9. DESIGN FOR CARETAKER, RETRIEVAL, PERFORMANCE

9.1 CARETAKER OPERATIONS

The caretaker phase of the repository operation will begin when the last waste package is emplaced and will continue until activities begin to decommission and close the facility. Primary activities to be carried out during the caretaker phase are monitoring and maintenance of the facility and execution of the performance confirmation program. The length of the caretaker period is set by the lengths of the retrievability period and the waste emplacement schedule, as discussed below.

9.1.1 Previous Work

Little design activity has been directed specifically toward the caretaker phase since the beginning of repository advanced conceptual design in 1993. There appear to be no major technical issues associated with execution of the caretaker period, with the possible exception of the issue of the longevity of the facility itself. The duration of the caretaker period has increased from 26 years to 76 years as a result of a DOE decision documented in the *Civilian Radioactive Waste Management Program Plan* (DOE 1994b). This extended period will increase the likelihood of age-related failures of the tunnels and installed components, and will result in higher maintenance-related costs in the latter years of the caretaker phase.

9.1.2 Design Inputs

All text in this subsection is excerpted directly from the *Repository Design Requirements Document* (RDRD) (YMP 1994a), the reference source for repository requirements. Upper-level requirements from within the program (e.g., MGDSRD and CRD) and outside the program (such as 10 CFR 60 requirements) are included in the RDRD (YMP 1994a). The specific requirements from the document quoted below are considered applicable to aspects of the caretaker function. Other requirements from the RDRD (YMP 1994a), which may apply in a more general way, are not included here.

> 3.2.1.3 CARETAKER MODE REQUIREMENTS
>
> When the repository has reached its legislated or physical capacity for waste disposal, it will be in the caretaker mode. The option to retrieve any and all emplaced waste will be preserved from the time of emplacement for up to 50 years. Performance confirmation will continue during this mode.
>
> The GROA [geologic repository operations area] shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA [U.S. Environmental Protection Agency] as listed in Section 3.2.2.

NOTE: As discussed above, the period of retrievability has been extended to 100 years. Therefore, the length of the caretaker period has also been extended. Taken in conjunction with a 24-year waste receipt and emplacement schedule, this 100-year retrieval period sets the duration of the caretaker phase at 76 years.

9.1.3 General Description

As previously noted, the caretaker phase begins upon completion of waste emplacement operations. During the caretaker period, the surface waste handling facility will be in a "cold shutdown" or "mothballed" condition. The only surface facilities in continuous operation during the caretaker phase will be those supporting the ongoing operation of the subsurface facility.

Two primary functions will be ongoing during the caretaker phase: maintenance of the facility to provide access and preserve the retrievability option, and execution of the performance confirmation program. The performance confirmation program is discussed in Section 9.3, and the issue of access maintenance is discussed below.

9.1.3.1 Continued Access of Main Drifts

During caretaker operation, access to the subsurface facility will be maintained. This activity involves the continued operation of utilities such as the ventilation system, lighting, electric power distribution, pumping, monitoring systems, and personnel transportation systems. Maintenance of access also requires upkeep of the drifts themselves. Supplementary ground support may be needed occasionally, and some major re-work of portions of the main accessways will likely be required. It is anticipated that a schedule of regular inspections of the accessible portions of the subsurface facility (i.e., all drifts not containing emplaced waste) will be developed and executed. Results of these inspections will prompt maintenance as needed to preserve access to the facility.

During the caretaker phase, the ventilation system will be reconfigured so that only one fan system is used. (During the active simultaneous development and emplacement phases, two separate and independent systems are employed.) The intake airflow from the surface will come down the north and south ramps and the former development exhaust shaft, flow along the main drifts, and exit the underground up the emplacement exhaust shaft. This process will maintain the facility's ability to limit airborne radionuclide release via the standby HEPA filtration facility on the surface at the emplacement exhaust shaft. A figure showing the configuration of ventilation flowpaths for the caretaker period is shown in Section 8.7.

9.1.3.2 Continued Access of Waste Emplacement Drifts

The performance confirmation program, or other operational monitoring program, will provide the repository operator with input regarding the condition of the waste emplacement drifts. If unacceptable deterioration of portions of emplacement drifts is indicated by the monitoring program, remediation of those drift sections may be performed. This would involve cooling of the affected drift, removal of waste packages, and performance of the remedial activity.

Waste packages removed from an emplacement drift could be stored in an empty emplacement drift. It is anticipated that a small number of drifts, in addition to those minimally required to house the waste inventory, will be excavated and equipped for this purpose. The waste packages may be re-emplaced in the repaired drift, or left in the extra drift.

9.1.4 Summary

Very little design activity has been directed toward the caretaker period, primarily because no major technical uncertainties exist which are specific to this period, and because very little is known at this time about the requirements of the performance confirmation program. While issues such as gaining access to closed, heated emplacement drifts are of major technical interest, they are not specific to the caretaker phase. It is expected that, as performance confirmation issues become better defined, the caretaker phase will come into sharper focus, and specific requirements for this phase will be developed.

9.2 RETRIEVAL

The ability to retrieve any or all of the emplaced waste in the repository must be maintained for a period of time starting when the first waste package is emplaced and extending until the start of the closure operation. The length of the retrievability period is set at 50 years in 10 CFR 60. The DOE has extended this period of retrievability to 100 years from the emplacement of the first waste package (DOE 1994b).

A decision to retrieve the waste inventory could be prompted by either of two events:

- A loss of confidence in the site's ability to meet long-term performance requirements (cited in 10 CFR 60.111(b)(1))
- A determination that the recovery of valuable resources from the emplaced waste inventory is necessary.

The act of recovering the individual waste packages from the emplacement drifts will be discussed in this section.

9.2.1 Previous Work

Retrieval concepts developed for the potential repository at Yucca Mountain are extensively described in three CRWMS M&O documents briefly discussed below.

The retrieval of small waste packages from vertical boreholes located in the floor of each emplacement drift is discussed in *Alternatives for Waste Package Emplacement, Retrieval, and Backfill Emplacement* (CRWMS M&O 1993h). Among factors listed for normal retrieval were rock temperature, borehole condition, condition of the borehole liner, and radiation. Retrieval functions included access to the emplacement borehole, access to the waste packages, removal of the waste packages, and delivery of the waste to the surface facilities. Off-normal conditions that might impede retrieval were listed as a jammed isolation cover for a vertical borehole, jamming of emplacement and alignment rails and rollers caused by squeezing ground in the bored alcoves, derailing of the waste package carrier, and impacts on one or more waste packages due to ground failure. Possible causes were given as tectonics, variability in rock characteristics, human error, aging and corrosion of equipment and facilities, and radiolysis.

The concept of waste emplacement was changed from a small waste container emplaced in a vertical borehole to a large waste package emplaced horizontally in the emplacement drift as described in *Repository Retrieval Concepts and Operations Report* (CRWMS M&O 1994s). The large waste packages were changed to include either 12 or 21 PWR assemblies, 24 or 44 BWR assemblies, or some other combination for special wastes. The changes directly affected the emplacement drift opening size, waste package support apparatus, and radiation shielding/isolation of the overall underground layout. Three horizontal emplacement modes were discussed in this report including center-in-drift, off-center in-drift, and in-short perpendicular-alcove. A general operational approach for normal retrieval based on the three emplacement modes was prepared; it included identifying the reason for retrieval, beginning retrieval preparations, providing access to emplacement drifts, preparing emplacement drift, retrieving waste packages from emplacement drift, loading each waste package into a shielded waste package transporter, and transporting the shielded transporter and waste package to the surface. For abnormal (off-normal) conditions, additional steps were added that included assess nuclear safety, developing a retrieval plan, providing the required special equipment, implementing abnormal (off-normal) retrieval operations, and preparing emplacement drift to the extent allowed by conditions. Retrieval equipment and operations were general and programmatic in nature in this document and tended not to discuss specifics.

The largest bulk of current retrieval design was developed for the *Retrieval Conditions Evaluation* (CRWMS M&O 1995am). Design and operations in this document were based on the general layout configuration described in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a, Volume II) and an emplacement drift cross-section for a center-in-drift mode of waste emplacement. Specific operational sequence was given for normal retrieval while off-normal conditions and retrieval operations were more generally described. Only transporting equipment was described for normal waste emplacement and retrieval as the waste package car was shown to perform dual functions including that of transporter and support base. Special equipment for off-normal conditions was generally described as having grappling and shielding capabilities. These equipment and procedures have been largely carried forth through the advanced conceptual design.

9.2.2 Design Inputs

9.2.2.1 Requirements

Retrieval of waste packages, if required, will be conducted in accordance to the following requirements as given in the RDRD (YMP 1994a):

3.2.1.3 CARETAKER PHASE REQUIREMENTS

When the repository has reached its legislated or physical capacity for waste disposal, it will be in the caretaker phase. The option to retrieve any and all emplaced waste will be preserved from the time of emplacement for up to 50 years. Performance confirmation will continue during this phase.

The GROA [geologic repository operations area] shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA [U.S. Environmental Protection Agency] as listed in Section 3.2.2 of the RDRD (YMP 1994a).

3.2.1.4 RETRIEVAL PHASE REQUIREMENTS

The retrieval phase includes functions related to removing waste packages from the underground facility.

A. The repository shall be designed and constructed to permit the retrieval of any SNF [spent nuclear fuel] and HLW [high-level waste] emplaced in the repository, during an appropriate period of operation of the facility, as specified by the Secretary of Energy.

   This schedule applies to the first repository only. The CRWMS WA [waste acceptance] system element will begin accepting title to waste in 1998 and the disposal function will continue until all waste is disposed of (conceptually, in a second repository).

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

3.2.2.5 CRITICALITY PROTECTION

A. All systems for processing, transporting, handling, storing, retrieving, emplacing, and isolating radioactive waste shall be designed to ensure that a nuclear criticality accident is not possible unless at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety. Each system shall be designed for criticality safety under normal and accident conditions. The calculated effective multiplication factor must be sufficiently below unity to show at least a 5 percent margin, after allowance for the bias in the method of calculation and the uncertainty in the experiments used to validate the method of calculation.

3.2.2.2.2 REPOSITORY SEGMENT – ENGINEERED BARRIER SEGMENT INTERFACE

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

A. The Repository Segment provides systems and facilities in support of the functions and services shown in Table 3-6 [See Table 3-6 in the RDRD (YMP 1994a)].

B. The Engineered Barrier Segment outputs to the Repository Segment include heat [from nuclear waste], exhaust air, mechanical load, retrieved waste packages, and performance.

3. The Engineered Barrier Segment shall be able to withstand shock [TBD] and vibration [TBD] levels characteristic of handling, emplacement, retrieval and seismic environments, without adverse impacts on waste containment and isolation capability.

3.2.5.1 RELIABILITY

The Repository Segment shall provide a fault-tolerant (or fail-safe) system that allows for the continued management, handling, transfer, storage, emplacement, retrieval, and isolation of SNF [spent nuclear fuel] and HLW [high-level waste] in a safe manner that optimally protects health, safety, and the environment under all operational conditions. Nothing in this section shall be construed to indicate that NRC [Nuclear Regulatory Commission]-mandated redundancy of systems may be neglected.

3.7.4.1 WASTE HANDLING REQUIREMENTS

A. Waste Handling

4. The facilities and equipment used for waste-handling operations shall be designed so that waste-handling operations can be performed in reverse order to permit retrieval of emplaced waste packages.

3.7.5 REPOSITORY UNDERGROUND REQUIREMENTS

D. Retrieval of Waste. The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of 10 CFR 60.111.

E. Underground Openings

1. Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.

9.2.2.2 Assumptions

Retrieval may be necessary or required, as stated in the *Controlled Design Assumptions Document* (CDA) (CRWMS M&O 1995a), Key Assumption 016:

> The repository will be designed for a retrievability period of up to 100 years after initiation of emplacement.

9.2.3 Retrieval Description

Retrieval time, as required by the RDRD (YMP 1994a), will include the combined period to construct the repository and emplace the contained waste (YMP 1994a). Retrieval of all waste packages and other nuclear wastes is estimated to not exceed 34 years from the date of the directive to retrieve (CRWMS M&O 1994s).

9.2.3.1 Retrieval Under Normal Conditions

Waste package retrieval logistics under normal conditions will essentially be the reverse of waste package emplacement operations as described in Section 8.6.3.2.1. Access to the upper block emplacement drifts will be provided by the east and west service main drifts through which both emplacement and retrieval will be conducted. To remove waste packages from any particular drift, pre-retrieval and retrieval activities will be performed. Pre-retrieval activities will include initiating ventilation in the waste emplacement drift, confirming that no debris obstructs equipment operation, and monitoring drift temperature until it is within prescribed limits. Normal retrieval may be conducted simultaneously from the east and west service main drifts on both sides of the upper emplacement block. Approximately four weeks prior to retrieval, the shield door of the specified emplacement drift will be opened and cooling by ventilation will occur. Cooling for retrieval is discussed in Section 8.7.

Normal retrieval will be performed from both the east and west sides of the upper emplacement block and from the west side of the lower emplacement block while following a well-defined procedure as described below:

Travel to the Emplacement Drift – The retrieval locomotive will be placed atop a locomotive carrier and pushed by a transfer locomotive along the inside track of the service main drift to the turnout of a specific emplacement drift. The train will be parked while the track switch is changed to the closed position that allows the rail traffic to enter the turn. The transfer locomotive will push the carrier over the switch and around the curve. After the transfer locomotive has pushed the carrier into the curve, the switch in the service main drift will be changed to the open position so that rail conveyances following the emplacement train can pass the emplacement drift unimpeded. The carrier and transfer locomotive will continue through a second switch which will place the train on one of two parallel tracks that will be designated as the waste emplacement track. The train will continue until the rails on the locomotive carrier mate with the rails of the emplacement drift. As noted earlier, the shielding doors will be in the open position for cooling.

Removal of Waste Package from the Emplacement Drift – The retrieval locomotive atop the locomotive carrier will activate and move into the emplacement drift and travel through the drift to the first waste package in line. The retrieval locomotive will couple with the waste package railcar, deactivate the brake mechanism, and pull the waste package and railcar to the entrance of the emplacement drift where the waste package loading mechanism engages the railcar and secures it until ready to load into the waste package transporter. The retrieval locomotive decouples from the railcar and passes through the emplacement drift opening to the travel position on the locomotive carrier. The transfer locomotive, retrieval locomotive, and retrieval locomotive carrier leave the cross-cut area in the same manner in which they entered and move onto the track in the main service drift. The track switch is opened and the train proceeds past the cross-cut opening to allow entry of the primary locomotive and the waste package transporter.

Removal of the Waste Packages from the Repository – The primary locomotive will push the waste package transporter into the cross-cut drift, around the curve, and abut to the step-up of the emplacement drift where the braking mechanisms on both are activated. The waste package and supporting railcar are pulled forward by the waste package loading mechanism until the transporter's internal handling mechanism engages the waste package and railcar. Both are pulled into the transporter. The loaded waste package transporter is withdrawn from the cross-cut drift and pulled through the service main drift and up the north ramp to exit the repository.

The above steps are repeated until all waste packages have been removed from the emplacement drift.

9.2.3.2 Retrieval Under Off-Normal Conditions

9.2.3.2.1 Description of Potential Off-Normal Conditions

Off-normal conditions in the underground repository are the result of events that deviate from the predicted behavior of the repository host rock, engineered structures and facilities, or operations. Each such condition may be caused by natural or manmade processes that have performed unexpectedly, either as an event which has accelerated beyond expected deterioration rates or which has failed in a sudden, catastrophic manner. Potential off-normal conditions considered to most affect retrieval of waste packages are discussed below.

Deterioration of Drift Inverts Causing Track Failure – The drift invert is installed to support the rail, conveyances, and loads that will be associated with each emplacement drift. The combined estimated load of the railcar and largest waste package is 82.5 metric tons. Two alternative designs include an invert of crushed tuff or similar material that is dumped, planed, and compacted and an invert which is composed of cast-in-place concrete.

Deterioration of an invert of compacted fill will likely be a normal time-dependent process of settlement in which the track ties settle non-uniformly. Little if any settlement is expected to occur during the caretaker period, however. Deterioration of a concrete invert is expected to be generally a time-temperature-humidity process in which decomposition of the hydrated phases, deterioration of the aggregate, and thermal incompatibilities between the paste and the aggregate cause changes in concrete strength and elasticity. While the maximum predicted temperature at the drift floor for a thermal loading of 100 MTU/acre has been calculated to be about 170 to 179°C in 67 to 87 years after emplacement, appreciable deterioration of the concrete due to temperature alone is unlikely to occur as the compressive strength of concrete will be maintained up to about 300°C (CRWMS M&O 1995am).

9.2.3.2.2 Waste Package Removal During Off-Normal Conditions

Waste packages may be removed from emplacement drifts during off-normal conditions that may require extraordinary efforts to extract the waste packages. Suggested methods for waste package removal are discussed below.

9.2.3.2.2.1 Retrieval after an Emplacement Drift Rockfall

Rockfall is an off-normal event in an emplacement drift. The number and severity of rockfalls that may occur are tied to the frequency distributions of occurrence, location, and size of the rockfalls. While rockfall events are not currently definitive, the possibility that such events will occur mandates potential solutions to various resulting scenarios. These solutions are described in the preliminary procedures for various failure scenarios given below.

Unaffected Waste Packages – Ventilation will be established to provide a cooling airflow if air can pass through the emplacement drift to the exhaust drift following a rockfall. Normal recovery of all waste packages on the service main drift side of the rockfall will be performed when an acceptable re-entry temperature of about 50°C is achieved. The rockfall will be evaluated via mobile remote television arrangement or manned, shielded vehicle to assess required actions. The fallen rock and accompanying debris (bolts, mesh, steel sets, etc.) will be removed by remote-controlled equipment in a six-step process as shown in Figure 9.2.3-1. After the rockfall is cleared, the remaining waste packages can be removed. Ground control remediation can then proceed.

Covered Waste Packages – Ventilation will be established to provide a cooling airflow if air can pass through the emplacement drift to the exhaust drift following a rockfall. Normal recovery of all waste packages on the service main drift side of the rockfall will be performed when an acceptable re-entry temperature is achieved. The rockfall will be evaluated via mobile remote TV arrangement or manned, shielded vehicle to assess required actions. The fallen rock and accompanying debris (bolts, mesh, steel sets, etc.) are removed by remote-controlled equipment using care to separate the rockfall material from the waste package which will be buried amid the debris. If required, large boulders will be reduced in size as shown in Step 3 of Figure 9.2.3-1 and gathered in accordance with Step 6. Specialized equipment which is not shown may be used to recover waste packages from beneath large rockfalls which cannot be reached by the impact hammer or loader shown in Figure 9.2.3-1. Grappling eyes may be spot welded to the exposed end of the waste package or railcar by a remotely-controlled welder and the waste package is winched from beneath the rock. The waste packages will be then removed from the emplacement drift so that remote-controlled equipment can completely clear the track.

