and operation. We have, however, attempted this logical separation.

2.1.3 Natural Features.

The natural design features include all the site characteristics considered in the site suitability/site selection process that will be incorporated into or affected by the repository design, such as:

- Repository horizon (depth) and rock type
- Thickness and continuity of repository horizon
- Stratigraphy
- Geologic structure
- Aquifer locations and characteristics
- Tectonic setting
- Undetected features.

Much of this information is presented in the form of data in supporting volumes to the preconceptual design study and is discussed in Section 6. Summary comments are provided where appropriate in the discussion of repository construction (Section 3).

REFERENCES

- (2) TM-36, Volume 1, P.1-1, "Executive Summary"

3.0

REPOSITORY CONSTRUCTION

Comments made here are based largely on TM-36, Volumes 8, 10, 12 and 14, "Repository Preconceptual Design Studies." Other volumes are specifically referenced where appropriate, as are specific pages or sections for clarity.

3.1 SURFACE FACILITIES.

3.1.1 Hoists and Headframes.

a. Men and Materials (M & M).

All hoists serving this shaft are specified to conventional mining standards and appear appropriate to this application. No radioactive materials are planned to be transported in this shaft and the risks to men and materials are of the normal occupational type.

The M & M headframe is an integral concrete structure containing hoists, guide towers, rock surge bins, etc. No significant detail is given of these facilities but it is assumed they would be satisfactory in view of the normality of the risk environment.

The provision of an auxiliary cage in this shaft provides important operational security of shaft operations. It does not in itself, however, protect the operation from loss of ingress and egress in the event of any emergency such as a major hoisting accident which could totally halt M & M shaft operations.

No specific comment on the airflow direction or velocity in the M & M shaft is found in TM-36. Considering its importance as an emergency access to and from the repository, it is imperative to assume that the airflow in the M & M shaft is always into the repository and in sufficient quantity to meet expected needs, particularly those arising out of an emergency situation.

b. Low Level Waste (LLW).

The initial use envisioned for the shaft, access to and rock hoisting from the early excavation operations, is only of significance in the occupational risk sense. The proposed arrangement, that of a conventional, lattice steel 'A' frame headframe, with a single drum, ground-mounted hoist, is satisfactory from that point of view. The use of the facility for lowering LLW is potentially rather different, however. We would prefer tower mounting of the hoist in this case since this would give improved containment of the facility and also probably improve weather proofing. Single drum, single conveyance hoisting is quite acceptable in this application and is preferable, for these light loads, to balanced operation with its inherent risk of inter-vehicular interference. No detail is provided, however, of the conveyance to be included in the system. Operational incidents giving potential release of LLW material are not tolerable to the same degree as normal occupational accidents and we would, therefore, expect to see explicit discussion of the following design features.

- Conveyance design, with particular respect to confinement and/or securing of LLW payload for transit.

- Loading and unloading procedures, including clearances and guidance methods for pallet insertion and removal.
- Conveyance decking (precise locating at load/unload positions) procedures.
- Hoist controls, interlocks, indicators, overspeed detections, etc. A high level of redundancy in all critical systems should be specified.
- Rope attachments. There is a particularly good case in this application for using detaching hooks rather than fixed attachments. Retardation and conveyance behavior in severe overwinds deserves thorough treatment.
- Procedures for detecting a slack rope condition and taking appropriate corrective action.
- Inspection and maintenance procedures and standards for hoist, control equipment, ropes, attachments, etc.
- Hoisting capacity, speeds of operation, braking distances. These are particularly of interest due to the large volumes of LLW expected and the possibilities of some casks containing cement stabilized waste.

To summarize this comment, no discussion is presented on the detailed operation of the hoisting system and the detail of the control system. It is in these areas that the great majority of mine hoisting accidents originate.

c. Canistered Waste Shaft.

This facility is provided with a concrete headframe carrying two tower-mounted friction hoists. We agree with this headframe configuration, although the same comments concerning lack of detailed specification of safety systems can be made for this shaft as are listed above for the LLW shaft.

The choice of friction hoists over drum hoists is more controversial. It is recognized (TM-36, Volume 8) that total rope loads will be unusually, probably uniquely, high and that this will

lead to a preference for multirope systems. The relatively small payload weight relative to cage tare and counterweight weights should also tend to ensure the maintenance of satisfactory rope tension under normal operating conditions--an essential prerequisite for operation of a friction hoist.

In spite of these positive factors, however, friction hoists remain susceptible to loss of control in the event of the loss of rope tension such as could be caused by the jamming of a conveyance in the shaft. This risk would be well within acceptable ranges for normal type operations with the loads and equipment specified, but the risk areas would need to be specifically addressed before being judged acceptable for handling of canistered waste.

Another problem with friction hoists is rope creep on the friction wheel, causing inaccuracy in the conveyance location indicator given by any wheel-or hoist-mounted device. It is essential that the control system for this application includes reliable compensation devices or, preferably, direct conveyance location signals from points in the shaft. In particular, final cage location at load/unload points should be controlled and verified by local position detectors. Such verification would also have to be a part of an extremely thorough system of interlocks to ensure the safety of the load/unload operations. These involve the use of sections of moveable overhead rail to bridge the gap between the cage-mounted rails and the fixed rails on the shaft stations. Such moveable sections would interfere with cage travel if not correctly interlocked. Redundancy of location detectors, signal transmission systems and critical controls should be seriously considered.

Given the seriousness of a possible accident in the canister waste shaft, maximum hoisting and lowering speeds as well as maximum braking distances should be specified. It is not possible therefore to comment on the adequacy of the braking mechanism described on Drawing F-41. In any case, it is felt that a level of redundancy should be built into the canistered waste shaft system by the inclusion of safety dogs or similar mechanism that would be activated instantaneously in a free fall situation.

3.1.2 Radwaste Storage at Stations.

The design of the surface facilities includes a temporary storage room near to the shaft to hold nuclear waste containers during temporary hoisting delays. This is considered to be a high radioactivity area. We consider that routine shaft maintenance must be planned for requiring men to travel down the waste handling shaft. To minimize the potential exposure, it is, therefore, desirable that the temporary storage area should not be an integral part of the shaft station/headframe facilities.

Prudent design would include a temporary nuclear waste storage area near the canister waste and LLW shafts at the shaft bottom. Provision for the accessory services such as fire fighting, decontamination room, etc, should also be made in the shaft bottom area.

3.1.3 Main Power Supply.

All elements of the power supply system are discussed in Section 3.7.

3.1.4 Fans.

All elements of the ventilation system are discussed in Section 3.5.

3.1.5 Air and Water Lines.

For dust control and operating requirements, it should be noted that there will be air compressor equipment and compressed air and water lines underground in all rock types.

3.2 SHAFT SYSTEM.

Five shafts are planned for all cycles except the Cycle II Heat Removal case in a repository in salt where seven are required to provide additional ventilation. All appear properly specified and their locations and separation are satisfactory from an operational safety standpoint. However, the shaft locations may adversely influence the long-term containment capability of the repository by providing a centrally located pathway to the biosphere. The possibility of damage to shaft seals due to thermal expansion/cracking has not yet been adequately investigated. If it is significant, alternative shaft locations remote from the HLW storage rooms may have to be considered.

3.2.1 Excavation.

With one exception, (the LLW shaft in a repository in salt), all shafts are specified to be sunk and lined using conventional techniques. This involves drilling and blasting, concrete lining in 40 to 60 feet lifts and control of formation water inflow by pre-grouting. All these methods are known to be normally

successful in such applications and can be expected to produce satisfactorily operational shafts.

It is, however, a peculiar requirement of shafts in this application that they be prevented from acting as conduits for the longitudinal transfer of water between aquifer formations and the repository level. This requirement has also to be maintained for centuries after the end of waste placement and must, therefore, be demonstrated to a very high standard.

The conventional techniques specified have several inherent weaknesses in this respect which should be specifically addressed in detailed design.

a. Concrete Quality.

- Shaft lining concrete is typically of very variable quality caused, often, by placement behind forms through long down-lines without thorough remixing. Seals between subsequent lifts are also frequently of poor quality.

b. Rock Fracture.

- Blasting operations, followed by a period of time before lining, will give rise to a zone of fractured rock around the shaft which could have an unacceptable permeability. This could be reduced by controlled blasting, pre-bolting, closer lining, etc. In salt and shale media, if satisfactory results cannot be demonstrated by these methods, non-explosive excavation methods could be specified. Such alternatives could be substantially more expensive than the conventional methods specified and would also almost certainly take significantly more time.

c. Water Control Techniques.

- Salt: Cement and chemical grouting are specified for water control through aquifer zones and, together with freezing, represent the usually applied techniques. The choice of grouting appears correct in terms of long-term permeability reduction but this should be specifically verified.

Grouting of the completed lining is specified where water seepage occurs behind hydrostatic linings (Dwg. A-45). It is not, however, shown on Dwg. A-39 (behind the steel liner in the bored LLW shaft, probably in error) or in any example in the simple concrete lining through non-aquifer zones. It is considered essential that provision is made, or at least the need recognized, for positive grouting of the rock-lining interface and, where necessary, for any fractured rock zone. If the decommissioning plan for shaft sealing relies on any of these features to control long-term hydrological performance, this will need to be clearly stated as a basis for design and control of sinking and lining procedures. It may be necessary to develop special remote sensing systems (radar and sonic methods) that may be used to assure the quality of grouting and to monitor the development of voids and joints in and behind the liner.

- Granite: No appreciable water inflow is expected during shaft sinking operations in granite except during the construction of the shaft collar.
- Shale: Grouting is specified for water control during shaft sinking operations through the water bearing sandstone beds above the repository horizon. Well point and freezing techniques have been considered for water control during construction of the shaft collar.
- Basalt: No appreciable water inflow is expected during shaft sinking. Freezing of the water bearing sand and gravel overburden is expected to control water inflow during shaft collar construction. The possibility that there may be substantial water inflows along basalt interflows (rubbly basalt) that act as aquifers has been ignored in the discussion of water control techniques.

d. Bunton Fastenings.

- In addition to any pipes placed from the shaft lining inner face to the rock formation for grouting purposes, bolts are placed and required throughout the operational life to fasten shaft finishings. Such bolts and pipes represent corrosion potential over the long-term and should be specified of appropriate materials to minimize that problem.

3.3 REPOSITORY EXCAVATION

3.1 Layout Design.

As a general comment on the layout design, the reasoning for having similar mine layouts in the four different geologic media has not been discussed in TM-36. Thus, if the purpose of TM-36 was to determine the feasibility of constructing a repository in any of the four media and to make a comparative evaluation between the media, this has not been adequately demonstrated in TM-36. It is evident that containment capabilities of the repositories in the different media will all be significantly different from each other because of their differing physical, thermal and hydrological properties. Proposing similar layouts in different media does not, therefore, allow for unbiased comparative evaluations.

a. Salt.

Detailed drawings of planned layouts are shown in Dwg. A-25 to A-28, B-25 to B-27 and C-25 to C-28. The general dimensions shown are generally compatible with conventional salt mining experience. The layout concept appears to be one in which the storage area is divided into panels with each panel composed of a number of storage rooms. Successive panels are separated by

buttress pillars and rooms within the panel are separated by smaller yield pillars.

It appears that all of the important design criteria have been considered, based on qualitative comments in Volume 8, including the following:

- Thermal spalling around the storage room;
- The subsidence effects due to repository excavation;
- Surface uplift due to thermal loading;
- The possible effect of rock movement on shafts;
- Stability of rooms and pillars with limited closure in storage rooms.

We are, however, unable to provide a sensible review of these various design areas for the following reasons:

- The design logic for the "yield" pillar system is not clearly established; nor are the relative support functions of the buttress and yield pillars stated;
- The supporting data in Volume 19 (Thermal Analyses) and Volume 20 (Thermomechanical Stress Analyses) provide no significant design data or analysis for bedded salt;
- The references from which the design dimensions have been derived are not specifically cited.

Numerical analyses to evaluate these factors are not presented for bedded salt. General comments offered with respect to the design process are presented in Volume 18, Pages 3-6:

The main objective in determining the mine layout, room geometry and thermal loading for a repository in salt is to limit room closure to acceptable amounts during the operational and retrievable phases of the repository while concurrently maintaining pillar stability. Room closure rates are affected not only by thermal loading but by the mine geometry as well. As an example, room closure can be reduced significantly by the use of barrier or buttress pillars to relieve overburden loadings on more narrow pillars. Although some localized overstraining of rooms and pillars will occur in salt . . . it is not anticipated that any support will be required except in isolated areas.

To our knowledge, the barrier-pillar concept has not previously been presented in other references; it is normally used in situations where it is desirable to increase the extraction ratio--not a valid requirement for a repository. It is our opinion that an analysis of pillar stresses and closures should be presented to support the conclusions reached on acceptable thermal loadings. The need for roof support is not clearly related to either overstraining or structural weakness and the objectives, extent and type of predicted support should be specified.

b. Granite.

Detailed drawings of planned layouts are shown in Drawings F-25 to F-30, G-25 to G-30 and H-25 to H-30. The dimensions shown are generally compatible with conventional hard-rock mining experience. The layout concept appears to be one in which the storage area is divided into panels with each panel composed of a number of storage rooms. Successive panels are separated by 90-foot barrier pillars and rooms within the panel are separated by 60-foot pillars in the case of HLW, 25-foot pillars for ILW and CW and 30-foot pillars for LLW.

It appears that most of the important design criteria have been considered including the following:

- Limitations on thermal loading to minimize thermal weakening around the waste canisters (Vol. 19-3.4);
- The surface uplift due to thermal loading (Vol. 20-5.6.2.1);
- The subsidence effects due to repository construction (Vol. 20-3.3.1);
- The stability of rooms and pillars (Vol. 20-3.2);

The design procedures, logic and limitations for the repository in granite have been well presented and discussed in Volume 19 (Thermal Analyses) and in Volume 20 (Thermomechanical Stress Analysis). The repository design, however, shows no appreciation of the excellent structural characteristics of granite. The logic for designing a single-level repository with small storage rooms (similar dimensions as those in salt and shale) has not been presented.

c. Shale.

Detailed drawings of planned layouts are shown in Dwg. K-25 to K-27, L-25 to L-27, M-25 to M-27 and N-25 to N-27. The dimensions shown are generally more conservative than conventional coal mining experience. Extraction ratios of 23 to 30 percent within panels should be adequate for overall ground stability if provision is made to control deterioration of the exposed surfaces.

d. Basalt.

The comments made about the layout design in granite apply equally to the design in basalt. The design does not take advantage of the good structural properties of hard rock.

3.3.2 Excavation Sequence.

One of the main areas of risk in the repository rises from the inherent variability of geologic formations. A plan for final design and excavation of such a facility must address in substantial detail the procedures to be followed, thus preventing discovery of adverse conditions being delayed to a point where risk of a radioactive release is present or, at the least, preventing a prohibitive amount of time and money being spent.

The sequence of repository operation proposed is generally an "advancing" system, i.e., one in which the general direction of progress is from the shaft area towards the extremities of the repository (Dwgs. A-23, A-24, A-25). Such a system has major advantages, in that it permits placement of waste to begin at as early a stage in repository development as possible. It has a major disadvantage in that it precludes rigorous geologic investigation of the repository area prior to emplacement by the only really reliable method, pilot development. In addition, personnel and material would have to pass through areas where waste had been emplaced, and this may increase operational risks associated with the failure of seals and barriers.

With the scheme proposed, the possibility exists of an adverse feature being exposed by mining in, for example, HLW room 20, or some other room in the sector, at a time when emplacement of HLW had been underway for over 10 years in rooms lying on the opposite side of the main corridors. In the event of a major water inflow in such circumstances, therefore, an active repository area could be directly and immediately affected; the shafts could be

substantially threatened and long-term containment would be significantly reduced.

In our opinion the fundamental principles to be followed should be as follows:

- In the absence of conclusive evidence, from surface investigations, of geological reliability, an initial program of pilot development should be scheduled to cover the entire repository area prior to the commencement of emplacement.
- If the above is determined to be impractical, the repository should be designed as a series of individual unit areas. Each unit should be capable of being an effective sealer from the others and, in particular, any unit(s) in which active mining is underway should be capable of isolation from active storage areas.

In Volume 8, p. 5-2, it is stated that a "panel" concept will be used, each panel consisting of a number of storage rooms. The report does not, however, address the vitally important issue of the procedures for sealing one panel from another, to minimize the impact of adverse structural geology or groundwater, or even to control potential radioactive release via the excavation. The design and operation of the doors (seals) is likewise not presented.

The rooms within each panel are mined in the reverse sequence to the placement of canisters. Simultaneous mining and placing in the same panel are thus never permitted. The differences in sequence produces a greater delay between the completion of the mining of a panel and its use as a repository. Considerable work and lead time may be required between excavation and emplacement of

waste. This could have an impact on the integrity and containment capabilities of rooms.