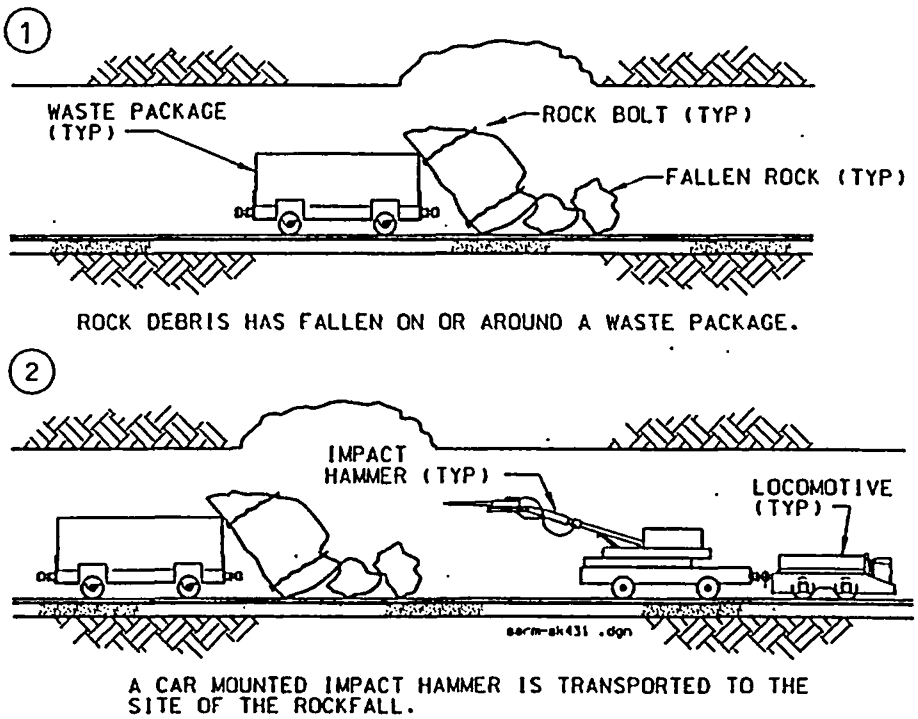


Figure 9.2.3-1. Off-Normal Retrieval Operation with Rockfall

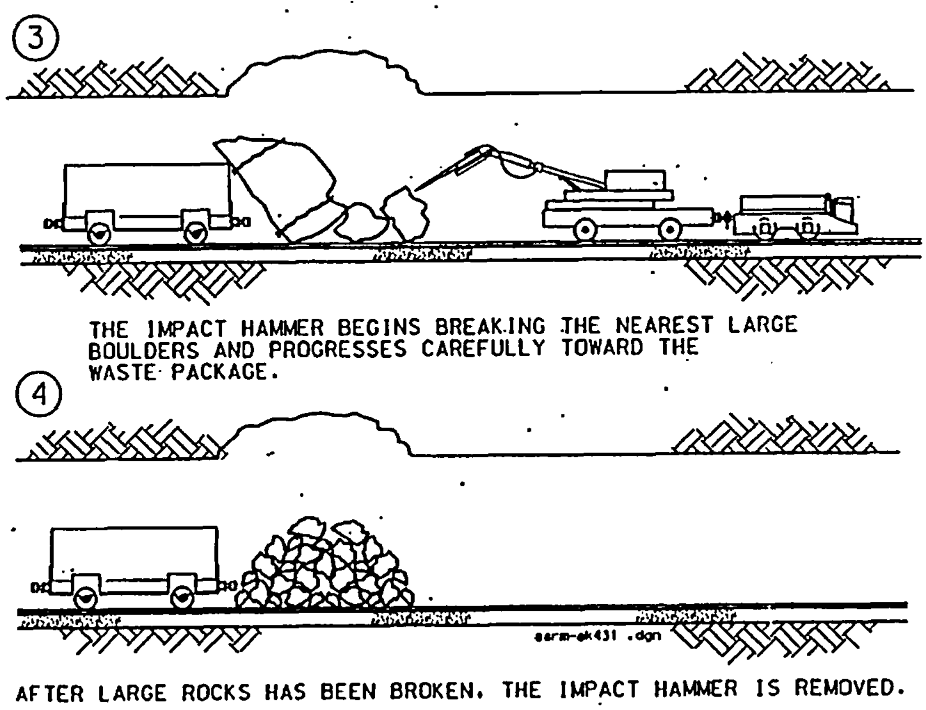
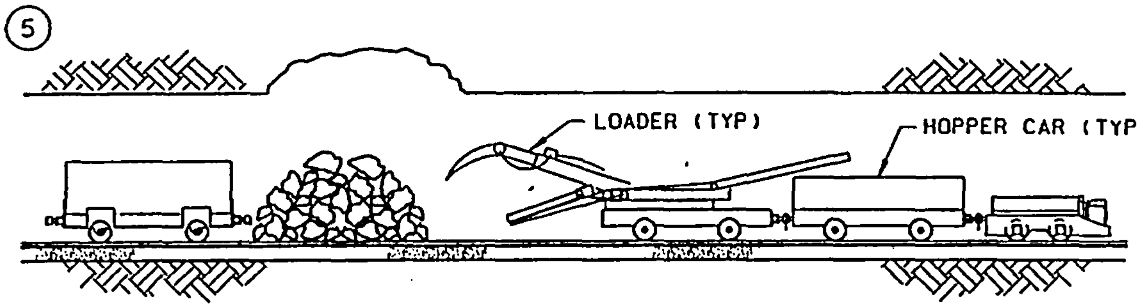
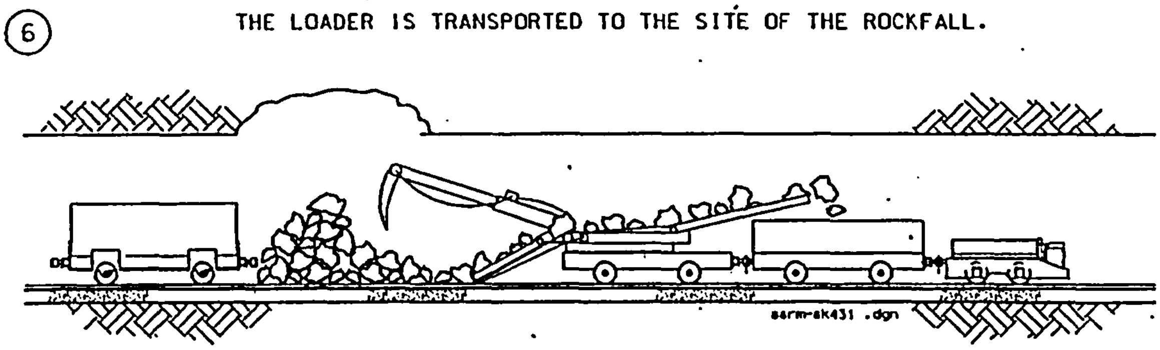


Figure 9.2.3-1. Off-Normal Retrieval Operation with Rockfall (Continued)



THE LOADER IS TRANSPORTED TO THE SITE OF THE ROCKFALL.



THE LOADER ARM SCOOPS RUBBLE ONTO THE APRON WHERE GATHERING ARMS FEED THE ROCK DEBRIS ONTO A CONVEYOR AND INTO A HOPPER CAR.

Figure 9.2.3-1. Off-Normal Retrieval Operation with Rockfall (Continued)

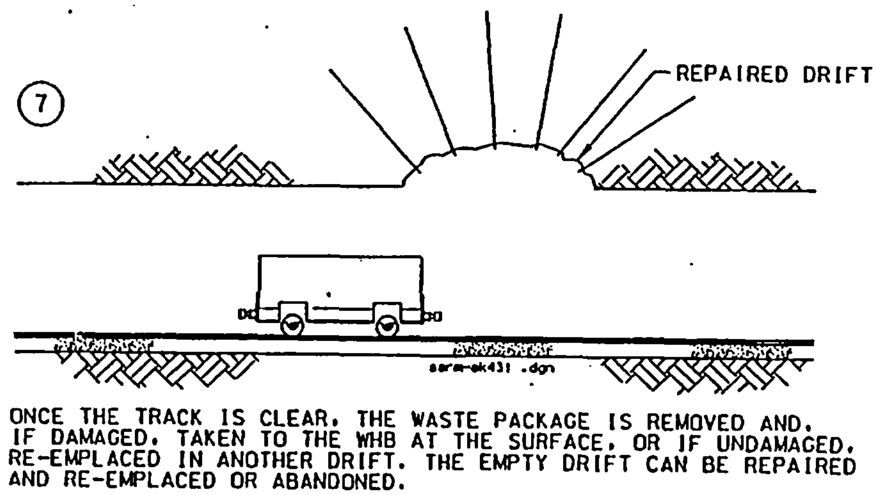


Figure 9.2.3-1. Off-Normal Retrieval Operation with Rockfall (Continued)

Blocked Airway – A portable fan will be placed in the tunnel boring machine launch main to pull air through tubing or a duct to the point of obstruction. The ventilation tubing will be added section by section as the drift cools. The tubing advance will be coordinated with waste package removal. As the area around a waste package is cooled, the waste package will be removed as described above. An additional section of tubing will be added as each waste package ahead of the rockfall is retrieved.

This method is likely to take longer than will be required for normal ventilation due to the limited amount of air that will be provided for cooling and the delay required to advance the tubing.

The rockfall will be evaluated and removed as previously described.

Breached Waste Package – The breaching of a waste package may occur as a result of partial or total crushing, penetration due to a shard forced into the interior of a waste package, or defects in the waste package. While such an event is very unlikely, the impact is so great on the subsurface operations that retrieval of a breached waste package must be addressed.

Detection of contamination anywhere in the subsurface will initiate an immediate decrease in air flow as high-efficiency particulate air filters begin to operate (see Section 8.7), cessation of subsurface activities, and evacuation of personnel. Remote monitoring will be conducted to determine the appropriate area or specific point of contamination before suitably protected personnel re-enter the repository to effect repairs. A considerable length of time may be required to locate the breached waste package or packages especially if the contamination detected is being carried in air leakage from a closed emplacement drift. After the contamination has been located, the affected drift will be cooled using the minimum air flow needed. Retrieval of unaffected waste packages will be performed while using remote monitoring to evaluate each waste package prior to recovery. When the source waste package is encountered, the rockfall debris will be pushed aside, if possible, so that the waste package can be retrieved before removing the rock. The damaged waste package will be pulled into a special transporter and moved to the surface waste handling building for special handling. The rock debris will be removed and the area around the waste package position cleaned of all contamination. All affected materials will be treated as contaminated waste products and disposed accordingly.

9.2.3.2.2.2 Retrieval After Damaged Rail System

A crawler-mounted, low-boy transporter will be used to pass over the damaged rail section, grapple and winch each waste package, and remove the waste packages individually from the affected emplacement drift until a sufficient number of waste packages have been removed to permit track repair by personnel behind shielding. Rail system damage due to rockfalls or package removal will be repaired by straddling the track, cutting away affected rail clips and joining splines (fish plates), lifting the damaged rail section, and replacing with a new rail section complete with rail, fish plates, and track bolts. After the track has been replaced, the remaining waste packages may be removed using normal procedures.

9.2.3.2.2.3 Retrieval With an Inoperative Railcar

A typical railcar may become immobile due to corrosion bonding of the wheels to the track or the inability of the wheel axles to turn in the bearings. Three progressive courses of action will be employed: the retrieval locomotive will nudge the railcar in an attempt to free the wheels; a second and/or larger retrieval locomotive will couple to the first locomotive which is coupled to the railcar and attempt to pull the railcar from the emplacement drift; and the car will be grappled and winched either onto a low-boy trailer or dragged from the drift if all else fails.

9.2.3.2.2.4 Retrieval With a Derailed Railcar

Spreading or misalignment of the track or seismic activity will be the probable cause of a derailed railcar. Severely damaged rail segments leading to the waste package will be replaced. Otherwise, a track mounted crane or robotic arm will approach the derailed waste package with a track rerailer and place the rerailer adjacent to the leading railcar wheel flange on each rail. An attachment with cable will mate with the railcar coupler and the entire railcar unit will be pulled so that the forward wheel flanges roll up the rerailer and onto the track. The entire car length will be slowly pulled past the rerailer to ensure that all wheels are securely on the track. The waste package will then be retrieved in accordance with normal operations.

A derailed railcar weighing to 81 tons (waste package and railcar combined weight) could likely require a greater tractive effort than may be exerted by emplacement or special application locomotives. For such an event, a special self-propelling conveyance with winch and anchor may be developed which will couple with the derailed car and pull the car up the rerailer by winching toward the anchor point.

9.2.4 Retrieval Equipment

9.2.4.1 Equipment for Normal Conditions

Equipment used for normal retrieval will be identical to those specific items identified for waste emplacement in Section 8.6.4. Retrieval equipment includes locomotives (waste package transporter unit, transfer unit, retrieval unit), carriers (waste package transporter, retrieval locomotive carrier, and waste package railcar), railcar mover, and loading/unloading mechanism. Equipment operation during retrieval of waste packages will conform to those procedures previously identified for waste emplacement.

9.2.4.2 Special Equipment for Off-Normal Conditions

Off-normal conditions as previously described will require specialized equipment that is maintained and readily available for events classified as off-normal. Functions to be performed include the clearing of rock debris, repair of damaged track, rerailing of waste package cars, removal of disabled railcars, and cleanup of released radioactive waste products from damaged containers. While the equipment to perform these functions has not been designed, the activities that certain special equipment might perform is described below.

To clear rock debris, equipment must be able to handle large slabs lying on waste packages as well as small boulder-sized pieces strewn about the track and waste package. A potential unit might include a long folding or retractable arm capable of extending over the top of a waste package. Attachments to that arm will include a detachable impactor for breaking, as shown in Figure 9.2.3-1, and/or a claw for grasping and pulling, which is not shown. Large boulders will be reduced in size by the impactor. Each attachment will be interchangeable. The unit will be rail-mounted. A second unit will have a gathering apron extending across the full width of the track to collect large rock debris and two articulating arms that reach out and pull debris onto the gathering apron. Rock debris, after being collected upon the apron, will be moved by a drag chain flight conveyor to a collection hopper at the rear of the unit. Only debris that impedes passage of rail conveyances needs to be removed.

To repair damaged track, tasks generally include tamping of ties (if compacted fill or ballast is used), jacking to lift rail and ties, distribution of ballast (invert material), lining of track, attaching rail to ties, and joining rail segments. In lieu of an overhanging crane that may not perform well due to the space constraints in underground openings, a crawler-mounted unit that straddles the track may be used. The track repair unit might include a rotating magazine for holding new rail segments, a track gauger, tie tamper, power jacks, ballast distributor, tie spacer, and bolt driver and tightener.

9.2.4.3 Remote Handling

Many off-normal retrieval conditions will require remotely controlled equipment to perform one or more various retrieval activities including removal of fallen rock and drift support appliances (if applicable), repair of damaged rail sections, rerailing of railcar and waste package units, dragging or lifting inoperative railcars and waste packages upon carriers, cleanup of spilled radioactive material from breached waste packages, and recovery and replacement of invert sections contaminated by breached waste packages. Equipment systems incorporating remote handling functions will include operator control stations, wireless communication networks, video monitors, and various sensing devices described in Section 8.6.5.

9.3 PERFORMANCE CONFIRMATION

Performance confirmation is a program of baseline data acquisition and ongoing monitoring that ensures assumptions made during the repository licensing process are correct and confirms that the repository system is functioning, and will continue to function, as it was presented at the time of licensing.

9.3.1 Previous Work

Requirements to guide the development of a performance confirmation program are not yet in place. For this reason, there has been very little design effort expended on performance confirmation program development. However, data are being collected, both from the Exploratory Studies Facility and the surface-based testing programs, that will provide much of the baseline information needed to initiate the formal performance confirmation program once it is developed.

A performance confirmation systems study is underway during FY 1996. The objective of the study report is to provide the technical bases for recommendations for performance confirmation program-related updates to the *Repository Design Requirements Document* (RDRD) (YMP 1994a) and/or *Engineered Barrier Design Requirements Document*, (EBDRD) YMP 1994c)(with primary emphasis on the identification of the important issues. The report will also contain an overview of the performance confirmation approach in the form of a draft *Performance Confirmation Plan.* This study is the first step in defining the requirements for the performance confirmation program.

9.3.2 Design Inputs

All text in this section is excerpted directly from the RDRD (YMP 1994a), the reference source for repository requirements. Upper-level requirements from within the program (i.e., CRWMS upper-level requirements) and outside the program (such as 10 CFR 60 requirements) are included in the RDRD (YMP 1994a). The specific requirements quoted below are considered applicable to aspects of the caretaker function. Other requirements of the RDRD (YMP 1994a), which may apply in a more general way, are not included here.

3.7.6 PERFORMANCE CONFIRMATION REQUIREMENTS

A. General Requirements.

1. The GROA [geologic repository operations area] shall be designed to include the capability to support tests appropriate or necessary (as determined by the NRC [U.S. Nuclear Regulatory Commission]) for the administration of the regulations of 10 CFR 60. These tests may include tests of

    a) radioactive waste,

    b) the geologic repository including its SSCs [systems, structures, and components],

    c) radiation detection and monitoring instruments, and

    d) other equipment and devices used in connection with the receipt, handling, or storage of radioactive waste.

2. Environmental monitoring equipment shall be provided to acquire baseline data for performance confirmation.

3. The tests required in Section 3.7.6.A.1 shall include a performance confirmation program carried out in accordance with Subpart F of 10 CFR 60.

4. The performance confirmation program shall provide data that indicates, where practical, whether:

   a) Actual underground conditions encountered and changes in those conditions during construction and waste emplacement operations are within limits assumed in the licensing review; and

   b) Natural and engineered systems and components required for repository operation, or that are designed or assumed to operate as barriers after permanent closure, are functioning as intended and anticipated.

5. The program shall include in situ monitoring, laboratory and field testing, and in situ experiments, as appropriate, to accomplish the objectives stated in Subpart F of 10 CFR 60 (3.7.6.A.2) above.