If the development mining sequence of the panels were such that the head and tail entries were developed to connect with the exhaust corridor before mining of the storage rooms was started, the mining and placement operations could both retreat toward the main corridors in adjacent panels. Overall development would be reduced. The rate of mining could be kept in pace with canister placement. Ventilation would be simplified and there would be no need for the construction and removal of ventilation stoppings (barriers).

As a general comment, the report only briefly touches upon the issues of progressive repository development and operation, which will certainly impact on the occupational risks. Repository development is an important and integral part of repository design and alternative schemes should be evaluated to minimize occupational risks.

Operational procedures to reduce damage to the host rock and thus improve the containment capability of the host rock have not been discussed in TM-36. It is unclear if the properties of the generic shale are such that weathering of the exposed surfaces during the retrievability period will not create serious stability problems. Due to the creep properties of salt and the weathering properties of shale, it may reasonably be expected that a considerable maintenance effort will be needed during the life of the repository in those media to keep the main corridors and the exhaust corridors open and safe for operations.

3.3.3 Geological Investigation.

No provision is made in the report for ongoing geological/hydrological evaluation. The major types of geologic or similar risk recognized are:

- Features such as faults, breccia pipes, etc., which cross sedimentary units and could form a transmissive path;
- Features such as shale interbeds within the salt which could impede the repository operation or in some way alter the thermal or mechanical performance of the repository rooms;
- Man-made features such as exploratory drillholes or pre-existent holes.

It is recognized that the design under review is titled "preconceptual". It is, however, based on generic stratigraphies. The design for bedded salt (Dwg. A-22) for example, postulates the presence of salt in a horizontal bed of adequate thickness to contain two operating levels 74 feet apart, as well as other major facilities such as surge bins. Such an assumption is acceptable, provided that specific attention is given to verifying the truth of these assumptions before an irrevocable commitment is made.

The potential for variation in geological properties and the risk inherent in their existence are high enough that the procedures to disprove them are an essential part of conceptual design. Among the basic elements in such procedures which are not found in TM-36 are:

- Exploratory drilling prior to shaft sinking;
- Non-drilling exploration (geophysical and remote sensing methods) to establish geologic continuity and to search for major structures;

- Pilot excavation to prove or disprove the assumptions of rock mass behavior;
- Design and sequencing of underground development and pilot drilling to ensure that risk is minimized.

3.3.4 Full Scale Pilot Test.

No provision has been made in TM-36 for a full scale pilot test facility in the early stages of the construction of the repository. The divergence between the predicted behavior of the rock mass under thermal and mechanical loading, based on laboratory test results and on data from other mining locations and its actual behavior is well known. It is standard practice in large mines to conduct a prototype full-scale test of the planned layout whenever there is a major or novel design change. The need for such a pilot test is most particular to a repository in salt where knowledge of the salt mass creep behavior under thermal and mechanical loading is an area of considerable uncertainty.

A typical test facility could include two storage rooms with a pillar between them, all dimensions being identical to those planned. The facility would be instrumented to measure various deformations, strains, temperature gradients, etc. The planned number of HLW canisters would be emplaced in the rooms. The rooms would be sealed and the behavior of the rock mass in the vicinity of the rooms would be monitored through the instrumentation. The facility could also be instrumented and tests carried out to obtain valuable information on hydrological and solute transport properties of the rock mass.

There may be some delay in the commissioning of the repository as a result of the pilot test. Data would be collected and analyzed simultaneously with the development and construction of the various facilities in the shaft bottom area and with the development of the main entry and exhaust airways. The data collected during this time period should be adequate for the estimation of the short-term (5 year) behavior of the rock mass. Any design changes as a result of the test facility data may then be made prior to mining of the storage rooms.

3.4 MINE EXCAVATION AND TRANSPORTATION SYSTEMS.

The methods of mining and handling material from the repository are quite adequately described in the various volumes of TM-36. The only area in which the report is not clear lies in the method by which the mining operations and nuclear waste handling operations will be separated from the point of view of both vehicle/equipment operation and ventilation. This is considered an essential requirement to minimize the occupational risk.

3.5 VENTILATION SYSTEM.

In general, the ventilation systems for all the underground operational phases have been clearly thought out and are well presented. We have no doubt that the system, as described, will operate satisfactorily under normal circumstances.

The system relies for its safety and integrity on two principles:

- Airflow in active storage areas is at all times directed away from the working storage area, towards the area

where radwaste is already stored and from there to the exhaust system. No personnel would normally be required to work in air which has passed over emplaced waste.

- Airflow from the mining operation, representing a high proportion of the total volume, is kept separate from air that has passed through active storage areas. Only the air from storage areas is normally filtered to a high standard prior to discharge, although provision is made for filtering all air for a limited time, if necessary.

Both of the above principles are sound and should normally be effective. It is necessary to demonstrate, however, the degree to which they will stand up to unexpected or accident situations. This has not been done in TM-36.

The most undesirable event would be a reversal of flow direction, particularly in the storage portion of the repository. This could be caused deliberately by fan reversal, by circuit alteration due to wall failure or partial fan failure, or possibly by complete fan failure.

Deliberate fan reversal is often employed in operating mines under special circumstances such as for smoke control in fire fighting or to assist in melting ice buildup in intake hoisting shafts. It is, however, forbidden by law in many other circumstances and, in our opinion, should not be permitted if it could lead to a reversal of airflow direction in an active storage area. If reversal is considered a necessary provision for fire control in active mining areas, the ventilation circuit for such areas should be completely and reliably separated from that of the storage areas. Variances from applicable regulations should be sought, if necessary, to permit this.

Inadvertent reversal can be caused by fan failure or by some fault in the isolation of the separate airflow circuits. Significant fan failure would be caused, most probably, by major power failure. The TM-36 design provides for substantial security of supply and for local backup generation on a reduced basis. There would, however, be delay between the original outage and the availability of emergency power. The performance of the circuit under such conditions, with the reduced fan availability planned for emergency power situations, should be thoroughly evaluated.

It is presumed that adequate dust suppression measures will be taken to conform to present MSHA standards. The crusher room-conveyor-loading pocket complex appears to be located in fresh air that would flow through the main corridors to the mining areas. It will be necessary to exhaust this air through a small ventilation drift to be driven between the conveyor incline and the mining exhaust corridor.

In the retrievable case in each cycle, rooms are to be sealed after placement is completed for the period until retrieval operations commence (5-25 years). It will be difficult to maintain the integrity of these seals for that period and contamination of the fresh air could occur in unacceptable quantities. To reduce the risks of such leaks, the panels should be maintained at a lower pressure relative to the fresh airways by letting the connections between the panels and the placement exhaust airway remain open.

Under normal conditions, control and separation of airflows underground will depend on the integrity of walls, seals and doors. Such features should be specified to standards of performance suited to the sensitivity of their specific duties

and network analyses should be performed to evaluate the effects of failures. These should also be used to determine the need for instrumentation to provide warning of leakages. The largest single isolating feature is the divider in the ventilation exhaust shaft. Even though the system has been specified to contain sensors to detect adverse leakage across this divider, the system should fail-to-safety to the greatest extent possible. This could be facilitated by ensuring that pressure differentials across the divider are such as to guarantee that any leakage will be into, rather than out of, the compartment containing possibly radioactive air. The same principle could be applied to other sensitive isolating structures.

3.5.1 Airway Maintenance.

No indication is given of the radiation hazards that could be expected to build up over the operating period in return airways. These tunnels will, however, require regular inspection and, possibly, maintenance and cleanup. Provision will also be needed for examining the divider in the exhaust shaft.

3.5.2 Airflow in Shafts and Main Corridors.

No specific comment is made on the airflow direction or quantity in the Men and Material, LLW or Canistered Waste Shafts. It is assumed that they are proposed as dead zones. It is normally considered necessary to guarantee airflow direction in such facilities at a minimum quantity, at least at any time when personnel are in the shaft. In the M&M shaft, this could be assumed to be at all times, particularly including power loss emergency situations. For the radwaste handling shafts, it would

at least include inspection, maintenance and emergency situations.

This facility could probably be provided by controlled direct return of air to the exhaust shaft from the LLW and Canistered Waste Shafts. Such a tunnel is, anyway, required in this area to ensure direct exhaust of air from the service areas.

The air velocities in main supply air corridors (Vol. 10, Table 6-3) are greater than those normally used in current hard rock mines. In order to ensure that siliceous dust from the walls of the main and branch corridors is not made airborne and carried to the work areas, current practice is not to exceed an air velocity of 500 FPM in unlined main airways.

3.5.3 Air Heating and Cooling.

Proper consideration is given to heating of sub-freezing air prior to passage into the mine. The specified temperature of 40°F is, however, higher than necessary to prevent ice accumulation. It is suggested that, in any case where heat removal capacity is an important system design parameter, equal consideration should be given to pre-cooling of supply air. The planned concentration of supply air in one intake shaft is an ideal opportunity to maximize the absolute quantity and minimize the seasonal fluctuation in thermal performance of the system by temperature and humidity modulation.

3.6 DRAINAGE AND PUMPING.

Water inflows into the repository during its operating life are estimated at maximum rates of:

- 0 for salt (V.8, 1-7)
- 50-100 gpm for granite (V.10, 1-7)
- 700-1,500 gpm for shale (V.12, 1-7)
- 265 gpm for basalt (V.14, 1-7)

These estimates do not consider the possibility of water inflow through flow paths between overlying water-bearing formations and the repository created as a result of mining and heating the rock mass. The generic values of hydraulic conductivity used to obtain these estimates have not been derived from formation specific values. They are of the form of site specific hydrological criteria that must be met in the selection of a repository site. In our opinion, these criteria appear to be unattainable. The estimates of water inflow could, therefore, be unrealistically low.

No specific mention is made of the provisions to be made for handling water inflows into the mine. In Volume 8, Page 4-8, reference is made to shaft seepage water being collected and directed to the "main pumps" for pumping to the surface. These pumps are not specified, nor is any location for this facility indicated on the drawings. A pumping design should specify the quantities anticipated, general pump type and any special features such as control systems, warning signals, etc.

Consideration should also be specifically given to the need for a major standby capability for use in the event of unexpected uncontrolled water inflows. Coupled with this should be consideration of tunnel gradient and elevations to ensure a flooding sequence in an emergency which would afford maximum

survivability of shaft access and minimum contamination of water.

3.7 POWER SUPPLY.

The electrical supply and reticulation system has generally been extremely well designed to ensure security of operation under normal and emergency conditions. There are, however, one or two areas where improvement could be considered related to the underground workings.

Both cage hoists available in the M&M shaft are fed normally from the same side of the primary bus system and also, in emergency, from the same local generation bus. Security of supply would be improved by separating them. At the least, if the suggestion made elsewhere in this report for an emergency evacuation facility in one of the other shafts is accepted, that hoist should be either independently powered or separated in the bus system.

Power for underground operations is specified as being taken underground in multiple cables, all located in the M&M shaft. This is a busy, high-speed hoisting shaft and the supply should, in our opinion, be duplicated through another shaft and interlinked underground with suitable protective switchgear.

3.8 COMMUNICATIONS AND CONTROLS.

The system, as described, should perform adequately for operation of the underground and related facilities. Among the features which would have to be specified in a more detailed design would be high quality shaft radio communications for both normal operation and maintenance.

Security of the operation lies very substantially in the systems which will be used to control hoists and radwaste handling systems. There is, in our opinion, more potential for radiation release in these operations than in any other part of the system. As noted elsewhere in this review, this aspect is not discussed thoroughly in TM-36.

3.9 EMERGENCY ESCAPE.

Both man cages included in the design are located in the M&M shaft and thus have the potential for being incapacitated by the same event. It is essential that a man-hoisting facility be provided in one of the other shafts, preferably in a separate and secure intake airstream and separately powered. We would suggest a cage on rope guides in the supply air shaft.

Specific consideration should also be given to the quality of isolation of airflow that will exist between parallel main corridors into the repository panels. A vehicle fire in one of them, for example, should not contaminate the intake air in all of the repository panels.

3.10 BACKFILLING AND DECOMMISSIONING.

At the appropriate stage, storage rooms are scheduled to be partially backfilled with mined rock. The main corridors would be similarly backfilled prior to decommissioning. It is anticipated (Volume 10, p. 5-13) that the rooms will be backfilled to within a few feet of the roof and no compaction is used to improve the in-place density.

No mention is made of the objectives of this filling or of the necessary (structural, permeability, retardation, absorption) standards to be obtained. It is not, therefore, possible to comment on the likelihood of their attainment. The proposed backfilling will certainly inhibit airflow around and close to canisters but can hardly be expected to provide a long-term barrier against hydrologic flow through the storage rooms.

We would expect that the true performance criteria for backfill will be dictated by long-term containment considerations and will be found to be markedly higher than can be met by the proposed system. They will, therefore, require the development and provision of innovative methods of fill placement and compaction and, possibly, the use of additive materials. Costs of such procedures could be significant but may be shown to be warranted in terms of long-term repository performance.

To avoid the need for a crossover that would separate backfilling from placement activities, a perimeter corridor used only for backfilling is proposed for the five-year retrievable case in Cycles I, II and III. The perimeter corridor is shown in the mine master plans (Dwgs. 25) to be parallel and adjacent to the placement exhaust corridor.

Such an arrangement poses a risk of radiation exposure to the workers involved in the backfill operations. The backfill corridor can reasonably be expected to be contaminated before backfill operations commence, even with stoppings between the two corridors. Backfill operations will be downstream of the airflow over the canisters.

The overall ventilation and operational problems could be reduced if the backfill corridor on the perimeter was used as the mining exhaust corridor and if all three main corridors were used for fresh air supply. All ventilation flow, even in mining panels, would flow out-by towards the perimeter. In order that the mining exhaust be kept separate from the placement and backfill exhaust, the mining exhaust corridor would be on the perimeter side of the placement exhaust corridor. Such a system would minimize the number of ventilation stoppings or seals that will need to be constructed. The importance of maintaining the integrity of the seals for the working life of the repository will also be greatly reduced.

4.0

NUCLEAR WASTE HANDLING

This section includes a discussion of specific aspects of nuclear waste handling that are not covered in Section 3.0.

4.1 HOISTING.

4.1.1 Loading and Unloading.a. Low Level Waste.

This radwaste form will be lowered in palletized lots in an undefined cage which will be used only for this purpose. Loading and unloading will be by forklift.

The main hazards in this operation lie in accidental breaching of nuclear waste containers (drums) due to dropping, jamming, etc. Protection against such events would require secure palletizing of drums, proper fastening and/or confinement in the cage and rigorous procedures for operation and maintenance of all equipment. Such features are an integral part of design and must be specifically spelled out.

Safety during the actual lowering operation relies on proper specification of hoist control systems, as discussed previously, and rigorous maintenance procedures on all parts of the system. We see no reason why this should not be successful in this design but the vital importance of this area demands specific attention during design.

b. Canistered Waste.

This waste form will be lowered in heavily shielded, and thus thoroughly enclosed, cages which should provide satisfactory protection against all but the most violent events during actual lowering. Protection against such incidents depends primarily upon proper specification of the hoisting system and associated protective devices such as speed governors and interlocks. These were discussed in a previous section. Maintenance of all parts of the system is, however, also critical and must be possible to the highest standards in spite of any radiological problems. It must also be possible to safely correct any malfunctioning transfer equipment at any point in the cycle.

These factors are of particular importance in any transfer system on and off the shaft conveyances requiring accurate location of rails or similar devices, especially if temporary rail sections are to be inserted into the cage path to effect transfer. Problems of precise conveyance location and rope stretch changes on load transfer make these operations especially difficult, particularly with a friction hoist.

4.2 TRANSPORT ON REPOSITORY LEVEL.

4.2.1 Low Level Waste.

This waste form is loaded by forklift directly onto flatbed trucks for transport to the storage room. The main risk areas in this operation are mishandling during loading/unloading, dropping of drums from the truck and traffic accidents.

A final plan would have to specify drum/pallet restraints, vehicle/roadway width comparisons, vehicle speeds, traffic densities and controls, etc. No such information is contained in TM-36 for low level waste.

Vehicle fire is a real risk area. Such fires underground are extremely hard to control and very dangerous in view of intense heat and smoke generation from tire, fuel and hydraulic fuel combustion. The risk of radioactive release and dispersion would be acute. Vehicles must, therefore, be specified to minimize the risk of fire initiation and be equipped for prompt suppression.