6. The program shall:

   a) Not adversely affect the ability of the natural and engineered elements of the geologic repository to meet the performance objectives.

   b) Provide baseline information and analysis of that information on those parameters and natural processes pertaining to the geologic setting that may be changed by site characterization, construction, and operational activities.

   c) Monitor and analyze changes from the baseline condition of performance of the geologic repository.

   d) Provide an established plan for feedback and analysis of data, and implementation of appropriate action.

7. The Repository Segment shall be capable of monitoring underground conditions and evaluating them against design assumptions.

B. Testing. During the early developmental stages of construction, a program of in situ testing of such features as borehole and access seals, backfill, and the thermal interaction effects of the waste packages, backfill, rock, and groundwater shall be conducted.

C. Rock Measurements. The Repository Segment shall be capable of measuring, as a minimum, rock deformations and displacement, changes in rock stress and strain, rate and location of water inflow into underground areas, changes in groundwater conditions, rock pore water pressures, including those along fractures and joints, and the thermal and thermomechanical response of the rock mass as a result of development and operations of the geologic repository.

D. Thermomechanical Response. The Repository Segment shall be capable of in situ monitoring of the thermomechanical response of the underground facility until permanent closure to ensure that the performance of the natural and engineering features are within design limits.

E. Laboratory Experiments. To support the waste package monitoring program required by 10 CFR 60.143(a) and (b), the GROA [geologic repository operations area] shall be designed to include facilities (to the extent appropriate for on-site work) capable of supporting laboratory experiments that focus on the internal condition of the waste packages. To the extent practical, the environment experienced by the emplaced waste packages within the underground facility during the waste package monitoring program shall be duplicated in the laboratory experiments.

F. Backfill Test. A backfill test section shall be constructed to test the effectiveness of backfill placement and compaction procedures against design requirements before permanent backfill placement is begun.

G. Borehole and Access Seal Tests. Test sections shall be established to test the effectiveness of borehole and access seals before full-scale operation proceeds to seal boreholes and accesses.

The CDA Document (CRWMS M&O 1995a) contains assumptions that are related to the Performance Confirmation Program that influence the design. These assumptions are Key 053, Key 054, and DCS 013.

9.3.3 General Description

As noted above, there has been essentially no design effort expended on performance confirmation, and no description of the performance confirmation program is available. The extent of the program, the types of data to be collected, and the collection interval needed remain largely unknown. As required by 10 CFR 60.72, records will be kept of conditions encountered during the construction of the repository. It is not known whether the acquisition of these data will be considered as part of the performance confirmation program or simply a required function of repository construction. 10 CFR 60.141 requires that the information acquired during repository construction and operation be utilized to confirm or provide the basis for change of the data which were used during the design and licensing of the facility. The evaluation of the data will be a central function of the performance confirmation program.

The program may or may not involve the periodic recovery of emplaced waste packages for inspection and/or testing. If all emplacement drifts required continuous monitoring, the operational impacts would be severe. However, if only selected drifts are continuously monitored, or if all drifts are monitored intermittently by mobile remote data acquisition units, the impacts to repository operations would be lessened. The approach will be consistent with the concept of operations that is shown in the CDA Document (CRWMS M&O 1995a).

9.3.4 Summary

As requirements are defined for the performance confirmation program, the questions of areal coverage, monitored parameters, and frequency/method of measurement will be better defined.

9.4 CLOSURE

The closure phase of the repository starts after the caretaker phase and retrieval phase (if required). Closure of the repository begins when the Nuclear Regulatory Commission amends the license to authorize permanent closure. During this phase of operation, portions of the underground facility will be backfilled and sealed. Surface facilities will be decontaminated and dismantled or converted to other uses. A protective system of physical and institutional barriers will be established (CRWMS M&O 1995a).

9.4.1 Previous Work

The closure design is currently limited and incomplete; previous work has provided only tentative goals and general methodology. The *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a) identified the need for backfilling and sealing of primary underground openings and discussed various general considerations including selection and placement of backfill materials.

Preliminary sealing and backfilling concepts for repository closure were developed in a program by Sandia National Laboratories. The work by Sandia has largely been consolidated in two publications which are briefly discussed below.

In *Initial Field Testing Definition of Subsurface Sealing and Backfilling Tests in Unsaturated Tuff* (SNL 1993c) Sandia identified and described several field tests to evaluate the performance of sealing components. These components included shaft, ramp, and borehole seals and associated fill; drift fill and seals; and Topopah Spring member host rock. Two sets of testing were proposed. In the first set, seal component testing was proposed that included small-scale in situ test, intermediate-scale borehole seal tests, fracture grouting tests, surface backfill tests, and grouted rock mass tests. This testing will be followed by performance confirmation testing and will include seepage control tests, backfill tests, bulkhead testing in the Calico Hills unit, large-scale shaft seal and shaft fill tests, and remote borehole sealing tests. In this 1993 publication, uncertainties associated with the sealing components emplacement and performance were summarized.

In *A Review of the Available Technologies for Sealing a Potential Underground Nuclear Waste Repository at Yucca Mountain, Nevada* (SNL 1994) Sandia discussed the results of a broad study of determining whether or not seals for shafts, drifts, and boreholes can be placed with reasonably available technology. The scope of the study was to review selected sealing case histories through literature searches and site visits, determine whether reasonably available technologies exist to seal a potential repository at Yucca Mountain, and identify any deficiencies in existing sealing technologies. The study concluded that available technologies or easily developed new technologies were adequate in four key areas and that adequate technology does not exist in two key areas. These areas are summarized as follows:

- Available Technology
  - Technology for placement of general backfill in underground openings. Under moderate temperature conditions that are below 38°C, off-the-shelf technology is available and is being routinely used in many operations. Backfill is also routinely placed and compacted on the surface to exacting specifications during civil construction.
  - Technology exists for the placement of large-scale bulkheads in underground shafts and drifts at moderate temperatures.
  - Technology exists to place grout in fractured rock masses at moderate temperatures.
  - Technology exists or could be easily developed to precondition areas where seal components are to be placed.
- Unavailable Technology
  - Technology does not currently exist to demonstrate the long-term durability and performance of seal components.
  - Case histories are not available that adequately document sealing component placement or performance under greatly elevated temperatures, high-radiation environments, and potentially unstable underground openings.

9.4.2 Design Inputs

9.4.2.1 Requirements

All text in this subsection is directly excerpted from the RDRD (YMP 1994a), which documents the requirements for repository design. Upper-level requirements from within the program (i.e., CRWMS upper-level requirements) and outside the program (e.g., 10 CFR 60 requirements) are included in this requirements document. The specific requirements quoted below are considered applicable to the closure aspects of the repository. Other requirements from the RDRD (YMP 1994a), which may apply in a more general way, are not included in this section.

> 3.1.1.3.4 MONITOR PERFORMANCE – FUNCTION 1.4.4.4
>
> This function includes planning for long-term monitoring of the performance of the geologic repository after it has been permanently closed.

3.1.1.4 CLOSE MINED GEOLOGIC DISPOSAL SYSTEM – FUNCTION 1.4.5

This function includes permanent closure of the repository to human access. This may include final backfilling of all or part of the underground facility (if deemed necessary by analysis and authorized by the license), closing and sealing openings (ramps, shafts, and boreholes), decommissioning surface facilities, reclaiming the site, and establishing institutional barriers. This does not preclude partial backfilling before permanent closure. This function begins upon approval of the license amendment for permanent closure and continues until the last institutional barrier is established and the license is terminated. Provisions may be added for post-permanent closure monitoring.

3.1.1.4.1 CLOSE UNDERGROUND OPENINGS – FUNCTION 1.4.5.1

This function includes final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement. It includes removing underground equipment, backfilling underground openings, and the sealing of shafts and ramps.

3.1.1.4.2 DECOMMISSION SURFACE FACILITIES – FUNCTION 1.4.5.2

This function includes the permanent removal from service of surface facilities and components (necessary for preclosure operations only) after repository closure, in accordance with regulatory requirements and environmental policies. It includes decontaminating, dismantling, and removing facilities and reclaiming the site.

3.1.1.4.3 ESTABLISH INSTITUTIONAL BARRIERS – FUNCTION 1.4.5.3

This function includes establishing active and passive institutional controls for restricting access and avoiding disturbance to the MGDS controlled area and minimize or prevent intentional and unintentional activities in and around the MGDS that could breach the barrier systems for at least 1,000 years.

3.1.1.4.4 RECLAIM SITE – FUNCTION 1.4.5.4

This function includes actions taken to restore the MGDS site to as close as practicable to its original undisturbed condition.

3.2.1.4 RETRIEVAL MODE REQUIREMENTS

C. The GROA [geologic repository operations area] shall be designed so that until permanent closure has been completed, radiation exposures, radiation levels, and releases of radioactive materials to unrestricted areas will at all times be maintained within the limits specified in 10 CFR 20 and applicable environmental standards for radioactivity established by the EPA [U.S. Environmental Protection Agency], as listed in Section 3.2.2.

3.2.1.5 CLOSURE AND DECOMMISSIONING MODE REQUIREMENTS

When the NRC [U.S. Nuclear Regulatory Commission] amends the repository license to authorize permanent closure, the underground facility will be backfilled (if required and authorized) and sealed; the surface facilities will be decontaminated and dismantled or converted to other uses.

The final state of the GROA [geologic repository operations area] shall conform to plans approved as part of the license for permanent closure and decontamination and dismantlement of surface facilities.

3.2.1.6 POSTCLOSURE MODE REQUIREMENTS

This mode begins at permanent closure and includes the isolate waste function and any residual functions such as maintaining the institutional barriers and performance confirmation.

A. The repository shall include facilities with the capability of implementing a post-permanent closure monitoring program in accordance with the application to amend the license for permanent closure.

B. The repository shall identify the controlled area and the GROA [geologic repository operations area] by monuments that are designed, fabricated, and emplaced to be as permanent as practicable.

C. The disposal system shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table A-1 of Appendix A of 40 CFR 191; and have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table A-1 of Appendix A of 40 CFR 191. [TBR]

D. Facilities shall be provided to support active institutional controls at the repository site, including physical barriers to human intrusion and maintenance facilities. [TBV]

NOTE: CDA (CRWMS M&O 1995a) contains clarifying language for this requirement (RDRD 3.2.1.6.D)

3.7.4.4 OTHER SURFACE FACILITIES

L. Decontamination and Dismantlement.

1. Surface facilities shall be designed to facilitate decontamination or dismantlement to the same extent as would be required, under other parts of NRC [U.S. Nuclear

Regulatory Commission] regulations, with respect to equivalent activities licensed thereunder.

2. The SSCs [systems, structures, and components] shall include features that will facilitate decontamination for future decommissioning, increase the potential for other uses, or both.

3.7.5 REPOSITORY UNDERGROUND REQUIREMENTS

J. Seals.

1. Seals for accesses and boreholes shall be designed so that following permanent closure they do not become pathways that compromise the geologic repository's ability to meet the performance objectives for the period following permanent closure.

2. Materials and placement methods for seals shall be selected to reduce, to the extent practicable, (a) the potential for creating a preferential pathway for groundwater to contact the waste packages; or (b) for radionuclide migration through existing pathways.

3. The seals for accesses and boreholes shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to applicable environmental standards for radioactivity established by the EPA with respect to both anticipated processes and events and unanticipated processes and events.

3.7.6 PERFORMANCE CONFIRMATION REQUIREMENTS

G. Borehole and Access Seal Tests. Test sections shall be established to test the effectiveness of borehole and access seals before full-scale operation proceeds to seal boreholes and accesses.

6.1 GLOSSARY

Decommission means to remove (as a facility) safety from service and reduce residual radioactivity to a level that permits release of the property to unrestricted use and termination of license.

Permanent closure is final backfilling of the underground facility and the sealing of shafts and boreholes.

9.4.2.2 Assumptions

Permanent closure of the repository begins after the completion of emplacement of all scheduled radioactive waste and after a specified waiting period during which retrieval is possible in accordance with the MGDS Concept of Operations in the CDA.

Surface decommissioning includes decontamination, dismantlement, facility removal activities, and site reclamation. Institutional barriers include land records and warning systems that will be placed around the repository site to prevent human disturbance.

Subsurface closure involves removing underground equipment, backfilling of main drifts, sealing, and implementing a postclosure monitoring system to serve the performance confirmation program. If backfilling of emplacement drifts is to be performed, the closing process will start with cooling of the emplacement drifts for inspection. Drift inspection may include repairing ground support systems if deemed necessary.

9.4.3 Backfill and Sealing

Backfilling is currently planned as part of the activities associated with closure of the repository. Backfilling as set forth in the CDA will be performed throughout the ramps, shafts, and main service drifts.

Backfilling will be a part of the sequence of closing subsurface openings which involves removing underground equipment, preparing the main openings to receive backfill, backfilling the main openings, emplacing repository seals, and implementing postclosure monitoring (if required). Items to be removed prior to backfilling will include equipment, rail, utilities and support services, and unsuitable materials. Many of these items will be needed to support backfilling and sealing operations. In addition, certain utilities and support items, such as ventilation duct, will be temporarily installed during backfilling and sealing and will be removed when no longer needed. Preparing the openings to receive backfill includes installing utilities and equipment specifically dedicated to backfill operations.

Seals will be placed only in the ramps, shafts, and boreholes in accordance with the MGDS Concept of Operations in the CDA. The seals will be strategically located to lessen radionuclide migration over extended time frames, will likely be integrated with closure backfilling in accordance with the CDA, and will be bracketed by the backfill. Placement of seals will involve preparing the underground openings to receive the seals, obtaining and transferring seal material, and constructing the seals.

Emplacement of backfill and seals will likely be performed in a series of parallel operations commencing with backfilling of the main service drifts adjacent to the waste emplacement drifts in the lower block and continuing through closure of shafts and ramps. Because backfilling will be a retreating operation, material will be stowed at the extremities of the repository and progress back to the surface openings while maintaining sufficient access and ventilation to maintain personnel and equipment. Initially, the established ventilation base for the caretaker period will be modified as main drifts are plugged so that ventilation will eventually be provided to working headings through ducts.

9.4.3.1 Backfill Transportation and Handling Equipment

9.4.3.1.1 Surface Backfill Handling

Backfilling as described in the CDA involves the full range of activities from obtaining material from the surface stockpile or other source, processing (screening, crushing, and possibly, washing) to obtain the required grading, placing the processed material into a stockpile for subsequent loading, and transferring the material to the openings for placement (CRWMS M&O 1995a). Design relating to backfill surface facilities has not been prepared due to several unspecified factors including the unknown amount of material degradation and settlement following a 100-year storage period, the undecided choice of using a single or multiple component fill material, and the unknown required backfill emplacement rate. Surface equipment will include loading, hauling, and processing equipment as discussed in Section 8.8.4.1. This equipment is common for both backfilling of emplacement drifts (if required in the future) and of main drifts and ramps.

A secondary concern of using TSw2 tuff excavated from the repository is the potential of reintroducing the excavated rock enriched with organic and inorganic nutrients after 100 years of surface exposure that might support and nourish various species of microorganisms capable of promoting waste package corrosion. In addition to the possible removal of deleterious fines, washing plus chemical treatment may be considered to render the backfill material sterile to microbial use.

Haul trucks will be used to transport backfill material to the shaft sites which will be located in the rugged terrain upslope.

9.4.3.1.2 Underground Backfill Handling

Backfill material will be transported underground by open gondola railcars as discussed in Section 8.8.4.1.

Backfilling will likely be performed in multiple locations to reduce the required time. Approximately 2.6 million cubic meters of material will be required (as shown in Table 9-1) in the service main drifts, shafts, and miscellaneous underground excavations. Backfilling will be conducted simultaneously in both shafts and at two underground locations. Two or three backfill units are the probable number that can be operated and maintained on a routine basis. To supply these locations, two transfer points will be installed to unload gondola cars and to load stower supply cars.

Table 9-1. Required Backfill Volume for Closure

Excavation	Drift/Shaft Length (m)	Required Fill Volume (m^3)
9.00-m diameter tunnel boring machine	11,350	684,000
7.62-m diameter tunnel boring machine*	21,730	906,000
Mobile miner	22,770	960,000
Drill and blast	80	5,000
Shafts	700	25,000
Total		2,580,000

* Includes excavation performed for ESF

9.4.3.2 Backfill Placement Equipment

9.4.3.2.1 Backfill Stowing Equipment Description

Pneumatic stowing is currently the preferred method to emplace backfill material in the service main drifts and ramps as well as around ramp seals due to the large volume of material that can be moved, the potential for completely filling the drift, the shorter time required to emplace material, and the operational flexibility to handle the unexpected which this method affords.

Pneumatic backfilling is a means of transporting dry solid material through a pipeline while suspended in compressed air and placing that solid material into a void, excavated or natural. A preferred stowing arrangement, as shown in Figure 9.4.3-1, will be to mount the stower and material feed equipment on railcars entrained with a material supply car or supply cars and locomotive. While backfilling, the stower car and one supply car may be positioned at the site of backfilling while another supply car is shuttled by the locomotive back and forth to a material feed storage pile. This equipment precludes the use of long pipeline runs and provides the flexibility to move throughout the repository and backfill at several widely scattered locations. Should rail and other manmade materials be removed prior to backfilling, stowing equipment will be mounted on either crawler or steel tire units.

The pneumatic backfilling system shown in Figure 9.4.3-1 will include an air compressor or blower, stower, hydraulic drive unit, electrical power feeder and switchgear, material receiving hopper, and pipeline. An informal survey of various field operations and literature sources of former backfilling applications performed in the 1970s and 1980s show the following:

- The blower size ranged from 110 to 630 kw at sea level, 300 kw being most common, and produced between 1.4 to 2.8 m^3/s air flow, 1.9 m^3/s being most common. Air pressure at the blower ranged from 55 to 100 kPa with a pipeline operating pressure of 28 to 34 kPa. The blower speed varied between 1,600 and 2,300 revolutions per minute (rpm).

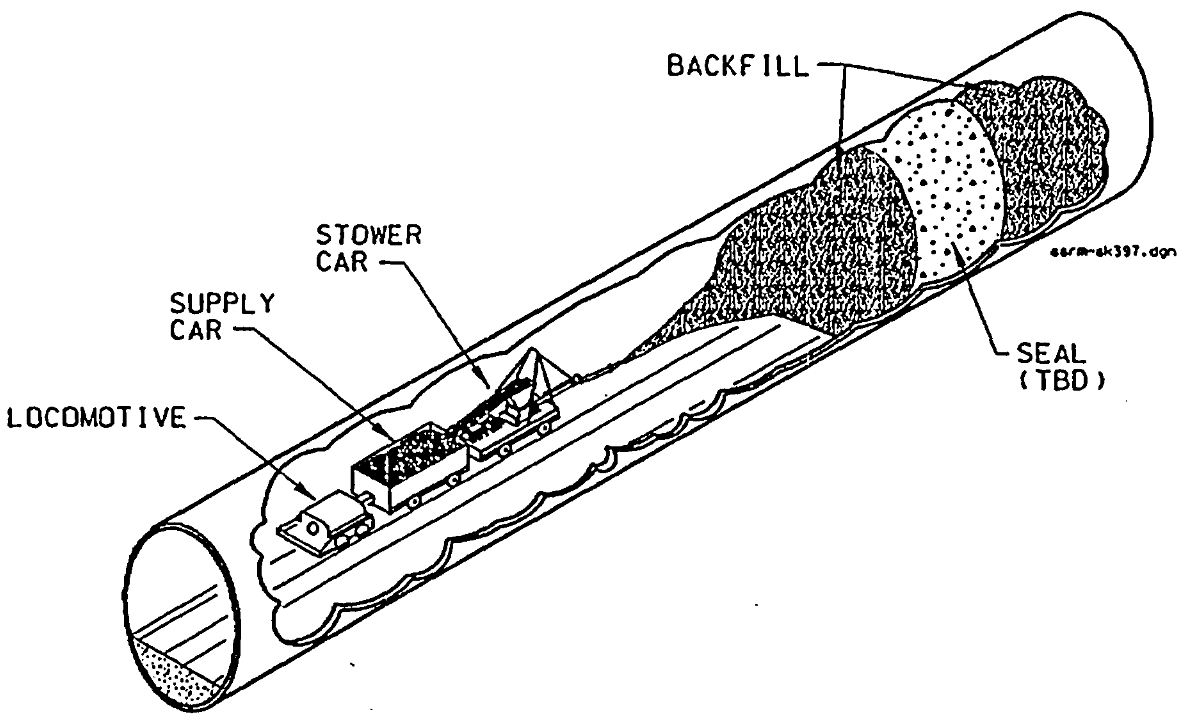


Figure 9.4.3-1. Pneumatic Backfilling at Closure

- Pipelines included both 20.3 and 25.4 cm nominal diameter pipe of schedule 40 and 80 steel construction, rubber-lined light-duty construction, and fiberglass construction were used.

- Piping arrangements included vertical drops of up to 610 m and horizontal runs to 610 m, though plugging problems became excessive in some cases when horizontal pipeline lengths exceeded 370 m.

The central component of the typical industrial pneumatic backfilling system is the stower. The stower is a large rotary air lock that introduces coarse abrasive materials into a fast moving, low pressure airstream. Eight compartments are formed by elongated plates mounted to a central shaft that turns within a curved, tight-fitting case. The bottom of the stower is vertically-elongated, forming an enclosed trough through which compressed air flows. Fill material is dumped into the top open-to-the-air compartment and is carried into the base compartment. The tight fit of the rotor to the casement prevents compressed air from escaping. Once suspended, the material is conveyed through a pipeline connected to the bottom of the stower. Most of the pneumatic backfilling systems surveyed on an industry-wide basis used long pipelines to distribute the material. The mobile system shown in Figure 9.4.3-1 essentially removes the pipeline which is expensive and subject to plugging by using a relatively short pipe to aim the backfill at the point of emplacement. The pipe snout is swiveled and elevated to completely sweep the opening cross-section for complete drift filling.

9.4.3.2.2 Backfill Stowing Quality Control

Loose, dry, rocky, or sandy material when stowed pneumatically produces a backfill that may only be partially adequate as an engineered barrier to radionuclide migration. Two conditions can develop including failure to completely fill the drift and settlement of the backfill which can potentially create air gaps along the fill. Pneumatic backfilling tends to produce piles with steeply sloping sides. The material is shot from the end of the pipeline at high speed and impacts causing some compaction which tends to produce a higher internal angle of friction than would be produced by a dumping application. The material accumulates along the line of the trajectory from the end of the pipeline to the point of surface contact with little lateral dispersion. Unless the point of discharge is aimed upward or aimed from side to side, the backfill material will not pile evenly to the top of and across the drift. Pneumatic backfilling generally does not completely fill an underground void during regular mining operations because insufficient time is usually allotted to fill, shut down for examination, reposition the discharge nozzle, and start up several times until the void is completely filled. Severe dusting during pneumatic backfilling obscures vision and precludes continuous monitoring of the stowing activity. In spite of the difficulties, very little void space remains if care is taken to shut down and reposition the discharge nozzle.

The general backfill is expected to settle naturally over a period of time after emplacement, which can be greater after the occurrence of one or more seismic events at the repository site. It has been suggested that settlement will be less than 10 percent of the total height (SNL 1994).

9.4.4 Shaft and Ramp Seals

Shaft and ramp seal design has been delayed due to incomplete information concerning site characterization and the performance of possible seal components. Backfill will be emplaced on both sides of each shaft and ramp seal as assumed by the MGDS Concept of Operations in the CDA. Figure 9.4.3-1 shows that pneumatic stowing will be used to emplace the backfill which brackets the seals and fills the main drifts. The backfilling that accomplishes these functions and the potential backfill which may fill the emplacement drifts (if required) may need varying compositions and behaviors when further study is completed. The dumping method of backfilling discussed in Section 8.8 and the pneumatic method of backfilling discussed in Section 9.4.3.2 may be supplemented by a third, undesignated method that provides a backfill-to-seal interface that may not be available with application of the other two methods. Without a further definition of what sealing is to accomplish, seal design cannot be developed beyond the most preliminary stages.

The backfill described in the above subsections of Section 9.4 relates to bulk fill which is applied at a high rate to reduce the emplacement time, achieves low compaction, and has fair to moderate contact with the surrounding rock. Drift seals may require direct contact with a backfill which meets a higher level of quality than may be provided by bulk filling techniques. Principal uncertainties concerning seals include the method of seal construction, composition of seal materials, nature of the interface between the backfill and seal, and characteristics of the backfill.

Following a literature search and number of field visits, Sandia National Laboratories compiled a number of applicable seal geometries that may be applicable to the repository (SNL 1994). The terms "bulkheads," "plugs," and "seals" are used synonymously by Sandia and will be also used in this report. The seals included inundation plugs, hydraulic fill containment bulkheads, abandonment bulkheads, and consolidation plugs and are briefly described as follows:

- Inundation plugs may be installed in shafts, ramps, or drifts to protect from sudden inflows of water. Inundation plugs must often withstand very large pressures and are usually designed for full hydrostatic head to the water table at the site of the operation.

- Hydraulic fill bulkheads are used to retain backfills that having been stowed as a slurry, are held in place during drainage or decanting of the water until the moist backfill has consolidated.

- Abandonment bulkheads are installed to seal off abandoned underground excavations to minimize pumping and/or ventilation requirements. Such bulkheads are designed to withstand hydrostatic pressure in wet conditions and are designed to be explosion-proof in gassy conditions.

- Consolidation bulkheads are used to provide a protection barrier behind which grout curtains can be installed. Consolidation bulkheads may be constructed in a shaft to provide a stable platform upon which inclined, vertical grout holes may be drilled or constructed at a drift heading to maintain the structural integrity of the rock face during grouting through inclined, horizontal drill holes. Such bulkheads are designed to withstand specific hydrostatic limits.

- Conversion bulkheads have been identified for use where an underground excavation has been adopted for gas storage. The construction of the seal includes multiple components incorporated into a complex geometry for minimizing leakage. The case studies found by Sandia also included an oil-filled annulus.

Clearly, some of the seal types given above may not be adequate for repository application on the basis of gaseous or liquid permeability. Variations of the inundation plug and conversion bulkhead may be the most applicable for sealing the repository if permeability becomes an issue due to their higher likelihood of providing impermeable seals.

Basic seal shapes for any application are parallel-sided, arched, or tapered. Parallel seals may be optionally keyed into the surrounding rock, while arched and tapered seals are inherently keyed. The preparation of a keyway will require an over-excavated section at a typical shaft or ramp seal location. Preparation of a keyway requires more preparation and materials than unkeyed seals. Various rock-connected and nonrock-connected construction options are available as shown in Figure 9.4.4-1. As shown in Part a) seals of single composition are keyed into the rock in different arrangements which are designed to couple the seal with the host rock to resist leakage. While leakage may occur through the seal, along the interface between seal and host rock, or through the host rock only, the seal geometries in Part a) of Figure 9.4.4-1 are used when potential leakage through these three pathways is reduced to insignificance. More elaborate seal construction as shown in Part b) of Figure 9.4.4-1 may be used in nonrock-connected situations. Single component seals may be installed as shown in Figure 9.4.4-1 or in multiple component seals as shown in Figure 9.4.4-2.

The seal shown in Figure 9.4.4-2 is a typical nonrock-connected structure in which multiple components interact with fluid intrusion along the seal and host rock interface to minimize leakage. For such seals, specific components are selected for their capability to interact with other components, the intruding fluid, and the host rock.

The development of seal design will likely concentrate on the behavior of potential seal materials and the host rock and the ability to emplace these seals to meet future requirements.

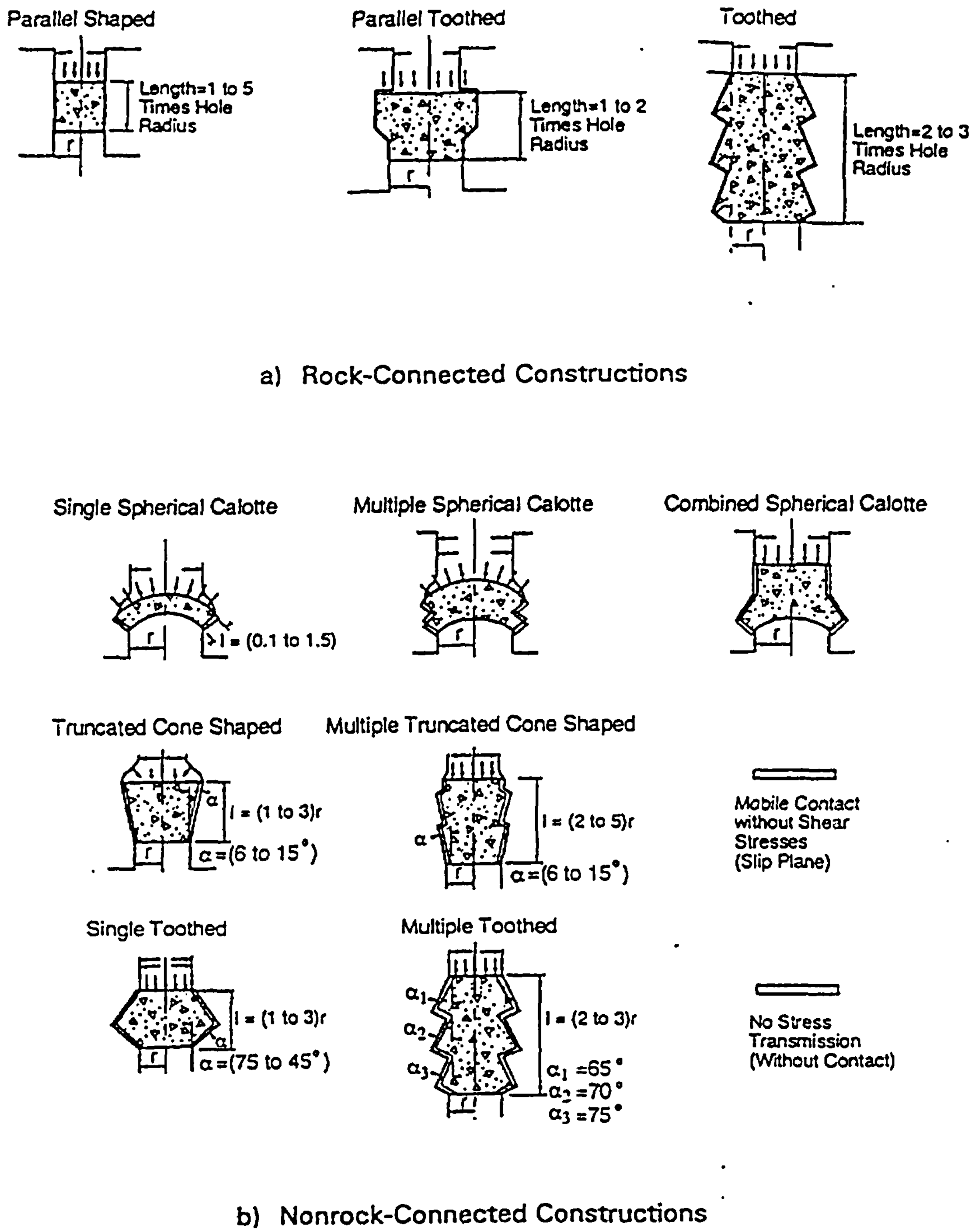


Figure 9.4.4-1. Seal Geometry Alternatives

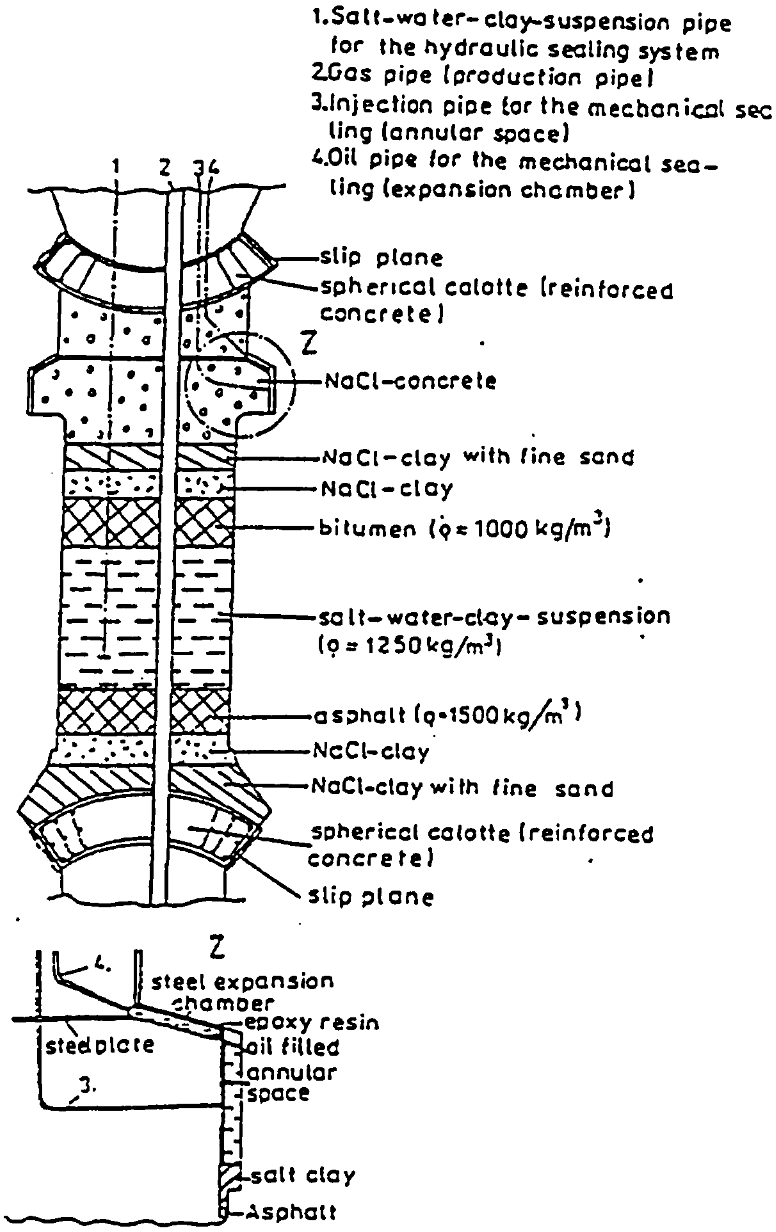


Figure 9.4.4-2. Typical Composite Seal Structure

10. SAFETY DESIGN

10.1 PRELIMINARY DESIGN BASIS EVENT HAZARDS ANALYSIS

10.1.1 Introduction

10.1.1.1 Purpose

This section identifies a list of possible hazards associated with the repository advanced conceptual design (ACD) and provides a preliminary qualitative analysis of the related radiological safety risks. It also documents a process by which the list of hazards is screened to define a list of credible, limiting Design Basis Events (DBEs). The DBE list defines the scope of future detailed quantitative DBE analyses. A preliminary assessment of the repository ACD capability to withstand DBEs is also provided.

Although the level of detail of this section is necessarily different from that of the *Waste Package Off-Normal and Accident Scenario Report* (CRWMS M&O 1996c), the *Preliminary MGDS ACD System Safety Analysis* (CRWMS M&O 1996b), and the two specific analyses (rockfall and criticality) in Volume III, Section 7, of this report, all share the same Preliminary Hazards Analysis, Preliminary Hazards Lists, event screening criteria, and basic assumptions. For this reason, this section and Volume III, Section 7, have been integrated and coordinated with (CRWMS M&O 1996c) as its development proceeds in parallel with the development of this report.

10.1.1.2 Background

This analysis builds on safety assessments done prior to the ACD phase of the design. In particular, lists of potential hazards in two previously issued documents, (SNL 1992) and (SNL 1987), have been used as the starting point for this analysis.

10.1.1.3 Design Methodology

Overall DBE analysis methodology begins with a Preliminary Hazard Analysis of all initiating events identified as applicable to the preclosure phase of the Mined Geologic Disposal System Advanced Conceptual Design (MGDS ACD). This analysis is qualitative in nature and is intended to be inclusive and to characterize at a high level the hazards associated with the repository.

The hazards identified in the Preliminary Hazard Analysis are then screened to filter out all events that are not credible or not limiting or not radiological safety hazards (not capable of causing a radioactive release). The remaining events are defined as preliminary DBEs for the MGDS ACD.

10.1.1.4 Design Status

Safety analysis is an ongoing process throughout all design phases of this project. In the ACD phase, this preliminary DBE hazards analysis has developed a list of DBEs applicable to the repository ACD design. Future safety analysis work will subject each individual DBE on this list to a detailed quantitative DBE analysis.

These DBE analyses will verify the validity of the event as a DBE or document the fact that it no longer warrants consideration as a DBE. Each analysis also will determine what (if any) important to radiological safety (IRS) structures, systems, and components (SSCs) must be credited by design to prevent or mitigate the DBE so that resultant doses to the public and to the worker clearly are less than the limits stated in 10 CFR 20 and 10 CFR 60.