4.2.2 Canistered Waste.

The system described is much more sophisticated than for LLW, in view of the shielding requirement and appears to satisfactorily cover many of the contingencies listed above. The main remaining risk area lies in the loading of the canisters onto the transporter. The mechanism for grasping the canisters for hoisting into the transporter shielded container will be remote controlled and essentially automatic. It must, however, work all the time, without fail, if canister droppage is to be avoided. Details of interlocks to ensure safe operation are not provided. The comments made above on vehicle fire apply equally here./

4.3 EMPLACEMENT.

4.3.1 Low Level Waste.

Positioning of LLW in the storage room is performed by forklift, offloading the pallets from the trucks and placing them in the chosen location. The protection required for security of

this operation is proper drum confinement on the pallets and satisfactory operating procedures to protect emplaced pallets of LLW drums from damage by forklifts or trucks. Rock conditions, particularly in the roof, should be carefully examined before waste placement begins to ensure that no significant failures are to be expected prior to backfilling. After waste emplacement in a particular location, it is very unlikely that scaling or support operations could be tolerated for fear of drum damage. If such procedures are considered impracticable for the expected pre-backfilling period, the pallets will have to be designed with protective tops.

4.3.2 Canistered Waste.

Waste canisters are emplaced in vertical holes drilled into the floor of the storage rooms. During the retrievable period, (5 years for Cycles I and III, 5-25 years for Cycle II), the holes are pre-lined with steel sleeves.

Drilling and pre-lining of the holes should present no problem, although accuracy of location and verticality will have to be ensured to abnormally high standards. Precise alignment of the canister within the transporter shielded container and the hole could, however, be a major problem. TM-36/10 states that "instrumentation on the transporter would permit the operator to adjust alignment" (pp.5-11). Failure in this respect, however, is considered more of an operational efficiency problem than one of radiation safety in all but the most extreme cases. Accurate guidance of these heavy vehicles will also be necessary if they are required to pass over holes, whether or not emplacement has been completed, in order to prevent damage to the concrete plug

and its shoulder seat which provides a barrier to airborne radioactive release from the hole.

In the Cycle II Heat Removal case in a repository in salt, a trench will be excavated in the room floor and equipped with precast concrete bracing/locating grids prior to emplacement. The illustration of this scheme, Dwg. E-32, is idealized. In practice, it may be substantially more difficult to control alignment of emplacement holes to the required accuracy. Specific measures will also be necessary to prevent accidental damage to the structure by an inaccurately driven vehicle.

4.3.3 Alternative Canister Emplacement Schemes.

Ten different schemes for the placement and ventilation of the canisters in salt are discussed in TM-36 (V.8, App. C) and two are chosen as those with significantly fewer operational problems. The basis for this choice appears to be operational - no special transporter design, no maintenance and no mining difficulties. These criteria are not pertinent. The primary criteria should be related to the risk of exposure to radiation during the operational life of the repository and of escape of radionuclides to the biosphere in the long term. From this point of view, the non-heat removal vertical hole-in-the-floor configuration could present serious risks due to the possibility of corrosion of the sleeve and canister in the long term and due to the possibility of the canister being wedged in the hole from heat spalling in the retrievable period. A quantitative comparative risk analysis between the various schemes under similar conditions and assumptions is the best way to evaluate the different schemes.

It is also likely that different emplacement schemes and indeed, different mine layouts, would be suitable depending on the type of waste and the repository media.

4.4 RETRIEVAL.

Retrieval of waste is required for a minimum period of five years during which time satisfactory repository operation is to be assumed. Some of the details of retrieval methods will be similar to those described above for emplacement such as precise location of transporters, handling of canisters and pallets and transportation problems. Other particular problems concerning retrieval are listed below:

4.4.1 Low Level Waste.

The pallets of LLW will be stacked in the storage rooms and are simply removed in sequence using the forklift/truck combination. The only major problem that may occur in the five-year storage period will be roof or wall failures.

In the best case, where no failures have occurred, the roof must be checked for loose rock before re-entry is possible. It will be difficult to remove any loose rock detected without possibly damaging the drums. It is our opinion that the LLW storage rooms must be designed and adequately roof bolted where required to ensure that no roof problems develop. This is not demonstrated in TM-36.

Where failures do occur, pallets and drums may be damaged or dislodged. Provisions for handling damaged drums and clearing contaminated rock must be provided.

4.4.2 Canistered Waste.

Canistered waste will be stored in the floor. It is reasonable to assume that the canister/overpack/sleeve system can be designed to minimize waste leakage during the five-year retrieval period.

Storage rooms will be reventilated and opened before retrieval. The rooms must then be inspected for roof and wall failure, as well as for radioactive contamination, before retrieval is possible. Provision for clean-up must be provided, including disposal of possible contaminated rock. This can be done with no risk of damage to the stored waste.

A means must also be provided to ensure that the mechanical condition of the canister can be verified before it is lifted out of the storage hole. It must be expected that a small number of canisters may be failed, or will fail, during the retrieval process, to the point where contamination occurs. Indeed, a significant possibility exists that the canisters could crack under a combination of thermal loading and the presence of small traces of chloride and oxygen in water (V. 21, P. 7-3). Procedures for handling these canisters are not detailed in TM-36.

For SURF waste, the condition of the canisters during the 25-year retrieval period is much less certain. The above comments concerning breached canisters and handling procedures are, therefore, of vital importance in this case. As a general comment, the report does not consider the occupational risks

associated with retrieval and decommissioning operations. This should be a part of the design process.

4.4.3 Sleeve Corrosion.

Sleeves made of carbon steel are to be used during the retrievability phase of the operation. The choice of carbon steel is questionable, particularly in light of the discussion on corrosion rates observed on specimens from the Carey Salt Mine (V.22, App. A). Again, a quantitative comparative evaluation should be presented as a basis for the choice of material. The problem of maintaining the integrity of canisters and sleeves in a corrosive environment is well suited to laboratory research and no choice of material need be made until more definitive information on corrosion rates as functions of environment, temperature and time are obtained.

5.0

SYSTEMS ANALYSIS

A systems study of the interactions between the various design modules is lacking in TM-36. It is a possibility that different wastes may be better suited to storage in different repositories in different media with differing emplacement schemes.

A systems study would also consider the material handling capacities of the various components of the waste handling-transport-emplacment systems and the mining-haulage-crusher-hoisting systems. Surge storage requirements would be determined from such an analysis as well as vehicle and machinery capacity specifications. The specifications would, in turn, impact on room and corridor dimensions, service area requirements, ventilation requirements, etc. The expected differences in machinery between what is currently used in mines and what would be needed to handle nuclear waste and to mine the repository are sufficiently great that particular attention should be paid to identify potential bottlenecks and design against their occurrence. An important result of the pre-conceptual repository design will be the development of specifications for the particular equipment that will be needed.

6.0

DESIGN SAFETY FEATURES

Many safety features are described briefly in TM-36 and have been discussed further in this memorandum. Specific details of other important safety features are not covered in TM-36 and, in some cases as noted elsewhere in this memorandum, are not addressed at all.

Performance criteria such as maximum cage speeds and braking distances have not been addressed. The maximum rate of waste receipts is of the order of 30,000 canisters and 90,000 drums per year (Table 5-4 to 5-8). Such a rate would translate to an average of 45 trips per day or an average cage speed of about 500 feet per minute for the canistered waste. The risks associated with lowering a canister at such speeds have not been evaluated. The requirement for surge storage on surface and underground, based on such a rate of receipt have not been presented. It is unclear if the capacity of the two nuclear waste handling shafts will be adequate.

As a general comment, the safety features described have not been evaluated by any form of risk analysis and defense in depth has not been clearly demonstrated in critical areas.

7.0

DATA BASE

7.1 GEOLOGY.

Generic geological sections and structural data for the four geologic media have been developed from specific data for the corresponding major formations. A good attempt has been made to do this on a logical, consistent basis and we have not determined any major deficiencies in the process.

The concept of distilling a significant amount of geological variability into one "generic" geology inevitably leads to a loss of detail and reality. Thus, while the general stratigraphy may be acceptable, the presence of interbeds of limited thickness or other minor variations which may have an impact on detailed design criteria tends to be overlooked.

For overall thermal and thermo-mechanical analyses, this generalization may not be significant. However, we consider it important that the impact of geological variability on design criteria should be evaluated and we see no evidence in TM-36 that this has been done. It appears that little real use has been made of the geological data due to the absence of any detailed geomechanical design procedures.

7.2 BASELINE ROCK PROPERTIES.

A comprehensive review of the literature pertaining to the physical properties of the major formations of salt, granite, shale and basalt in the United States has been presented. In-situ physical property information and the results from studies of rock mass behaviour have not been presented. The large information base

on underground mining and construction in salt and in granite and other hard rocks that exists in the foreign countries should not be ignored.

The following rock parameters that are considered essential for the design of the repository have not been presented in TM-36:

- Rock mass classification indices
- R.Q.D.

7.3 GROUNDWATER MOVEMENT AND NUCLIDE TRANSPORT

TM-36/21 - Groundwater Movement and Nuclide Transport - specifically emphasizes the estimation of the following for repositories in granite, shale and basalt:

- Groundwater inflow into shafts and into the repository;
- Groundwater movements as affected by the repository heat load;
- Migration of radionuclides.

No estimation of the above items are provided for a repository in bedded salt under the presumption that bedded salt is an impermeable medium and, therefore, no groundwater flows through bedded salt are possible. No defense of this assumption has been provided. This is considered to be a serious deficiency of TM-36 particularly in the light of the conclusions that there is a possibility of significant radionuclide escape into the biosphere via groundwater flow paths in 400-600 years for repositories in granite, shale and basalt. Due to the presence of aquifers overlying the bedded salt mass under thermal loading, particularly with respect to the propagation of cracks and

dissolution, a few conductive fractures around the repository could cause migration effects of radionuclides through salt similar to those described for other media.

Since the repository would be constructed entirely within the salt layers, no inflow of water into the repository is expected to occur; providing the design and layout of the facilities eliminate the possibility of major shearing or rupturing through the ground to adjacent water-bearing strata (our emphasis). Since shears in the salt would be self-healing, this possibility is minimal.

It is our opinion that elimination of the possibility of shearing and water inflow has not been demonstrated in TM-36 by virtue of the repository design--due to the fact that no geomechanical analyses are presented. Also, while shears in salt may be self-healing, questionable anyway in the short-term, any shearing that occurs above the salt horizon may indeed allow water penetration to the salt. This could lead to salt solutioning. The adequacy of the repository design in this respect needs to be substantiated.

Results of the radionuclide mass transport studies in repositories in granite, shale and basalt indicate that 99 Tc and similar nuclides would exit at the three-mile boundary at unacceptable levels 400-600 years after repository decommissioning and resaturation. TM-36/21 states that since proper coupling of the groundwater and nuclide migration models with the thermo-mechanical analyses was not possible, a major uncertainty exists in the suggested allowable areal thermal loads presented in the preconceptual design studies (P. 9-2). It is suggested, but not proven, that more complete analyses of this complex problem will lead to lower areal thermal loads that would reduce or eliminate problems with migrating radionuclides.

Due to the deficiencies and interactions described above, the whole design of the repositories in the four geologic media are associated with considerable uncertainty.

It should be recognized that the three-mile limit of administrative control used in the computation of radionuclide discharge is an arbitrarily chosen figure. Analyses of radionuclide migration has been carried out using point estimates of parameters with little attempt to qualify or quantify confidence in the analytical results.

The methods of analysis and the models used to estimate the migration of radionuclides via groundwater have been described in Volume 21 but have not been reviewed by Golder Associates.

7.4 THERMAL ANALYSES.

7.4.1 Introduction.

Thermal analyses have been presented in Volume 19 and are used to provide predicted temperature fields for the following studies:

- Thermo-mechanical stress analysis;
- Convective heat removal;
- Effect of temperature on geohydrology and nuclide transport;
- Surface uplift;
- Effect on the waste package.

The remote possibility of induced diapirism has not been considered.

The limits to thermal loading are stated to be controlled by storage room stability and waste package integrity during retrievable storage. These are short-term, near field considerations. The long-term effect, including thermal uplift and impact on nuclide migration, are less significant.

The analyses consider the three important heat generating waste forms, reprocessed HLW (Cycle I and Cycle III), and spent unprocessed fuel (SURF, Cycle II).

7.4.2 Thermal Modeling.

The methodology used for thermal modeling has correctly identified two periods of interest (Volume 19, P.1-3). These are the short-term operational phase (near field models) and the long-term containment phase (far field models).

The near field models are stated to be primarily influenced by:

- Average waste emplacement density;
- Time-dependent heat generation rate
- Rock thermal properties
- Ventilation cooling effect
- Storage room and waste emplacement geometry.

These features have been incorporated into a room and pillar model, with boundaries several hundred feet above and below the

repository horizon. This is adequate for the time period of interest.

The far field models are stated to be primarily influenced by:

- Average waste emplacement density
- Average rock thermal properties
- Stratigraphy
- Time dependent heat generation rate
- Repository geometry.

In the near field models, details of the waste canister storage configuration and storage room geometry are explicitly modeled. The predicted near-field temperatures, however, are not affected in any significant extent by precise details of the waste containers and this simplifies the model.

In the far-field models, the volume of rock affected and the long-term period of interest are such that the waste can be adequately modeled as an average thermal loading represented by a thin disc at the repository horizon. Explicit repository details are not modeled.

a. Quantitative Models.

Assumptions and approximations that have been made are, in our opinion, quite acceptable and will tend to provide conservative analyses. Model boundaries are either sufficiently far removed to have no consequence during the time of interest or are explicitly modeled with adiabatic boundary conditions, i.e., no heat transfer across the boundary.

The numerical analysis has been made using two different heat conduction codes, TRUMP and HEATING 5. Both codes have been tested against a variety of problems for accuracy and are considered to be acceptable. Analytic solutions have been used as checks to the numerical solutions for the far-field case.

b. Waste Forms and Packaging.

The data base for waste form presented in TM-36/2 has been used. This appears to be complete and we can offer no further comment.

7.4.3 Near Field Calculations.

The objectives and methodology for near-field analysis appear to be clearly set out. One approximation that has been made is that the ventilation and convection in the storage room is neglected (Volume 19, p. 2-2). This is certainly conservative, since continuous ventilation of the storage room can be shown to remove significant quantities of heat. However, the present concept appears to be that storage rooms will be sealed as soon as waste placement is completed and would be reventilated for later access. This certainly reduces the ventilation requirements and is considered satisfactory provided that the allowable temperatures (as established by thermo-mechanical analysis) in the rock are not exceeded.

No work is presented to indicate the required cool-down time or the volumetric requirements to reopen storage rooms that have been sealed for up to 25 years (the retrievability period for SURF). In the event of an emergency condition, high temperatures in the rooms may delay retrieval.

It is stated that calculations were checked by varying mesh spacing and time steps until results were in agreement by less than five percent. Provided that the model code has also been checked for accuracy using simple problems (so stated), then this procedure seems to be acceptable.

Results of analyses using the 2-D and 3-D models have demonstrated that temperatures predicted by the 2-D model are in close agreement to those predicted by the 3-D model to within a few feet of the canister. This is considered acceptable for the near-field models and the 2-D procedure has generally been used for the analyses presented.

a. Results.

Selected results of near field calculations are presented. The temperature profiles predicted from this work were used as input to stress analyses to evaluate room and pillar stability throughout the retrievability period. Data presented are stated to most closely represent the limiting area thermal loading for each rock type. These limits are:

	<u>HLW & SURF</u> <u>(5 years)</u>	<u>SURF</u> <u>(25 years)</u>
Salt	150 kw/acre	36 kw/acre
Granite	190 kw/acre	80 kw/acre
Shale	120 kw/acre	55 kw/acre
Basalt	190 kw/acre	80 kw/acre

b. Thermal Criteria.

The above limits for salt were determined in earlier work for "similar formation stratigraphies" (3 & 4). The limits for other media were determined from linear thermo-mechanical analysis presented in TM-36/20.

A major area of confusion is the thermal analyses related to the choice of thermal criteria. The two factors to be considered are:

- The effect of increased temperatures on the room and pillar stability;
- The effect of increased temperatures on the waste and canister.

There is no clear discussion of the interrelationship of criteria for these two factors nor of the concepts of average areal thermal loading (kw/acre) and local thermal loading (kw/can) in terms of the temperature criteria.

Salt: It is suggested in TM-36/19 (p. 2-21), based on the supplementary benchmark analyses, that the specified limits for salt are probably conservative, citing predicted load limits of 158 kw/acre for HLW in salt. This limit is based on a criterion:

That less than 25 percent of the salt in the unit cell bounded by horizontal planes at the top and bottom of the waste never exceed 200°C.

This criterion seems to be an arbitrary choice, related neither to rock structural stability nor to waste form stability. We consider that this could probably be clarified by in-depth

evaluation of the data not presented in TM-36/19 and the cited references.