10.1.2 Design Inputs

10.1.2.1 Design Requirements

The primary U.S. Nuclear Regulatory Commission (NRC) nuclear safety requirements applicable to the repository ACD include 10 CFR 20 and 10 CFR 60. Overlap and duplication between these requirements and U.S. Department of Energy (DOE) nuclear safety requirements has been avoided through issuance of DOE Order HQ 1321.1 (DOE 1995). This Order exempts CRWMS from DOE nuclear safety requirements that overlap or duplicate NRC requirements with the intent that NRC requirements are the only nuclear safety requirements applicable to the program.

The *Repository Design Requirements Document* (RDRD) (YMP 1994a) is the only design requirements document currently applicable to the repository ACD. Requirements for evaluation of DBEs, as stated in the RDRD, are noted as follows, even though most of them apply to the results of detailed quantitative DBE analyses, which are future work:

Section	Document Title/Text
3.1.5	MAJOR CONSIDERATIONS AND ASSUMPTIONS
A.	For activities and facilities for which the NRC has regulatory authority, the NRC requirements are the controlling "nuclear safety" requirements. This means that portions of DOE CFR requirements and DOE Orders that address topics covered by CFR requirements issued by the NRC are not applicable to the CRWMS. Specifically, there are no nuclear safety design-related requirements in DOE Order 5480.11 applicable to the RDRD.
3.2.4.6	DESIGN BASIS EVENTS AND ACCIDENTS
A.	Accidents. SSCs that are required to function during accidents shall be designed to withstand accident conditions so that their required functions and performance criteria can be met during such events.
B.	Design Objective. Conservatively estimated consequences of normal operations and credible accidents shall be limited in accordance with requirements contained in DOE Order 6430.1A, Section 1300-1.4, *Guidance on Limiting*

Exposure of the Public. [This section will develop events based on site function and licensing requirements. In accordance with the requirement of Section 3.1.5.A above, where there is NRC guidance on the subject, it will be used.]

C. Aircraft. Unless the safety analysis can demonstrate that the risk from an aircraft crashing into the facility is acceptable, potential aircraft crashes shall be considered among the spectrum of man-made missiles that confinement structures must be designed to withstand or against which they must be protected.

D. External Blasts and Missiles. The potential effects of a major explosion at a nearby facility or transportation route shall be considered among the spectrum of external blast effects and missiles that confinement structures must be designed to withstand or against which they must be protected.

E. Internal Blasts and Missiles. The probable consequence of DBEs involving internally generated missiles or blast effects shall be considered. Such DBEs typically involve failure of high-speed rotating machinery, cranes, experimental facilities, high-energy fluid system components, or explosives. Structures required to function following such accidents must be designed to withstand these DBEs.

10.1.2.2 Design Assumptions

Assumptions relevant to evaluation of DBEs are stated in the *Controlled Design Assumptions Document* (CDA) (CRWMS M&O 1995a), which refers to the *Reference Information Base* (RIB) (YMP 1995a) and the *Engineered Barrier Design Requirements Document* (EBDRD) (YMP 1994c). These assumptions are noted as follows, even though most of them apply to detailed quantitative DBE analyses, which are future work:

Assumption Identifier: EBDRD 3.2.4.6.A
Subject: EBS Design Objective

I. STATEMENT OF ASSUMPTION

A. An EBS design objective shall be to ensure that conservatively estimated consequences of normal operations and credible accidents are limited in accordance with requirements contained in DOE Order 6430.1A, Section 1300-1.4, Guidance on Limiting Exposure of the Public. (DOE 1995) exempts the CRWMS from the requirements of DOE Order 6430.1A, citing NRC requirements (primarily 10 CFR 20, -60, and -72) as the only nuclear safety requirements applicable to the program.

Assumption Identifier: TDS 006
Subject: Design Basis Tornadoes

I. STATEMENT OF ASSUMPTION

The Design Basis Tornado will be based on the "Parameters of Design-Basis Tornadoes for NTS [Nevada Test Site]," which is given in the *Reference Information Base* (YMP 1995a), Section 1.3b, Table 2. Even though tornadoes have never been observed on the NTS or within 150 miles of the NTS, the surface facilities design will be consistent with that used at the NTS.

Assumption Identifier: TDS 007
Subject: Winds (Operating Basis and Standard)

I. STATEMENT OF ASSUMPTION

The prevailing wind summary given in the *Reference Information Base* (YMP 1995a), Section 1.3a, Table 4, will be used as the Operating Basis Wind and Standard Wind for surface facilities design considerations.

Assumption Identifier: TDS 008
Subject: Floods (Design Basis)

I. STATEMENT OF ASSUMPTION

The Design Basis Flood shall be the 100-year and 500-year Probable Maximum Floods described in Section 1.54a of the *Reference Information Base* (YMP 1995a); Table 3 identifies the estimated ranges for peak flood characteristics.

Assumption Identifier: TDSS 022 **Subject:** Wind Intensity

I. STATEMENT OF ASSUMPTION

Wind intensity:
Annual Average: 3.22 m/s
Peak: >26.8 m/s

In addition, the *Reference Information Base* (YMP 1995a), Section 1.3b, Table 1, "Estimated Maximum High Winds at NTS," provides upper limits on wind intensities versus return frequency. For a return frequency of 100 years, the maximum wind intensity is 36.7 m per second with maximum gusts of 47.8 m per second.

10.1.2.3 Design Data

Facility design, concepts of operations, and operating basis data, including hazardous material inventories, used as a basis for this analysis are taken from the CDA Document, the RIB, and the RDRD. These data are described or referenced in other sections of this report.

10.1.3 Preliminary Hazards Analysis

10.1.3.1 Analysis Methodology

(SNL 1992) and (SNL 1987) identified lists of potential hazards applicable to previous versions of the repository design. These lists have been assessed for applicability to the repository ACD, modified as appropriate, and compiled into Preliminary Hazards Lists, Surface and Subsurface, in (CRWMS M&O 1996a).

A further modified list of the hazards identified in (CRWMS M&O 1996a) is analyzed qualitatively to estimate the degree of safety risk (radiological and non-radiological) associated with each. First, the (CRWMS M&O 1996a) event list is modified by a simple pre-screening. Two sets of events identified in (CRWMS M&O 1996a) are eliminated in accordance with two criteria noted in (CRWMS M&O 1996a):

- Events that are not applicable to the Yucca Mountain site
- Events that are not applicable to the preclosure phase of a repository at the Yucca Mountain site.

The events that are eliminated in this manner are listed in the Notes for Table 10.1-1. All other events identified in (CRWMS M&O 1996a) are evaluated for potential radiological releases in this section. Additionally, events occurring between carrier arrival at the site boundary and carrier arrival at the cask staging shed (impact limiters in place) are considered to be bounded by transport DBEs and are excluded from this analysis.

In (CRWMS M&O 1996a), hazards are classified into the following eight categories:

- Collision/crushing (Hazard Category 1)
- Contamination (H. C. 2)
- Explosion/Implosion (H. C. 3)
- Fire (H.C. 4)
- Radiation/Magnetic (H.C. 5)
- Thermal (H.C. 6)
- Personnel error (all such events lead to hazards described in one or more of the above categories) (H.C. 7)
- Natural phenomena and other external events (H.C. 8)

These categories are used for convenience (i.e., sorting) as the basis for arranging and numbering the events in Table 10.1-1. Under each category, (CRWMS M&O 1996a) lists several types of potential initiating events. For example, in the first category above, (CRWMS M&O 1996a) lists:

- Horizontal drops (Drops where the orientation of the long axis of the dropped item starts and remains in a horizontal direction)
- Vertical drops (Drops where the orientation of the long axis of the dropped item starts and remains in the vertical direction)
- Slapdowns (Drops where the orientation of the long axis of the dropped item rotates from the vertical (or nearly vertical) direction to a horizontal direction, where one end of the item "slaps down" onto the floor or another item)

Each applicable type is represented in Table 10.1-1 for all categories listed in (CRWMS M&O 1996a).

One specific additional type of event has been added to this list. "Non-mechanistic failure" of a waste package is added to allow for safety analysis of repository facilities in parallel with (prior to completion of) the design of the waste package. "Non-mechanistic failure," as used here, is intended to mean a failure of conservatively estimated consequence that is assumed to occur, even though there may be no known credible mechanism that causes the failure.

When the design of the waste package is completed, it is expected to show that the waste package will withstand all DBEs without failure. The non-mechanistic failure event will be used to analyze the response of the repository to a bounding assumed failure of the waste package. The analysis of this assumed failure is expected to show that the repository would mitigate the consequences of such a failure adequately.

Each hazard in the above categories is considered in the context of the operational processes and design features of the repository ACD to develop the following radiological safety risk characteristics:

- Specific mechanisms of occurrence
- Causes
- Inventories of radioactive material at risk

Table 10.1-1. MGDS ACD Preliminary Initiating Event List

Event No.[B]	Potential Hazard	Cause(s)[A]	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
Note: This table is a summary of preliminary work to date - Some specific conclusions will change as detailed analyses are developed and as the design matures. The overall design requirement (i.e., design in accordance with radiological safety limits) clearly will not change. A,B,C,D,E,F,G See notes at end of table						
SURFACE FACILITIES						
INTERNAL EVENTS						
1.1.1	Shipping Cask drop in Waste Handling Building (WHB) (horizontal) (impact limiters removed, lid bolted on)	Equipment failure (EF)/ Human error (HE)	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to WHB[E]	Contents of 1 Shipping Cask	Neglig.	2
1.1.2	Shipping Cask drop in Cask Maintenance Facility (CMF) (horizontal) (impact limiters removed, lid bolted on)	EF/HE	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to CMF[E]	Contents of 1 Shipping Cask	Neglig.	2
1.2.1	Shipping Cask drop in WHB (vertical) (impact limiters removed, lid bolted on)	EF/HE	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to WHB [E]	Contents of 1 Shipping Cask	Neglig.	2
1.2.2	Shipping Cask drop in CMF (vertical) (impact limiters removed, lid bolted on)	EF/HE	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to CMF [E]	Contents of 1 Shipping Cask	Neglig.	2
1.3	SFC drop (vertical - not onto DC)	EF/HE	SFC failure/Up to 21 PWR or 40 BWR SFAs damaged/release to WHB	Contents of 1 SFC	Major	1
1.4	SFA drop (vertical - not onto DC, but possibly onto another SFA)	EF/HE	1 or 2 SFA(s) damaged/release to WHB	1 or 2 SFAs	Moderate	2
1.5	HLWC drop (vertical - not onto DC, but possibly onto another HLWC)	EF/HE	1 or 2 HLWC(s) damaged/possible negligible release to WHB	1 or 2 HLWCs	Neglig.	1

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
1.6	WP drop (vertical)	EF/HE	Neglig.[D]		Neglig.	1
1.7	WP drop (horizontal)	EF/HE	WP[C]	1 WP	Neglig.	1
1.8	Shipping cask slapdown (impact limiters removed, lid removed)	EF/HE, Seismic (See 8.1 below)	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to WHB[E]	Contents of 1 Shipping Cask	Neglig. to Major	2
1.9	SFC slapdown	EF/HE, Seismic (See Event 8.1 below)	SFC damage or failure/ Possible damage to up to 21 PWR or 40 BWR SFAs/Possible release to WHB	Contents of 1 SFC	Moderate to Major	1
1.10	HLWC slapdown	EF/HE, Seismic (See Event 8.1 below)	HLWC damage or failure/ Possible release to WHB	1 HLWC	Neglig.	1
1.11	WP slapdown	EF/HE, Seismic (See Event 8.1 below)	WP[C]	1 WP	Neglig.	2
1.12	SFA drop onto sharp object	EF/HE	Damage to SFA/release to WHB	1 SFA	Moderate	2
1.13	WP drop onto sharp object	EF/HE	Damage to WP/release to WHB	1 WP	Neglig. To Major	2
1.14	Cask collision (impact limiters removed, lid removed)	EF/HE	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to WHB[E]	Contents of 1 Shipping Cask	Neglig. to Major	2
1.15	SFC collision	EF/HE	Possible SFC damage or failure/ Possible damage to up to 21 PWR or 40 BWR SFAs/Possible release to WHB	Contents of 1 SFC	Moderate to Major	1
1.16	SFA collision	EF/HE	Possible SFA damage/Possible release to WHB	1 SFA	Moderate	2

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
1.17	HLWC collision	EF/HE	Possible HLWC damage or failure/ Possible neglig. release to WHB	1 HLWC	Neglig.	1
1.18	WP collision	EF/HE	WP[C]	1 WP	Neglig.	1
1.19	Shield door jams shipping cask (impact limiters removed, lid removed)	EF/HE	Possible damage to shipping cask, damage to contents (SFC, HLWC, or up to 21 PWR or 40 BWR SFAs)/release to WHB[E]	Contents of 1 Shipping Cask	Neglig. to Major	NC
1.20	Shield door jams WP	EF/HE	WP[C]	1 WP	Neglig.	NC
1.21	SFC drops onto unsealed DC	EF/HE	SFC failure/Up to 21 PWR or 40 BWR SFAs damaged/release to WHB	Contents of 1 SFC	Major	1
1.22	SFA drops onto DC	EF/HE	1 or 2 SFA(s) damaged/release to WHB	1 or 2 SFAs	Moderate	2
1.23	HLWC drops onto DC	EF/HE	1 or 2 HLWC(s) damaged/possible negligible release to WHB	1 or 2 HLWCs	Neglig.	1
1.24	Automatic Center of Gravity Lift Fixture (ACGLF) drops onto WP	EF/HE	WP[C]	1 WP	Neglig.	2
1.25	Non-mechanistic failure of WP in WHB	Not specified	Release from WP to WHB	1 WP	Major	2 (Assum'd)
1.26	WP car derailment in WHB	EF/HE	WP[C]	1 WP	Neglig.	2
1.27	Transporter derailment outdoors	EF/HE	WP[C]	1 WP	Neglig.	2
1.28	Transporter derailment outdoors + WP ejected	EF/HE	WP[C]	1 WP	Neglig.	2
1.29	Transporter derailment outdoors + WP ejected + Non-mechanistic WP failure outdoors	Not specified	Release from WP to atmosphere	1 WP	Major	2 (Assum'd)

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
3.1	Decon (or other pneumatic or pressurized) system missile - nozzle/ valve stem/pneumatic device	EF	Possible SFC, SFA, or HLWC damage/Possible release to WHB/DC[C]	1 SFC, 1 SFA, 1 HLWC, or 1 DC	Neglig.	2
3.2	Decon system failure - internal flooding into/around WP	EF	Criticality threat/Possible release to WHB/WP[C]			
4.1	Fire in WHB fuel handling area	Combus- tibles/ Heat source	Possible SFC, SFA, or HLWC damage/Possible release to WHB/ WP[C] (after welding)	One or more SFCs, SFAs, HLWCs, WPs	Neglig. to Major	1, 2
4.2	Fire in WHB external to fuel handling area	Combus- tibles/ Heat source	No release/Fire barriers will protect fuel handling areas	None	Neglig.	1, 2
5.1	Fuel damage by laser radiation/heat/burnthrough during welding process	EF/HE	Possible SFC, SFA, HLWC or DC damage/ Possible leakage to WHB due to incomplete welds	One DC or SFC, one or more SFAs or HLWCs	Neglig. to Moderate	1
EXTERNAL EVENTS						
8.1.a	Seismic activity (earthquakes)	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to cata- strophic	2, NC
8.1.b	Seismic activity (active faulting, shear zone at the site)	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to cata- strophic	NC

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
8.2	Flooding (storm, river diversion)	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible wetting or submergence of or damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.3	Lightning	Natural Phenom.	Possible fire or other damage to or collapse of buildings and other structures/ Possible damage to one or more Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.4.1	Volcanic activity (magmatic activity)	Natural Phenom.	Possible fire damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	NC (Pre-closure)
8.4.2	Volcanic activity (ashfall)	Natural Phenom.	Possible collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.5	Weather fluctuations and extremes (snow, hail, ice, temperature extremes)	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	1, 2, NC
8.6	Chemical effects (release of chemicals on site, e.g., toxic gas)	EF/HE	Personnel injury/No other significant effects/No releases[D]	None	Neglig. (No radioactive releases)	1, 2, NC

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[a]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
8.7	Sandstorm	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.8	Tornado	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.9	Extreme wind	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.10	Industrial activity accident	EF/HE	Unknown at this time - Possible fire or other damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	2, NC
8.11	Military accident (weapons testing, aircraft impact, bombing)	EF/HE	Possible fire or other damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	NC
8.12	Crash of commercial aircraft (helicopter, passenger planes, etc.)	EF/HE	Possible fire or other damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to catastrophic	NC
8.14	Intentional future intrusion	Sabotage, Terrorism	No significant effects	None	Neglig.	2, NC

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
8.16	Range fire	Natural Phenom./ HE or sabotage	Possible fire damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to cata-strophic	1, 2
8.18	Loss of offsite/ onsite (SBO) AC power	EF/HE	Interruption of handling operations & HVAC/No significant effects on radioactive materials/No releases [D]	None	Neglig.	1, 2, NC
8.41	Static fracturing (surficial fissuring, impact fracturing, hydraulic fracturing)	Natural Phenom.	Possible damage to or collapse of buildings and other structures/ Possible damage to all Shipping Casks, SFCs, SFAs, HLWCs and WPs/Possible large scale releases/WP[C]	Entire WHB inventory	Neglig. to cata-strophic	2, NC
			SUB-SURFACE FACILITIES			
INTERNAL EVENTS						
1.1	Transporter derailment in ramp or main drift	EF/HE	WP[C]	1 WP	Neglig.	1
1.1.1	Transporter derailment + WP ejected	EF/HE	WP[C]	1 WP	Neglig.	2
1.1.2	Non-mechanistic WP failure in main drift following transporter derailment + WP ejection	Not specified	Release from WP, Contamination of ramp or main drift	1 WP	Major	2 (Assum'd)
1.2	Emplacement rail car derailment	EF/HE	WP[C]	1 WP	Neglig.	1
1.2.1	Non-mechanistic WP failure in main drift following emplacement rail car derailment	Not specified	Release from WP, Contamination of emplacement drift	1 WP	Major	2 (Assum'd)

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
1.3	WP car rolls out of transporter	EF/HE	WP[C]	1 WP	Neglig.	1
1.3.1	Non-mechanistic WP failure following loss or absence of restraint and rollout of WP car from transporter	Not specified	Release from WP, Contamination of ramp or main drift	1 WP	Major	2 (Assum'd)
1.4	Transporter collision w/another transporter	EF/HE	WP[C]	1 or 2 WPs	Neglig.	1
1.5	Emplacement rail car collision w/emplacement locomotive	EF/HE	WP[C]	1 WP	Neglig.	1
1.6	Runaway transporter	EF/HE	WP[C]	1 WP	Neglig.	NC
1.7	Decoupled transporter	EF/HE	None	1 WP	Neglig.	1
1.8	External unloading mechanism fails	EF/HE	Emplacement rail car rolls out of sloped emplacement drift and falls in to main drift/WP[C]	1 WP	Neglig.	1
1.9	Transport cask internal off-loading mechanism fails	EF/HE	WP/emplacement rail car stranded halfway out of transporter cask	1 WP	Neglig.	1
1.10	Transport cask door jams WP	EF/HE	WP/emplacement rail car stranded halfway out of transporter cask/WP[C]	1 WP	Neglig.	1
1.11	Emplacement drift door jams WP	EF/HE	WP[C]	1 WP	Neglig.	1
1.12	Rockfall onto transporter	EF/HE (incl. rockbolt failure)	WP[C]	1 WP	Neglig.	1
1.13	Rockfall onto WP/emplacement rail car	EF/HE (incl. rockbolt failure)	WP[C]	1 WP	Neglig.	1

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
1.14	Steel set drop onto WP	EF/HE	WP[C]	1 WP	Neglig.	2, NC
1.15	Loss of WP cart restraint in sloped emplacement drift	EF	WP[C]	1 or 2 WPs	Neglig.	2 (Assumed)
3.1	Hydrogen Explosion (from batteries)	EF/HE	WP[C,F]	1 WP	Neglig.	2
3.2	Dust Explosion (from rubber conveyor belts)	EF/HE	WP[C,F]	1 WP	Neglig.	2
4.1	Fire	EF/HE	WP[C]	1 WP	Neglig.	2
6.1	Thermal cycling of WP	Blast cooling for retrieval	WP[C]	1 WP	Neglig.	2
EXTERNAL EVENTS						
8.1.a	Seismic activity (earthquakes)	Natural Phenom.	Possible damage to or collapse of drifts/ Possible damage to all WPs/Possible large scale releases/WP[C]	All subsurface WPs	Neglig. to catastrophic	2, NC
8.1.b	Seismic activity (active faulting, shear zone at the site)	Natural Phenom.	Possible damage to or collapse of drifts/ Possible damage to all WPs/Possible large scale releases/WP[C]	All subsurface WPs	Neglig. to catastrophic	NC
8.2	Flooding (storm, river diversion)	Natural Phenom.	Possible damage to or collapse of drifts/ Possible damage to all WPs/Possible large scale releases/WP[C]	All subsurface WPs	Neglig. to catastrophic	2, NC
8.3	Volcanic activity	Natural Phenom.	Possible damage to or collapse of drifts/ Possible damage to all WPs/Possible large scale releases/WP[C]	All subsurface WPs	Neglig. to catastrophic	NC (Pre-closure)
8.14	Intentional future intrusion	Sabotage, Terrorism	No significant effects	None	Neglig.	2, NC

Table 10.1-1. MGDS ACD Preliminary Initiating Event List[A] (continued)

Event No.[B]	Potential Hazard	Cause(s)	Unmitigated Consequences	Inventory at Risk	Conseq. Category	Frequency Category
8.18	Loss of offsite/ onsite (SBO) AC power	EF/HE	Interruption of handling operations & HVAC/No significant effects on radioactive materials/No releases[D]	None	Neglig.	1, 2, NC
8.35	Thermal loading	Design Condition	No significant effects	None	Neglig.	2, NC
8.36	Geochemical alterations	Natural Phenom.	No significant effects	None	Neglig.	2, NC
8.37	Waste and rock interactions	Natural Phenom.	No significant effects	None	Neglig.	2, NC
8.38	Rockfall	Natural Phenom.	Possible damage to or collapse of drifts/ Possible damage to all WPs/Possible large scale releases/WP[C]	All subsurface WPs	Neglig. to catastrophic	NC
8.41	Static fracturing (surficial fissuring, impact fracturing, hydraulic fracturing)	Natural Phenom.	Possible damage to or collapse of drifts/ Possible damage to all WPs/Possible large scale releases/WP[C]	All subsurface WPs	Neglig. to catastrophic	2, NC

Note A: The following external hazards have not been included in the Preliminary Hazards List because, as noted in (CRWMS M&O 1996a), they do not apply to the Yucca Mountain site:

8.13 Undetected* past intrusion (undiscovered bore holes or mine shafts)
8.17 Pipeline accident (Gas, etc.)
8.20 Avalanche
8.21 Coastal erosion
8.22 High tide, high lake or river level
8.23 Low lake or river level
8.24 Hurricane
8.25 Meteorite
8.26 Seiche
8.27 Tsunami
8.28 Dam failure
8.29 Waves
8.30 Undetected* features and processes (breccia pipes, lava tubes, gas or brine pockets, etc.)
8.31 Sedimentation
8.33 Landslide
8.40 Dissolution

*Undetected intrusions and undetected features and processes are considered to be not applicable to the Yucca Mountain site (CRWMS M&O 1996a).

The following external events have not been included in the Preliminary Hazards List because, as noted in (CRWMS M&O 1996a), they do not apply to preclosure phase of the Yucca Mountain Project:

8.15 Inadvertent future intrusion
8.19 Perturbation of groundwater system
8.32 Subsidence
8.34 Uplifting
8.39 Glaciation
8.42 Denudation and stream erosion
8.43 Magmatic activity (extrusive, intrusive)
8.44 Epeirogenetic displacement
8.45 Orogenic diastrophism

Note B: The numbering system used is the result of sequentially numbering the events identified in (CRWMS M&O 1996a).

Note C: Potential impacts to waste package are described in Vol. III, Section 7.0 of this report and in (CRWMS M&O 1996c). Pending detailed analysis of the waste package response to each event, it is assumed that waste package integrity is maintained in each case. Events 1.23 and 1.27 (surface) and 1.1.2, 1.2.1 and 1.3.1 (subsurface), however, will analyze the consequences of postulated non-mechanistic waste package failures.

Note D: Vol. III, Section 6.0 of this report includes an analysis showing that the maximum vertical drop event will not breach waste package integrity.

Note E: Transportation accidents are assumed to bound these events, as well as shipping cask events occurring between the site boundary and the Waste Handling Building. The shipping cask (lid bolted on) is assumed to withstand each event without breach and without damage to the contents.

Note F: Even if hydrogen or dust explosion were to occur, it would be on a relatively minor scale because of limited fuel supply. Obviously, either would be a significant burn/impact hazard to personnel in the vicinity. It is equally clear, however, that the threat of a radiological release caused by the explosion would be insignificant. There would be no significant effect on a transporter (mass in excess of 100 tonnes) or even a WP (mass of approximately 50 tonnes), both of which will be extremely robust structures. For example, neither derailment nor breach of containment is considered a credible outcome of such an explosion.

Note G: External events such as Loss of Offsite Power/Station Blackout and Toxic Gas Release are included as DBEs even though no radioactive release is expected to result. The NRC has required in the past (for nuclear power plant (NPP) applicants) that these events be analyzed because of the high decay heat rates present in NPPs. Active mitigation is required quickly to prevent such events at a NPP from causing a radioactive release.

For the MGDS, standard design of nuclear fuel handling equipment (e.g., cranes that stop movement and apply brakes on loss of power) should make such a release not credible. It is expected, however, that the NRC will expect this to be proven in the form of a documented DBE analysis.

- Consequence Category: Unmitigated consequences, in the following broad qualitative categories of severity:
  - Negligible: No significant radiological release.
  - Moderate: Release in the range of that caused by damage to a single spent fuel assembly (SFA)
  - Major: Release in the range of that caused by damage to a single spent fuel canister (SFC), which can hold up to 21 PWR/40 BWR SFAs each
  - Catastrophic: Release in the range of that caused by a severe earthquake (collapse of buildings), involving from several SFCs up to the entire inventory of the surface facilities
- Frequency Category: Frequency of occurrence of the initiating event (in the following broad categories). The following qualitative definitions of "frequency categories" are used in this section and the accompanying tables:
  - Frequency Category 1:
    Those initiating events that are reasonably likely to occur regularly, moderately frequently, or one or more times before permanent closure of the geologic repository operations area
  - Frequency Category 2:
    Other initiating events that are considered unlikely, but sufficiently credible to warrant consideration, taking into account the potential for significant radiological impacts on the health and safety of the public
  - Frequency Category NC:
    Those initiating events that are considered to be not credible during the preclosure phase

These definitions of frequency categories are in accordance with current requirements listed in Section 10.1.2.1. They also are consistent with the recently proposed changes to 10 CFR 60.

In addition to the hazards analysis, a further DBE screening process is documented in Table 10.1-2. This process answers the following questions to determine whether each event in Table 10.1-1 should be evaluated further as a potential DBE (all questions should be answered "Yes" for the event to become a DBE):

- Is the initiating event credible? An event is considered credible unless its estimated frequency of occurrence is clearly below the threshold of credibility, in which case it is considered to be not credible, or beyond the design basis. The basic threshold of credibility for both the NRC and the DOE is $1x10^{-6}$/yr (or one event every one million years).

Table 10.1-2. MGDS ACD Design Basis Event Screening Process

Event		Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
Type	No.							
SURFACE FACILITIES								
INTERNAL EVENTS								
Shipping Cask Drop in WHB	1.1.1	Shipping Cask drop in WHB (horizontal) (impact limiters removed, lid bolted on)	2	Yes	No	No (See 1.8)	No	No
Shipping Cask Drop in CMF	1.1.2	Shipping Cask drop in CMF (horizontal) (impact limiters removed, lid bolted on)	2	Yes	No	No (None)	No	No
Shipping Cask Drop in WHB	1.2.1	Shipping Cask drop in WHB (vertical) (impact limiters removed, lid bolted on)	2	Yes	No	No (See 1.8)	No	No
Shipping Cask Drop in CMF	1.2.2	Shipping Cask drop in CMF (vertical) (impact limiters removed, lid bolted on)	2	Yes	No	No (None)	No	No
SFC Drop	1.3	SFC drop (vertical - not onto DC)	1	Yes	Yes	Yes	Yes (1)	No
SFA Drop	1.4	SFA drop (vertical - not onto DC, but possibly onto another SFA)	2	Yes	Yes	Yes	Yes (2)	No
HLWC Drop	1.5	HLWC drop (vertical - not onto DC, but possibly onto another HLWC)	1	Yes	Yes	Yes	Yes (3)	No

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event								
Type	No.	Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
WP Drop	1.6	WP drop (vertical)	2	Yes	Yes	No (See 1.11)	No	No
WP Drop	1.7	WP drop (horizontal)	2	Yes	Yes	No (See 1.11)	No	No
Shipping Cask Drop in WHB	1.8	Shipping cask slapdown (impact limiters removed, lid removed)	2	Yes	Yes	Yes	Yes (4)	No
SFC Drop	1.9	SFC slapdown	1	Yes	Yes	No (See 1.3)	No	No
HLWC Drop	1.10	HLWC slapdown	1	Yes	Yes	No (See 1.5)	No	No
WP Drop	1.11	WP slapdown	2	Yes	Yes	Yes	Yes (5)	No
SFA Drop onto Sharp Object	1.12	SFA drop onto sharp object	2	Yes	Yes	Yes	Yes (6)	No
WP Drop onto Sharp Object	1.13	WP drop onto sharp object	2	Yes	Yes	Yes	Yes (7)	No
Shipping Cask Drop in WHB	1.14	Cask collision (impact limiters removed, lid bolted on)	2	Yes	Yes	No (See 1.8)	No	No
SFC Drop	1.15	SFC collision	1	Yes	Yes	No (See 1.3)	No	No
SFA Drop	1.16	SFA collision	2	Yes	Yes	No (See 1.4)	No	No

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event		Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
Type	No.							
HLWC Drop	1.17	HLWC collision	1	Yes	Yes	No (See 1.5)	No	No
WP Drop	1.18	WP collision	1	Yes	Yes	No (See 1.11)	No	No
Shipping Cask Drop in WHB	1.19	Shield door jams shipping cask (impact limiters removed, lid bolted on)	NC	No	Yes	No (See 1.8)	No	No
WP Drop	1.20	Shield door jams WP	NC	No	Yes	No (See 1.11)	No	No
Waste Form Drop Onto DC	1.21	SFC drops onto unsealed DC	1	Yes	Yes	Yes	Yes (8)	No
Waste Form Drop Onto DC	1.22	SFA drops onto DC	2	Yes	Yes	No (See 1.21)	No	No
Waste Form Drop Onto DC	1.23	HLWC drops onto DC	1	Yes	Yes	No (See 1.21)	No	No
Equipment Drop onto WP	1.24	Automatic Center of Gravity Lift Fixture (ACGLF) Drop onto WP	2	Yes	Yes	Yes	Yes (9)	No
WP Failure	1.25	Non-mechanistic failure of WP in WHB	2 (Assumed)	Yes	Yes	Yes	Yes (10)	No
WP Drop	1.26	WP cart derailment in WHB	2	Yes	No	No (See 1.11)	No	No

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event								
Type	**No.**	**Potential Hazard**	**Frequency Category**	**Credible?**	**Causes A Release?**	**Limiting Conseq. in Type?**	**DBE? If Yes: (DBE #)**	**Beyond DBE? (Residual Risk)**
WP Drop	1.27	Transporter derailment/ collision outdoors	2	Yes	No	No (See 1.11)	No	No
WP Drop	1.28	Transporter derailment/ collision outdoors + WP ejected	2	Yes	No	No (See 1.11)	No	No
WP Failure Outdoors	1.29	Transporter derailment/ collision outdoors + WP ejected + Non-mechanistic WP failure	2 (Assumed)	Yes	Yes	Yes	Yes (11)	No
Equipment Drop Onto WP	3.1	Decon system missile - nozzle/valve stem/pneumatic device	2	Yes	No	No (See 1.24)	No	No
Internal Flooding	3.2	Decon system failure - internal flooding into/around WP (criticality threat)	2	Yes	Yes	Yes	Yes (12)	No
Fire	4.1	Fire in WHB fuel handling area	1, 2	Yes	Yes	Yes	No (Deferred to Fire Hazards Analysis)	No
Fire	4.2	Fire in WHB external to fuel handling area	1, 2	Yes	No	No	No (Deferred to Fire Hazards Analysis)	No
Fuel Damage by Laser/ Welding Process	5.1	Fuel damage by laser radiation/heat/ burnthrough during welding process	1	Yes	Yes	Yes	Yes (13)	No

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event		Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. In Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
Type	No.							
EXTERNAL EVENTS								
Earthquake	8.1.a	Seismic activity (earthquakes)	2, NC	Yes	Yes	Yes	Yes (14)	Yes
Active Seismic Faulting	8.1.b	Seismic activity (active faulting, shear zones at the site)	NC	No	Yes	Yes	No	Yes
Flood	8.2	Flooding (storm, river diversion)	2, NC	Yes	Yes	Yes	Yes (15)	Yes
Lightning	8.3	Lightning	2, NC	Yes	Yes	Yes	Yes (16)	Yes
Volcanic Activity	8.4.1	Volcanic activity (magmatic activity)	NC (Preclosure)	No	Yes	Yes	No	Yes
Volcanic Activity	8.4.2	Volcanic activity (ashfall)	2, NC	Yes	Yes	Yes	Yes (17)	Yes
Weather	8.5	Weather fluctuations and extremes (snow, hail, ice, temperature extremes)	1, 2, NC	Yes	No	No (None)	No (Normal conditions, not considered initiating events, but as initial conditions in DBE analysis)	Yes
Toxic Gas	8.6	Chemical effects (release of chemicals on site, e.g., toxic gas)	1, 2, NC	Yes	No[a]	Yes	Yes (18)	Yes
Sandstorm	8.7	Sandstorm	2, NC	Yes	Yes	Yes	Yes (19)	Yes
Tornado	8.8	Tornado	2, NC	Yes	Yes	Yes	Yes (20)	Yes

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event								
Type	No.	Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
Wind	8.9	Extreme wind	2, NC	Yes	Yes	Yes	Yes (21)	Yes
Industrial Accident	8.10	Industrial activity accident	2, NC	Yes	Yes	Yes	Yes (22)	Yes
Aircraft Crash	8.11	Military accident (weapons testing, aircraft impact, bombing)	NC	No	Yes	Yes	No	Yes
Aircraft Crash	8.12	Crash of commercial aircraft (helicopter, passenger planes, etc.)	NC	No	Yes	No (See 8.11)	No	Yes
Safeguards & Security	8.14	Intentional future intrusion	2, NC	Yes	Yes	Yes	Yes (23)	Yes
External Fire	8.16	Range fire	1, 2	Yes	Yes	Yes	No (Deferred to Fire Hazards Analysis)	No
Loss of Power	8.18	*Loss of offsite/* onsite(SBO) AC power	1, 2, NC	Yes	No[a]	Yes	Yes (24)	Yes
Geolog. Fracturing	8.41	Static fracturing (surficial fissuring, impact fracturing, hydraulic fracturing)	2, NC	Yes	Yes	Yes	Yes (25)	Yes
SUB-SURFACE FACILITIES								
INTERNAL EVENTS								

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event								
Type	**No.**	**Potential Hazard**	**Frequency Category**	**Credible?**	**Causes A Release?**	**Limiting Conseq. in Type?**	**DBE? If Yes: (DBE #)**	**Beyond DBE? (Residual Risk)**
WP Drop	1.1	Transporter derailment in ramp or main drift	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Drop	1.1.1	Transporter derailment + WP ejected	2	Yes	No	No (See 1.11 - Surface)	No	No
WP Failure in Drift	1.1.2	Non-mechanistic WP failure in main drift following transporter derailment + WP ejection	2 (Assumed)	Yes	Yes	Yes	Yes (1)	No
WP Drop	1.2	Emplacement rail car derailment	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Failure in Drift	1.2.1	Non-mechanistic WP failure in main drift following emplacement rail car derailment	2 (Assumed)	Yes	Yes	Yes	Yes (1)	No
WP Drop	1.3	WP rolls out of transporter	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Failure in Drift	1.3.1	Non-mechanistic WP failure following loss or absence of restraint and rollout of WP car from transporter	2 (Assumed)	Yes	Yes	Yes	Yes (1)	No
WP Drop	1.4	Transporter collision w/another transporter	1	Yes	No	No (See 1.11 - Surface)	No	No