Using the same criteria for the repository described in TM-36, Vol. 19, Figure 2-1, the load limit varies from 140 to 180 kw/acre depending on canister separation. It is noted that there are some differences in the two repository models, notably in:

- Stratigraphy;
- Depth;
- Thermal decay rate;
- Room and pillar configuration.

We have not identified the precise nature of the differences.

It is our opinion that the "conservatism" of the data is not clearly demonstrated by the argument presented. The data is, however, generally compatible to that presented elsewhere (5).

The presence of low conductivity shale layers near to the waste canisters may be particularly significant. It is noted that the composite and generic stratigraphic sections TM-36 Volume 3, p. 2-12 and p. 2-13 (used for thermal analyses) are much, simplified compared with the specific example for the Salina Basin shown in TM-36 Volume 4, p. 3-11. We consider that the assumption of the 250-foot thick salt horizon with no interbeds of shale is unrealistic.

It is also noted that two different generic stratigraphies are presented in TM-36/3 for salt at less than 3,000 feet and less than 2,000 feet below surface. The latter was chosen for thermal analyses. No comparison is presented.

The conclusion is reached that:

. . . the particular description of the repository and stratigraphy will have a major impact and specific design considerations such as thermal loading limits may differ considerably from the generic values suggested.

While this statement is not clearly substantiated in the data presented, it does suggest that additional analyses using "archetype" basin stratigraphy should be made. We consider that this could usefully be incorporated with the second mock sitting study.

Granite, Shale and Basalt: The thermal limits that were derived from thermo-mechanical analyses satisfied a geotechnical design criteria that the ratio of pillar strength to pillar stress remained greater than two (V. 10, 12 and 14, p.1-6). Room stability was assured by requiring additional support if the ratio of stress to rock strength for a unit rock mass cube was less than two. While the analyses presented seems reasonable, the comparison of support requirements particularly for shale, with that used in the Azotea tunnel, the Oso tunnel and the Blanco Tunnel (V. 6, pp. 8-1 to 8-10) indicates a divergence between results from model studies and actual field practice.

7.4.4 Far Field Calculations.

Only a limited number of far field thermal analyses are presented for salt and reference is made to previous work completed (4).

The numerical modeling procedure used appears to be realistic and consistent with the nature of the problem. Temperature initialization has been used to develop consistent heat balance in the formation and includes surface effects.

An analytical model has been used for parametric studies in salt, considering only surface temperatures. We have not reviewed in detail the mathematical procedure. Typical surface temperature increase predicted for salt is less than 0.2°C after some 1,000 years. The comparison between numerical and analytical results presented appears reasonable, considering the parameter uncertainties and approximations.

We consider that the lack of data concerning far field temperatures in salt is a major deficiency in this work. The effect of increased temperature around the repository is of interest in the following:

- Thermally induced fracturing in the rock overlying the repository;
- Heat removal by overlying aquifers;
- Thermally induced movement around shafts.

These factors have not apparently been discussed either with respect to far field analysis or the near field analysis presented.

7.4.5 Convective Heat Removal in Salt.

The areal thermal load used to determine the canister emplacement configuration in TM-36/8 is based on the assumption that each storage room will be sealed following waste emplacement

The predicted local area thermal loads for PWR-SURF are (Table 5-1):

5 year retrieval	=	125 kw/acre
25 year retrieval	=	36 kw/acre

It is stated that these values will result in temperature increases in the surrounding rock that will not create significant instability in the storage rooms, thus allowing waste to be retrieved.

It has been demonstrated (TM-36/19, P. 4-1) that the local area thermal loading can be increased to 60 kw/acre while maintaining the 25 year retrievability option by providing a continuous flow of ventilating air to remove heat. Values of up 9,000 cfm have been calculated. This is generally in agreement with previous work by Golder (6).

The work presented in TM-36/19 does not, however, evaluate the risks associated with continuous ventilation. The question of whether SURF would, in fact, be buried at 190 kw/acre on the five-year retrieval option is debatable. The consequence of delaying retrieval by several years (for any number of technical/-political reasons) has not been assessed.

7.5 THERMO-MECHANICAL STRESS ANALYSIS.

Thermo-mechanical stress analysis studies have been done for shale, granite and basalt and the results are presented in Volume 20. This work includes the development of thermal loading guidelines and uses the results of the thermal analyses from Volume 19.

No stress analysis is presented for bedded salt, either in the form of results from previously completed work or as specific analyses of the preconceptual layouts shown in Volume 9. We are unable to determine, therefore, how the thermal loading guidelines for bedded salt were determined or how the stability of the openings in salt and shale media is to be assured for the required retrieval period. Other areas where data is lacking concern:

- Subsidence effects due to repository excavation;
- Surface uplift due to thermal loading;
- The effect of movement in the overlying strata on shafts and shaft linings;
- The effect of movement in the overlying strata on aquifers and potential leakage.

This is considered to be a major deficiency in TM-36.

7.6 FACILITY CONSTRUCTION FEASIBILITY AND COSTS.

The content of TM-36/18 is a collation of descriptive material from volumes 8, 10, 12 and 14. No attempt has been made to assemble the various design modules together to test the overall feasibility of each repository design.

It is not possible to comment in any detail on the capital and operating costs presented without knowledge of the data base from which they are derived. There is no reason, however, to believe that the costs presented are not of the right order of magnitude.

It would be an error to use the costs given in Volume 18 as a basis for a comparative evaluation of repositories in the four geologic media. Such a comparison would be unbiased only if the containment capabilities of each repository design were of the same order. This has not been demonstrated in TM-36.

Important cost items not addressed in TM-36/18 include:

- The cost of maintaining openings during the operating life of the repository;
- The costs associated with retrievability;
- The costs of sealing (isolating) panels;
- The costs of quality control and monitoring.

The unit costs associated with shaft sinking in the four geologic media given in Table 6-1 appear to be of the right order of magnitude. Since the reasoning for locating the repository at depths of 1,900 feet for salt, 2,200 feet for granite, 1,600 feet for shale and 2,100 feet for basalt have not been presented with reference to containment capabilities of the repository, it would be erroneous to make cost comparisons of repository performance by rock type.

Table 6-8 presents comparative unit mining costs by rock type. The unit costs are presented as dollars per ton. It would be preferable if the unit costs were presented as dollars per MTHM. Note that repositories in granite and basalt have twice as much storage capacity as those in salt and shale.

Support unit costs presented are:

Salt \$3.06/T;
Shale \$2.39/T;

Granite \$2.84/T;
Basalt \$2.50/T.

or in terms of storage capacity:

Salt \$243/canister;
Shale \$267/canister;

Granite \$280/canister;
Basalt \$323/canister.

It seems unreasonable that basalt and granite which have excellent structural characteristics should have higher support costs than shale and salt. Support in basalt and granite should be minimal. Support in shale has been stated in TM-36/20 to be ten foot friction type split set bolts on four foot centers with steel channels and mats. Support systems for salt have not been described and are indeed, an area of uncertainty, particularly during the retrievability period.

As a final comment, the cost figures presented in Table 6-1 through 6-9 are not considered adequate. It is not sufficient to provide overall lump-sum costs for a preconceptual design. The design is subject to changes and modifications and implementation of the final design is several years into the future. A precise breakdown into unit costs (per linear foot of drift or shaft for example) for each component such as mining, support, ventilation, maintenance, etc., would be more useful. The reader could then use the costs to estimate changes in cost due to design changes. A parametric analysis of costs would also be useful in that the sensitivity of costs to design changes or to uncertainties in basic assumptions could be determined.

REFERENCES:

- (3) Russell, J. E., 1973. "Areal Thermal Loading Recommendations for Nuclear Waste Repository in Salt." OWI/TM-37, draft, Oakridge. August, 1977.
- (4) Cheverton, R. D. and Turner, W. D. 1972. Thermal Analysis of National Radioactive Waste Repository: Progress Through 1972, ORNL-4789, 1972.
- (5) "Information Base for Waste Repository Design." NUREG/CRO459, Volume 4, March, 1979.

DEC 03 1979

UCRL 15177

Golder Associates

CONSULTING MINING AND GEOTECHNICAL ENGINEERS

November 29, 1979

University of California
Lawrence Livermore Laboratories
Post Office Box 808
Livermore, California 94550

Attention: Dr. R. Martin, L-390
Dr. H. F. Lutz, L-390

Re: Subcontract No. 8770703

Gentlemen:

Enclosed are some corrections and additions to our draft report "Review of Y/OWI/TM-36: Repository Design Performance in Salt, Granite, Shale or Basalt". They incorporate the comments on the report provided by Harry. This concludes Golder Associates' work on Tasks 19 and part of 15.