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event Type	Event No.	Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
WP Drop	1.5	Emplacement rail car collision w/emplacement locomotive	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Drop	1.6	Runaway transporter	NC	No	Yes	No (See 1.11 - Surface)	No	No
WP Drop	1.7	Decoupled transporter	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Drop	1.8	External unloading mechanism fails	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Drop	1.9	Transport cask internal off-loading mechanism fails	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Drop	1.10	Transport cask door jams WP	1	Yes	No	No (See 1.11 - Surface)	No	No
WP Drop	1.11	Emplacement drift door jams WP	NC	No	No	No (See 1.11 - Surface)	No	No
Rockfall (Internal)	1.12	Rockfall onto transporter	1	Yes	No	No (None)	No	No
Rockfall (Internal)	1.13	Rockfall onto WP/emplacement rail car	1	Yes	No	No (None)	No	No
Equipment Drop onto WP in Drift	1.14	Steel set drop onto WP	2, NC	Yes	Yes	Yes	Yes (2)	Yes

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event		Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
Type	No.							
Loss of WP Restraint	1.15	Loss of WP cart restraint in sloped emplacement drift	2 (Assumed)	Yes	Yes	Yes	Yes (3)	No
Hydrogen Explosion	3.1	Hydrogen Explosion (from batteries)	2	Yes	No[7]	Yes	No	No
Dust Explosion	3.2	Dust Explosion (from rubber conveyor belts)	2	Yes	No[7]	Yes	No	No
Fire in Drift	4.1	Fire	2	Yes	Yes	Yes	No (Deferred to Fire Hazards Analysis)	No
Thermal Cycling of WP	6.1	Thermal cycling of WP due to blast cooling for retrieval	2	Yes	Yes	Yes	Yes (4)	No
EXTERNAL EVENTS								
Earthquake	8.1.a	Seismic activity (earthquakes)	2, NC	Yes	Yes	Yes	Yes (5)	Yes
Active Seismic Faulting	8.1.b	Seismic activity (active faulting, shear zones at the site)	NC	No	Yes	Yes	No	Yes
Flood	8.2	Flooding (storm, river diversion)	2, NC	Yes	Yes	Yes	Yes (6)	Yes
Volcanic Activity	8.3	Volcanic activity (magmatic activity)	NC (Preclosure)	No	Yes	Yes	No	Yes
S&S	8.14	Intentional future intrusion	2, NC	Yes	Yes	Yes	Yes (7)	Yes

Table 10.1-2. MGDS ACD Design Basis Event Screening Process (continued)

Event		Potential Hazard	Frequency Category	Credible?	Causes A Release?	Limiting Conseq. in Type?	DBE? If Yes: (DBE #)	Beyond DBE? (Residual Risk)
Type	No.							
Loss of Power	8.18	Loss of offsite/ onsite (SBO) AC power	1, 2, NC	Yes	No[a]	Yes	Yes (8)	Yes
Thermal Loading	8.35	Thermal loading	1	Yes	No (Normal Design Condition)	Yes	No (Normal Design Condition, Not an Off-Normal Event)	No
Geochem. Alterations	8.36	Geochemical alterations	2, NC	Yes	Yes	Yes	Yes (9)	Yes
Waste/ Rock Interaction	8.37	Waste and rock interactions	2, NC	Yes	Yes	Yes	Yes (10)	Yes
Rockfall	8.38	Rockfall	NC	No	Yes	Yes	No	Yes
Geolog. Fracturing	8.41	Static fracturing (surficial fissuring, impact fracturing, hydraulic fracturing)	2, NC	Yes	Yes	Yes	Yes (11)	Yes

- Can the initiating event cause a radioactive release? Some events could involve hazards not capable of causing exposure to radiation. These events are outside the scope of a Design Basis Event analysis.

- Does the initiating event cause the most severe unmitigated consequence in its type? One bounding event in each type is retained as a DBE. Generally, if a design can provide adequate protection against the most severe event in the type, then it can provide adequate protection against all lesser events of the same type. For example, the consequences of an SFA drop or a high-level waste canister (HLWC) drop onto a partially filled disposal container (DC) are bounded by the consequences of an SFC drop onto a partially filled DC: SFC drop is the DBE for the "drop onto DC" type of event. The safety design basis can be defined without expending resources on a detailed analysis of the SFA drop and HLWC drop events.

Table 10.1-2 provides a preliminary basis for exclusion from or inclusion in the remaining list of DBEs. To provide completeness, this table also is used to identify those initiating events which are considered to have elements of residual risk that warrant further consideration. Some events, particularly natural phenomena hazards such as earthquakes, occur across a wide spectrum of severity versus frequency of occurrence. That part of the spectrum with frequencies below the threshold of credibility is identified as "beyond the design basis," which is part of the "residual risk" associated with the design.

Analysis done using the methodology described in this section is performed as a preliminary non-Q scoping analysis. More detailed Q analyses done as future work may shrink or expand the preliminary list of DBEs resulting from the analysis documented in this section.

10.1.3.2 Preliminary Hazards Analysis Results

Table 10.1-1 documents the results of a preliminary hazards analysis of all initiating events identified as applicable to the preclosure phase of the repository ACD. For the surface facilities, most identified events occur in the Waste Handling Building. A few events are postulated to occur outdoors, and a few occur in the Cask Maintenance Facility. No significant events occurring in the Waste Treatment Building (WTB) were identified.

10.1.3.3 Selection of Design Basis Events

To optimize the use of safety analysis resources in the performance of detailed, quantitative DBE analysis, a screening process is applied to the events in Table 10.1-1 using the methodology discussed in Section 10.1.3.1. The DBE screening process discussed above is documented in Table 10.1-2. After application of this process, the following events remain as credible and bounding DBEs applicable to the repository ACD.

The following two lists are the result of preliminary work to date. Specifically, some of the following events may be found to be not credible or not limiting and may therefore be deleted. Other events also may be added to this list as a result of subsequent analyses:

Surface Facilities Design Basis Events List:

Internal Events:

1. SFC Drop - vertical, not onto DC
2. SFA Drop - vertical, not onto DC, but possibly onto another SFA
3. HLWC Drop - vertical, not onto DC, but possibly onto another HLWC
4. Shipping Cask Slapdown - impact limiters removed, lid removed
5. WP Slapdown
6. SFA Drop onto Sharp Object
7. WP Drop onto Sharp Object
8. SFC Drop onto an Unsealed DC
9. Automatic Center of Gravity Lift Fixture Drop onto WP
10. Non-mechanistic Failure of WP in the Waste Handling Building
11. Non-mechanistic WP Failure Outdoors (Note: Assumed to occur following Transporter Derailment or Collision and WP Ejection, none of which is expected to cause a credible mechanistic WP failure)
12. Decon System Failure - Internal Flooding, into/around WP (criticality threat)
13. Fuel Damage by Laser Radiation/Heat/Burnthrough During Welding Process

External Events:

14. Design Basis Earthquake
15. Design Basis Flood
16. Design Basis Lightning
17. Design Basis Ashfall
18. Design Basis Chemical/Toxic Gas Release
19. Design Basis Sandstorm
20. Design Basis Tornado
21. Design Basis Wind
22. Design Basis Industrial Accident
23. Design Basis Intrusion
24. Loss of Offsite Power/Station Blackout
25. Design Basis Geological Static Fracturing (surficial fissuring, impact fracturing, hydraulic fracturing)

Subsurface Facilities Design Basis Events List:

Internal Events:

1. Non-mechanistic WP Failure in Main Drift (Note: Assumed to occur following:
   a. Transporter Derailment or Collision and WP Ejection
   b. Emplacement Rail Car Derailment or Collision and WP Ejection
   c. WP Rail Car Rollout from the Transporter

   none of which is expected to cause a credible mechanistic WP failure)

2. Steel Set Drop onto WP
3. Loss of WP Cart Restraint in Sloped Emplacement Drift
4. Thermal Cycling of WP Due to Blast Cooling for Retrieval

External Events:

5. Design Basis Earthquake
6. Design Basis Flood
7. Design Basis Intrusion
8. Loss of Offsite Power/Station Blackout
9. Design Basis Geochemical Alterations
10. Design Basis Waste and Rock Interaction
11. Design Basis Geological Static Fracturing (surficial fissuring, impact fracturing, hydraulic fracturing)

10.1.3.3 Preliminary Assessment of Repository Design Capability to withstand Design Basis Events

As discussed in Section 10.1.2, the existing applicable requirements documents already have requirements that address certain potential design basis events. As a result, the repository design presented in this report includes such "potentially required" prevention and mitigation functions as:

- Confinement Systems
- "Sealed" Buildings
- Filtered HVAC Supply and Exhaust
- Elevated Stack
- Preclosure Controlled Area Boundary
- Technical Specifications for Operations
- Operating Procedures
- Fire Barriers
- Fire Detection and Suppression Systems
- Control of Fuels (Types and Quantities)
- Control of Ignition Sources
- Flood Protection
- Lightning Protection System
- Building Design Loads
- Designed for Natural Phenomena, including Seismic.

It is concluded that the repository design presented in this report is adequate to prevent or mitigate potential DBEs within regulatory requirements. While not specifically identifying a complete list of DBEs, the existing requirement documents require the inclusion of many of the potential DBEs in Table 10.1-2 in the design bases of repository SSCs (e.g., natural phenomena, radiological protection). As a result many preventive or mitigative features have been included in the SSC design such that reasonable assurance is provided that the proposed design can withstand the potential Design Basis Events identified in Table 10.1-2 without significant modifications to the design. Since many of the repository SSCs are already on the *Q-List* (at a high level), the current radiological safety classification of the existing design should bound the formal identification of SSCs important to safety. SSCs will be reclassified as part of subsequent design, as required by DBE analysis results.

10.1.3.4 Administrative Controls

Each time the DBE analyses take credit for the operability of IRS SSCs to prevent or mitigate an event, they will identify the need for operating license conditions, technical specifications, procedures, and other administrative controls to complement the design. These controls will be required to preserve the safety design basis during the preclosure operational phase of the repository and will be applied under the quality assurance (QA) program as part of the repository design basis. DBE analyses also will identify other administrative controls, such as access controls, that can be used to minimize the frequency or consequences of the analyzed events.

10.1.3.5 Emergency Actions

DBE analyses also will contribute to the development of the Emergency Plan for the repository. Analysis of the timing and severity of DBEs will become part of advance plans for a required evacuation of the site or surrounding population and other protective measures taken to limit the effects of an event.

10.1.3.6 Beyond Design Basis Events

Some DBEs, and even some non-DBEs (initiating events that have been screened out for consideration as DBEs because they are not credible) may have aspects that warrant additional consideration as " residual risk." Residual risk is the risk that the regulator is asked to accept in licensing the facility for operation. DBEs that are natural phenomena hazards, such as seismic activity, occur across a continuous spectrum of severity versus frequency. The portion of the frequency spectrum beyond the threshold of credibility (frequencies less than once per one million years) is " beyond the design basis," part of residual risk.

Although they are beyond the design basis, system responses to these low probability-high consequence events will be reviewed as future work to identify possible low impact design changes or operating philosophies that either decrease the frequency of occurrence even further, or decrease the consequences if the event were to occur. In accordance with the mandate of NUREG-1318, these analyses are performed to identify areas where it would be cost effective to reduce significantly the overall risk of low probability-high consequence events.

10.2.1 Introduction

10.2.1.1 Purpose

The surface and subsurface facilities will be handling a significant quantity of highly radioactive materials. It is imperative that these facilities be designed in such a way to afford the maximum amount of protection from radiation and its effects to the operating personnel, the environment, and the general public. This section describes the radiological considerations that have been incorporated into the ACD of the MGDS. Requirements and criteria that will result in a sound radiological protection control program have been incorporated into the MGDS. These include items important to radiological safety (QA-1 Classification, QAP-2-3/Rev. 7) and items important to occupational radiological exposure (QA-7 Classification, QAP-2-3/Rev. 7). This section discusses the overall program which will assure that the MGDS will be a radiologically safe facility to operate.

10.2.1.2 Summary of Studies

A. ALARA Design Program – A documented ALARA Program has been established to support the study and design activities in such a manner as to meet DOE and operator ALARA criteria, ensure that during normal operation of the MGDS, exposures are ALARA, and design into the MGDS engineering the controls to handle anticipated abnormal operations. The ALARA Program will serve as a basis for the operational ALARA program that will be established at the start of repository operations by the MGDS operator.

B. Preliminary Dose Assessment for the MGDS Surface Facility Waste Handling Operations – The preliminary dose assessment was made for each step in each operation that occurs at the surface facilities. This assessment was made for each of the known types of transportation casks and served to identify the points in the concept of operations where a particular amount of attention should be paid to an operational step in order to reduce exposure.

C. Internal Radiation Streaming for the Transporter Cask/Multi-Purpose Canister Radial Gap – This study examined the radiation level that would be anticipated to occur above an multi-purpose canister placed in a transportation cask with the cask lid removed. The radiation resulting from streaming and scatter through a gap between the canister and the inside cask wall was determined to be significant even though the top of the canister itself is semi-shielded.

10.2.2 Design Input

10.2.2.1 Design Requirements

All text in this section is excerpted directly from the RDRD, which is the reference source for repository requirements. The specific RDRD requirements quoted below are considered applicable to aspects of radiological safety. Other RDRD requirements, which may apply in a more general way, are not included here such as those dealing with accident scenarios discussed in Section 10.1.

3.2.2.1 General Requirements

A. The Geologic Repository Operations Area shall, to the extent practicable, be designed and constructed to use procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are ALARA. ALARA principles shall be based on the applicable sections of NRC Regulatory Guides 8.8 and 8.10.

B. The Geologic Repository Operations Area design and operations shall include provisions for controlling doses such that, when approved operational procedures are followed, the exposure dose limits specified in 10 CFR 20.1201 for occupational doses, and 10 CFR 20.1301 for individual members of the public, are not exceeded.

C. The Geologic Repository Operations Area shall be designed so that, until permanent closure has been completed, radiation exposures and radiation levels and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in 10 CFR 20 and environmental standards for radioactivity as established by the EPA and specified in this document.

D. The Geologic Repository Operations Area shall provide means to limit the levels of radioactive materials in effluents, during normal operations, anticipated occurrences, and under accident conditions. Releases shall be limited as follows:

   Releases shall be limited as follows:

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

   2. Under accident conditions, the annual dose equivalent shall not exceed [TBD].

E. The disposal system shall be designed to meet the individual protection requirements specified by 40 CFR 191.15 [TBR].

3.2.2.2 Public Protection

A. Repository facilities shall be designed to operate so that the total effective dose equivalent to individual members of the public from the licensed operation does not exceed 0.1 rem

(1 mSv) in a year, exclusive of the dose contribution from the facility's disposal of radioactive material into sanitary sewerage in accordance with 10 CFR 20.2003. However, the facility may apply for prior NRC authorization to operate up to an annual dose limit for an individual member of the public of 0.5 rem (5 mSv) in accordance with 10 CFR 20.1301(c).

B. If members of the public have access to controlled areas, the limits for members of the public shall continue to be applicable to those individuals.

C. Repository facilities shall be designed to operate so that the dose in any unrestricted area from external sources does not exceed 0.002 rem (0.02 mSv) in any one hour.

3.2.2.3 Airborne Radioactive Material Control

A. Concentrations of radioactive material in air shall to the extent practicable be controlled through the use of process or other engineering controls (e.g. containment or ventilation).

B. When it is not practicable to apply process or other engineering controls in restricted areas to control the concentrations of radioactive material in air to values below those that define an airborne radioactivity area, the repository shall, consistent with maintaining the total effective dose equivalent ALARA, have the capability to increase monitoring and limit intakes by one or more of the following: control of access, limitation of exposure times, use of respiratory protection equipment, or other controls.

C. The Geologic Repository Operations Area shall be capable of implementing and maintaining air sampling sufficient to identify potential hazards, to permit proper protective equipment selection, and to estimate exposures.

3.2.2.4 Radiation Monitoring

A. Waste handling facilities shall be equipped to monitor occupational exposures to radiation at levels sufficient to demonstrate compliance with the occupational dose limits of 10 CFR 20, including:

1. Adults likely to receive, in 1 year from sources external to the body, a dose in excess of 10 percent of the limits in 10 CFR 20.1201(a).

2. Minors and declared pregnant women likely to receive, in 1 year from sources external to the body, a dose in excess of 10 percent of any of the applicable limits in 10 CFR 20.1207 or 10 CFR 20.1208.

3. Individuals entering a high or very high radiation area.

B. Equipment to monitor, as specified in 10 CFR 20.1204, the occupational intake of radioactive material by and assess the committed effective dose equivalent to:

1. Adults likely to receive, in 1 year, an intake in excess of 10 percent of the applicable annual limit on intake in Table 1, Columns 1 and 2, of appendix B to 10 CFR 20.1001 - 10 CFR 20.2401.
2. Minors and declared pregnant women likely to receive, in 1 year, a committed effective dose equivalent in excess of 0.05 rem (0.5 mSv).

C. Visual and audible alarm systems shall be provided to alert workers if radiation levels exceed established design levels. Visibility and audibility of alarms shall be in accordance with NRC Regulatory Guide 8.5.

D. Radiation monitors for monitoring radiation levels at various locations surrounding the site shall be provided. Appropriate monitors for ambient radiation, water, and airborne gaseous and particulate radioactivity will be used. Wells for monitoring radioactive contamination of groundwater shall be provided as required.

3.2.2.7 Transportation Protection

The Repository Segment shall be provided with the capability to comply with the requirements for packaging and transporting radioactive materials contained in 10 CFR 71 and 49 CFR 173 when shipping licensed radioactive material from the MGDS.

3.2.4.3.2 High Radiation Area Access Control

A. Access to high and very high radiation areas shall be controlled in accordance with the requirements specified by 10 CFR 20.1601 and 20.1602.

B. The repository design shall provide at each entrance or access point to a high radiation area:

1. One or more of the following features:

   a) A control device that, upon entry into the area, causes the level of radiation to be reduced below that level at which an individual might receive a deep-dose equivalent of 0.1 rem (1 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

   b) A control device that energizes a conspicuous visible or audible alarm signal so that the individual entering the high radiation area and the supervisor of the activity are made aware of the entry.

   c) Entryways that are locked, except during periods when access to the areas is required, with positive control over each individual entry.

2. Or, in place of the controls required by 3.2.4.3.2.B.1 above, continuous direct or electronic surveillance that is capable of preventing unauthorized entry.

3. Or an alternative method for controlling access to high radiation areas approved in advance by the NRC.

4. The controls required by subparagraphs 1 and 3 above shall not prevent individuals from leaving a high radiation area.