Sincerely,

GOLDER ASSOCIATES, INC.

Oscar B. Nair

OBN/cjr

Enclosure

cc: Ms. Lucy Cole, L-446

Other significant deficiencies of TM-36 may be summarized as follows:

- There is no provision made for iterative redesign (such as described by the flowchart in Figure 1). Redesign may be necessary due to changes in physical and hydrological properties of the repository environs caused by thermal and mechanical loading;
- There is no defense-in-depth of the multi-barrier concept of waste containment;
- No attempt is made to evaluate the performance of the proposed design with respect to the design objectives;
- The problems associated with retrievability and decommissioning have been ignored;
- No provision has been made to adjust layout and other design where adverse features are encountered;
- No provision has been made to prove or disprove assumptions of rock mass behavior prior to commissioning of the repository.

In general, we consider that the design procedure used for the preconceptual repository is not clear and lacks a logical, consistent argument. There is relatively little attempt made to evaluate the design, either in part or in total, in terms of the risks associated with nuclear waste storage, particularly the long-term containment aspects. It is frequently difficult to judge, therefore, the adequacy of the proposed design measures and safety features.

The maximum number of canisters that will be delivered to the repository during its life is of the order of 31,000 per year (Y/OWI/TM-36/2, Table D-1). This translates into an average canister lowering speed of 140 to 340 feet per minute depending on whether three shifts (6.5 hours per shift) or a single 8-hour daylight shift is used for canister lowering operations. It is not evident if these speeds are within the safety limits of the canister lowering operations. Given the seriousness of a possible accident in the canister waste shaft, maximum hoisting and lowering speeds, as well as maximum braking distances, should be specified. It is not possible therefore to comment on the adequacy of the braking mechanism described on Drawing F-41. In any case, it is felt that a level of redundancy should be built into the canistered waste shaft system by the inclusion of safety dogs or similar mechanisms that would be activated instantaneously in a free-fall situation.

3.1.2 Radwaste Storage at Stations.

The design of the surface facilities includes a temporary storage room nearby the shaft to hold nuclear waste containers during temporary hoisting delays. This is considered to be a high radioactivity area. We consider that routine shaft maintenance must be planned for requiring men to travel down the waste handling shaft. To minimize the potential exposure, it is, therefore, desirable that the temporary storage area should not be an integral part of the shaft station/headframe facilities.

Prudent design would include a temporary nuclear waste storage area near the canister waste and LLW shafts at the shaft bottom. Provision for the accessory services such as fire fighting, decontamination room, etc, should also be made in the shaft bottom area.

3.1.3 Main Power Supply.

All elements of the power supply system are discussed in Section 3.7.

The main objective in determining the mine layout, room geometry and thermal loading for a repository in salt is to limit room closure to acceptable amounts during the operational and retrievable phases of the repository while concurrently maintaining pillar stability. Room closure rates are affected not only by thermal loading but by the mine geometry as well. As an example, room closure can be reduced significantly by the use of barrier or buttress pillars to relieve overburden loadings on more narrow pillars. Although some localized overstressing of rooms and pillars will occur in salt . . . it is not anticipated that any support will be required except in isolated areas.

To our knowledge, the barrier pillar - yield pillar type of design is normally used in mines where it is desirable to increase the extraction ratio. Typical salt mine design practices (see Figure 2) are based on the theory that there is a transfer of load from the yield pillars to the barrier pillars if the span between buttress pillars is less than a critical value. A general rule of thumb is that the maximum span of the roof should not exceed the thickness of the overburden salt cover. (In the case of the repository, the span between buttress pillars will have to be less than the thickness of salt between the repository roof and the nearest overlying aquifer.) These design practices are uniquely related to mining requirements where openings need be kept open only for the length of time necessary to permit extraction.

It is our opinion that these design practices may not be applicable to repository design due to the requirements for long-term stability. An analysis of pillar stresses and expected short and long-term closures should be presented to support the design of the repository in salt. The expected room closures should include the effects of thermal loading of the pillars. The need for roof support is not clearly related to either over-stressing or structural weakness and the objectives, extent and type of predicted support should be specified.

b. Granite.

Detailed drawings of planned layouts are shown in Drawings F-25 to F-30, G-25 to G-30 and H-25 to H-30. The dimensions shown are generally compatible with conventional hard-rock mining experience. The layout concept appears to be one in which the storage area is divided into panels with each panel composed of a number of storage rooms. Successive panels are separated by 90-foot barrier pillars and rooms within the panel are separated by 60-foot pillars in the case of HLW, 25-foot pillars for ILW and CW and 30-foot pillars for LLW.

substantially threatened and long-term containment would be significantly reduced.

In our opinion the fundamental principles to be followed should be as follows:

- In the absence of conclusive evidence, from surface investigations, of geological reliability, an initial program of pilot development should be scheduled to cover the entire repository area prior to the commencement of emplacement.
- If the above is determined to be impractical, the repository should be designed as a series of individual unit areas. Each unit should be capable of being an effective sealer from the others and, in particular, any unit(s) in which active mining is underway should be capable of isolation from active storage areas.

In Volume 8, p. 5-2, it is stated that a "panel" concept will be used, each panel consisting of a number of storage rooms. The report does not, however, address the vitally important issue of the procedures for sealing one panel from another, to minimize the impact of adverse structural geology or groundwater, or even to control potential radioactive release via the excavation. The design and operation of the doors (seals) is likewise not presented.

The rooms within each panel are mined in the reverse sequence to the placement of canisters. Simultaneous mining and placing in the same panel are not permitted (Drawings A-19 and F-19). The differences in sequence creates a large delay between the completion of the mining of a panel and the initial placement operations in the panel. This delay could be minimized if the sequence of mining and placement were as shown in Figure 3. The development of separate airways for placement exhaust and mining exhaust on the perimeter of the repository would simplify the ventilation system and minimize the number of ventilation barriers that will need to be constructed. There will also be no need to build numerous ventilation barriers between the fresh airways and the mining exhaust airway and there will be no need for the exhaust overpass as shown in Drawings 19.

As a general comment, the report only briefly touches upon issues of progressive repository development and operation, which will certainly impact on the occupational risks. Repository development is an important and integral part of repository design and alternative schemes should be evaluated to minimize occupational risks.

Operational procedures to reduce damage to the host rock and thus improve the containment capability of the host rock have not been discussed in TM-36. It is unclear if the properties of the generic shale are such that weathering of the exposed surfaces during the retrievability period will not create serious stability problems. Due to the creep properties of salt and the weathering properties of shale, it may reasonably be expected that a considerable maintenance effort will be needed during the life of the repository in those media to keep the main corridors and the exhaust corridors open and safe for operations.

FIGURE 1 REPOSITORY PERFORMANCE EVALUATION METHODOLOGY

NOTES

1. Develop Preliminary Performance Model:

- (a) Compile all necessary parameters for input to performance model;
- (b) Develop analytical model to simulate behavior of repository within proposed geologic framework;
- (c) Perform sensitivity study on input parameters in the analytical model to determine which parameters have the most influence on the "performance" of the model;
- (d) Determine dependency between input parameters (if any), and methods to accommodate them during simulation;
- (e) Make initial estimates of stochastic descriptions of appropriate parameters for input to analytical model;
- (f) Make initial estimates of deterministic descriptions of appropriate parameters for input to analytical model;
- (g) Determine methods to incorporate uncertainty associated with proposed geologic framework and analytical model into simulation.

2. Prepare Site Investigation Plan:

- (a) Compile a list of appropriate measurement techniques for proposed location;
- (b) Develop plan of site investigation which maximizes the amount of useful data collected for a given investigative effort (Decision Analysis appropriate).

3. Adjust Performance Model:

- (a) Adjust stochastic descriptions of parameters as indicated by new data;
- (b) Adjust deterministic parameters as indicated by new data;
- (c) Review and modify analytical model if necessary.

4. I.e., Does the simulation of the repository result in an acceptable "risk of exposure curves"? This "acceptable risk" curve is viewed as initially relatively lenient. Later, as development of the repository continues it will be come more stringent until ultimately reaching the final requirements of repository performance guidelines.

FIGURE 2: LOADING PATTERN AND STRESS DISTRIBUTION IN BARRIER AND YIELD PILLARS.

FIGURE 3: PARTIAL PLAN MINING AND PLACEMENT VENTILATION

FIGURE 4 ALTERNATE SHAFT LOCATION PLAN

FIGURE 5
ALTERNATE SHAFT LOCATION PLAN