5. Control shall not be required for each entrance or access point to a room or other area that is a high radiation area solely because of the presence of radioactive materials prepared for transport and packaged and labeled in accordance with the regulations of the Department of Transportation provided that the packages do not remain in the area longer than 3 days and the dose rate at 1 m from the external surface of any package does not exceed 0.01 rem (0.1 mSv) per hour.

3.2.4.4 Radioactive Materials Monitoring

The Repository Segment shall be equipped to monitor the external surfaces of packages and casks known to contain radioactive material for radioactive contamination and radiation levels in compliance with 10 CFR 20.1906.

3.2.4.5.1 Shielding Design

A. Normally Occupied Areas. The shielding design basis shall limit the maximum exposure to an individual worker to one-fifth of the annual occupational external exposure limits. Within this design basis, personnel exposures must be maintained ALARA. Specifically, the shielding should be designed with the goal of limiting the total effective dose equivalent to less than one rem per year to workers, based on their predicted exposure time in the normally occupied area. The effective dose equivalent is the sum of all contributing external penetrating radiation (gamma and neutron). In addition, appropriate shielding must be installed, if necessary, to minimize non-penetrating external radiation exposures to the skin and lens of the eye of the worker. In most cases, the confinement barrier or process equipment provides this shielding.

B. Intermittently Occupied Areas. Shielding and other radiation protection measures shall be provided for areas requiring intermittent access, such as for preventive maintenance, component changes, adjustment of systems and equipment, and so forth, with the goal of limiting dose rates based on occupancy, time, and frequency of exposure to one rem per year.

C. Concrete. Concrete radiation shielding design shall comply with ANSI/ANS 6.4 and ACI 349 and shall consider the material specifications of ANSI/ANS 6.4.2 where it provides a critical confinement or structural function. For other shields, ACI 318 is appropriate and provides adequate strength for design earthquake loads.

D. Penetrations. Design of shield walls shall avoid straight-line penetrations to prevent radiation streaming.

3.2.4.5.2 Remote Shielded Operation

Remote shielded operation (i.e., with remote handling equipment such as remote manipulators) shall be considered where it is anticipated that exposure to hands and forearms would otherwise approach the dose requirements in Section 3.2.2 or where contaminated puncture wounds could occur.

10.2.2.2 Design Assumptions

Assumptions relevant to evaluation of radiological concerns, as stated in the Controlled Design Assumption Document, are noted as follows:

A. The Surface Facilities that house radioactive materials or in which work is performed on radioactive materials will be designed to control occupational exposures to ALARA and less than 500 mrem per year.

B. ALARA studies will be conducted as needed to establish the allowable dose rates upon which various radiological safety calculations will be based.

Additional assumptions regarding radiological concerns are required in order to proceed with current design related issues. The more significant of such issues include the following:

C. Limiting Repository Waste Characteristics: The most limiting waste that will be analyzed for shielding purposes will be the highest burnup light water reactor fuel that appears in the Characteristics Data Base. Based upon the current database, this limiting value is 60,000 MWd/IHM. Additionally, the limiting waste will be based upon the uncanistered fuel disposal container that contains fuel that has been allowed to decay for a minimum of 10 years prior to receipt at the repository.

D. ALARA Evaluations: The facility ALARA program as describes in detail how to calculate the various factors that are to be considered in an ALARA evaluation. Not included is a recommended value for "reasonableness." That is, how much should be expended to save a future man-rem of exposure. NRC guidance on this issue has been published in 10 CFR 50, Appendix I for Nuclear Power Reactor Effluents. No specific guidance is currently available in the Code of Federal Regulations for a HLW Repository design.

E. Dosimetry Calculations: Evaluations of radiation fields associated with HLW require translation into equivalent dose rate values of rem/hr. In general, such radiation fields are energy dependent with values from MeV values down to values approaching zero energy. The calculation of dose rate for both gamma fields and neutron fields is dependent upon the energy of the particular photon or neutron particle being evaluated which is a reflection of the relative effectiveness in producing damage to target material. Energy dependent conversion factors have been recommended by ANSI/ANS (1991) for both gamma and neutron field evaluations. However, a recent International Commission on Radiological Protection study recommends doubling the values for neutron field conversions into dose rate based upon a re-evaluation of world-wide dosimetry data for the effects upon human tissue. Most U.S. authoritative organizations have concurred with this recommendation, including the DOE in the most recent issue of the DOE Radiological Control Manual. However, the latter document was not specific in indicating which table values for neutron fields were to be doubled. Consequently, it is recommended that the ANSI/ANS (1991) tabulated values for neutron field conversion into dose rate be doubled in accordance with the recommendation of the International Commission on Radiological Protection consistent with ALARA. The existing guidance values for gamma field conversion into dose rate will be used as currently stated in ANSI/ANS (1991).

10.2.3 Design Considerations

10.2.3.1 General Considerations

This section describes the anticipated radiological safety concerns and considerations associated with the design and operation of the MGDS. The DOE policy on radiological control and safety for the design and operation of the MGDS is summarized below.

A. ALARA – Personal radiation exposure shall be maintained ALARA. Radiation exposure of the work force and public shall be controlled such that radiation exposures are maintained below regulatory limits and there is no radiation exposure without commensurate benefit.

B. Ownership – Each person involved in radiological work is expected to demonstrate responsibility and accountability through an informed, disciplined and cautious attitude toward radiation and radioactivity.

C. Excellence – Excellent performance is evident when radiation exposures are maintained well below regulatory limits, contamination is minimal, radioactivity is well controlled and radiological spills or uncontrolled releases are prevented.

Low-level radioactive waste materials are received from operational areas within the RCA. These secondary waste materials are primarily generated from decontaminating the surface of casks, canisters, from contamination coming off bare fuel assemblies, and from other equipment that has come into contact with contaminated materials. These low-level wastes are typical for nuclear fuel cycle facilities with hot cell operations. The radioactive sources in the waste materials will produce alpha, beta and gamma type radiations, with the gamma radiations providing the most significant whole body exposures and the alpha and beta radiations providing the most significant ingested exposure. There will also be some neutron radiations; however, these radiations constitute a small percentage of the total radioactive emissions.

Direct Exposures

Direct exposures will primarily be caused by the gamma radiations although there are a smaller amount of neutron radiations present. Direct exposures are minimized by limiting the quantity of the source materials, biological shielding, distancing personnel from the radiation sources, and reducing personnel exposure time. Section 10.2.3.3 identifies the radiation protective measures that have been designed into the various MGDS facilities to reduce and/or eliminate personnel direct exposures according to ALARA.

The ACD design includes general protective measures to minimize direct exposure consisting of permanent and temporary shielding, Radiation Area Monitors, Constant Air Monitors, remote operations and administrative procedures.

Internal Exposures

Internal exposures occur as a result of radioactively contaminated material entering the body by eating, breathing, or absorption through cuts, bruises, etc. Ingested exposure has the potential to be the most damaging type of exposure because of its proximity to sensitive body organs and because it takes time to egest the material from the body. Ingested exposures are minimized by minimizing direct contact between airborne contamination and personnel and by the use of good radiological safety practices.

The MGDS designs include protective measures consisting of Constant Air Monitors to measure the contaminated particulate matter in the air, the availability and use of breathing devises such as respirators, the use of glove boxes for contact operations involving materials that are known to be contaminated, and zoned heating, ventilation, and air conditioning (HVAC) confinement systems to control the spread of contamination and minimize the potential for contact with the operating personnel.

The wastes are packaged and immobilized to physically control and prevent contamination release during interim staging and shipping.

10.2.3.2 MGDS Site Radiological Control Program

It is the policy of the DOE and its contractors to conduct radiological operations during the design, operation, caretaker, and closure periods in a manner that protects and promotes the radiological safety of employees, visitors and members of the general public. This policy will be enforced through the implementation of an effective radiation control program, as approved under NRC license, that identifies and controls radiological hazards. The radiation control program will ensure that the receipt, possession, use, transfer and disposal of licensed materials are conducted such that the total dose to an individual does not exceed the standards for radiation protection prescribed in 10 CFR 20.

As part of the implementation of this program, in accordance with the classification QA-7 in QAP-2-3/Rev. 7, the operator will use radiation protection and awareness training, administrative procedures, personnel monitoring and engineering controls and techniques, that are based on sound and accepted radiation protection principles, to maintain occupational doses and doses to members of the general public that are ALARA. The program will be assessed and audited periodically to determine program content, implementation and effectiveness. The program will be modified, as warranted, to ensure compliance with the standards for radiation protection.

The key to conducting and maintaining an effective radiation control program is the individual employee. Each employee is expected to plan and conduct their radiological activities that promotes the achievement and maintenance of radiation doses ALARA. In support of the employee(s), supervisors and managers are accountable for ensuring that all personnel entering radiological areas and/or conducting radiological activities are properly trained and monitored, and that radiological activities are planned, authorized, and performed according to procedure and in a radiologically safe manner.

The Radiological Control Manager for the MGDS has the operational responsibility for the implementation program elements and maintenance of the radiation control program to meet regulatory requirements. Prior to the initiation of any radiological operation and during the conduct of such operations, the Radiological Control Manager is responsible for the review and approval of the activities associated with the operation to ensure that personnel doses are less than regulatory standards and that doses are maintained ALARA. Any activity which involves the use of radioactive materials, ionizing radiation producing equipment and/or involves the monitoring of personnel to ensure compliance with regulatory standards for radiation protection will be reviewed by the MGDS ALARA Committee.

The MGDS ALARA Committee will consist of management representatives from those divisions/organizations that conduct radiological operations and/or monitor personnel radiation doses. The Committee has the responsibility for the review and evaluation of radiation doses to ensure that sound radiological principles are employed in the conduct of those operations. The Committee will recommend, on the basis of the radiological protection evaluation, that the activity either be approved or denied. In addition to the review and evaluation of specific radiological operations, the ALARA Committee is responsible for determining the effectiveness of the radiological control program

All radiation areas within the MGDS facility area will be posted, in accordance with regulatory requirements, in order to control access to those areas and to maintain personnel radiation dose ALARA. In addition to posting areas, all containers/packages containing licensed radioactive materials will be labeled in accordance with regulatory requirements.

Radiological monitoring of employees and conducting radiation surveys will be performed to demonstrate compliance with regulations, meet license requirements and to meet the goals of the radiation control program. Monitoring of internal and external occupational doses will be conducted as required by regulations. The purpose of these activities will be to define and evaluate the extent of radiation levels, concentrations or quantities of radioactive materials, and potential radiological hazards that may be present. The results of these activities will be maintained as required by regulation. Area surveys and individual personnel monitoring results will be available to the individual employee upon request.

10.2.3.3 Design Specific Considerations

A. Site Access and Control – Transportation casks entering the site (RCA) will undergo monitoring for identification, security, and radiological inspection. The cask carrier will then be attached to the on-site prime mover and moved either into a temporary parking location or directly to the Staging area. If the casks arrive by truck, the truck will transport the cask to the required location. The shipping hardware, which consists primarily of the impact limiters and the personnel barrier, will be removed The carrier and the transportation cask will then be moved into the Waste Handling Building by the on-site prime mover.

B. Waste Handling Building – The Waste Handling Building is the primary location of the surface facilities. It is in this building that the majority of waste handling operations take place and is the only facility in which either bare waste or canisters are exposed. The operations of the facility, the facility layout, and the equipment that it takes to perform the operations are described elsewhere in this report; however, certain features have been incorporated into the Waste Handling Building design for the specific purpose of providing the necessary radiological protection for both operational and public radiological protection. These features are listed below:

- Air lock building entries and exits

- Cask transfer ports are shielded and are designed to eliminate or minimize the spread of contamination. They will be remotely operated to eliminate or minimize personnel radiation exposure.

- The cells in which the operations take place are shielded and all operations will be remotely performed.. Associated equipment such as shielding windows for direct viewing, television cameras for indirect and/or close up viewing, microphones for sound, mechanical and electromechanical manipulators for remote handling, and other remote handling tools will be provided.

- The building ventilation system is designed to insure the containment according to the applicable requirements.

- Provisions have been incorporated into the design to accommodate the normal maintenance activities such as manipulator repairs, decontamination, filter changeouts, etc.

C. Cask Maintenance Facility – The Cask Maintenance Facility at the MGDS services the transportation casks in which multi-purpose canisters and uncanistered SNF are delivered to the repository from their various points of origin. In addition, the Cask Maintenance Facility services the cask transporters and any ancillary equipment (personnel barriers, impact limiters, campaign kits, etc.) associated with the cask shipment. Cask, transporters, and equipment are inspected, tested, repaired, decontaminated, and otherwise maintained as required to keep the cask fleet in operation. Operations of the facility, the facility layout, and the equipment it takes to perform the operations of the facility are described elsewhere in this report. However, certain features have been incorporated into the Cask Maintenance Facility design for the specific purpose of providing the necessary radiological protection for both operational and public radiological protection. These features are listed below:

- Air locks between each confinement zone within the building
- Shielded radwaste staging areas
- A pool to minimize exposure and contamination
- Direct piping to a filtered HVAC system for cask purging
- An underwater vacuum system for cask interior cleaning
- Underwater closed-circuit television system for indirect and close up viewing
- A building ventilation system designed to enhance contamination control and provide containment according to the applicable regulations
- A building layout that allows for similar confinement zones to be placed together
- Provisions have been incorporated into the design to accommodate the normal maintenance activities.

D. Waste Treatment Building – Site generated secondary waste will be produced in the course of repository operations and maintenance. These wastes will include low-level radioactive waste, hazardous waste, and a small amount of mixed waste. The Waste Treatment Building is the location where these waste materials will be prepared for final disposition. The materials that will be processed in this facility will contain only low amounts of radioactivity and will have the potential for only small amounts of direct exposures. The main radiological protection in the Waste Treatment Building will be for ingested exposures and will consist of a controlled building HVAC systems, extensive constant air Monitoring systems, glove boxes, hoods, and personnel monitoring systems.

E. Waste Package Transporter – The waste package transporter will convey the final Waste Package into the repository for final emplacement and will be pulled by a single primary locomotive as described in Section 8.6. If required, the waste package transporter will also be used in the event that waste package retrieval is required. The waste package transporter will be designed to provide sufficient shielding around the waste package in order to minimize personnel hazards during inspection, maintenance, and transport activities. The final design, and maximum radiation exposure rate, will be determined using an ALARA type of analysis. This is expected to include a tradeoff study between the waste package transporter weight/size restrictions. The external radiation exposure rate is expected to be less than 100 (mrem) at 1 m from the outside surface, which, combined with suitable administrative restrictions, should provide adequate personnel protection.

F. Waste Package Emplacement – Emplacement of the waste package will be, for the most part, performed remotely with the possible use of a manned position inside of the primary locomotives. Local shielding of the operator station will be required for such a manned position in order make such a location permissible. Local shielding may also be required to support the control, alarm, and surveillance equipment that is needed for each emplacement drift as well as all other subsurface facilities.

G. Waste Package Backfill – Backfill, although not required, may nonetheless be considered in the future, Section 8.8. Should this be needed, shielding of critical controls, sensors, and monitors necessary during backfill will be required. Additionally, some shielding may be required of specialized primary equipment to ensure reliability in the harsh emplacement drift environment.

H. Waste Package Retrieval – Retrieval may be a relatively simple process or it might involve a waste package that has been buried by a rockfall. Specific radiation design solutions may be required to protect against the potential effects of both direct radiation and against the spread of loose radioactive material in the case of a breached waste package.

I. Underground Ventilation – Separate ventilation systems are provided for the development and emplacement areas of the repository as described in Section 8.8. These are maintained at positive and negative pressures respectively in order to minimize the spread of contamination in the event of a leaking waste package for all potential conditions. Additionally, these systems are separated within the repository by physical air flow barriers.

10.2.4 Summary

This section described the initial activities that have occurred during the FY 1995 in the incorporation of radiological safety into the design of the surface and sub-surface facilities. Since radiological safety had not previously been a part of MGDS design activities, the programs and approaches were created to accommodate the most limiting of requirements that are given in DOE Order 6430.1A, 10 CFR 20, and other documents that have been discussed the previous sections. A Design ALARA Program was established with the help and cooperation of the Health and Safety group to incorporate an organized approach into the design activities that would support the various design activities, insure that radiological safety issues were identified and addressed, document findings for future reference, and provide a means of creating an operation that could be conducted efficiently and safely. Several activities were conducted which directly impacted the material handling and the facility layouts as they developed during the course of the ACD. It should be recognized that these efforts will be needed throughout the entire course of the MGDS design including verification during and following construction.

10.3 INDUSTRIAL SAFETY

The safety of workers and members of the public is of paramount importance for the MGDS. This means designing and operating a system that allows for continued management, handling, transfer, storage, emplacement, retrieval, and isolation of spent nuclear fuel and high level waste in a safe manner that optimally protects health, safety, and the environment under all operational conditions.

10.3.1 Policy and Process

The safety and health of workers on the project receives the highest priority. For MGDS construction and operation, both radiological safety and occupational safety and health plans and procedures are followed. Radiological control for normal operating conditions is achieved primarily through design by employing the ALARA principle: For off-normal radiological events or accidents, DBE/Design Basis Accident (DBA) analyses are used along with Probabilistic Risk Assessments, where appropriate. Occupational safety and health is addressed by application of, primarily, Occupational Safety and Health Administration standards 29 CFR 1910 and 29 CFR 1926, and Mining Safety and Health Administration standard 30 CFR 57, supplemented by other standards as appropriate to achieve an adequate level of protection for the workers as, for example, in the *Safety and Health Plan* (YMP 1995c). Consideration of safety begins at the design with YAP-30.48, *System Safety Analysis*, as described by the *System Safety Plan* (YMP 1995f). Preliminary Hazards Analyses are used to identify and mitigate hazards and this analytical process continues down to job task level which uses Job Safety Analysis methodology to assure worker protection.

10.3.2 Previous and Ongoing Work

Providing for the safety and health of workers and operating personnel on the project has already been incorporated for the ESF and is the result of an integrated interdisciplinary effort that directly affects design as well as operating practices.

These safety efforts continue for the MGDS and are not only integrated from a design discipline and operational standpoint but from a radiological and non-radiological standpoint as well. Design efforts concerning ALARA (Section 10.2, Vol. II) and DBEs and DBAs are also coordinated (Section 10.1, Vol. II) . For example, the Preliminary Hazards Analysis is used as the focal point for surface, subsurface, and Waste Package (Section 8, Vol III) DBEs/DBAs from a radiological standpoint. The same Preliminary Hazards Analysis is used for non-radiological safety in the form of a System Safety Analysis to insure thoroughness and consistency. Other related deliverables being conducted in parallel are the *Preliminary MGDS System Safety Analysis* (CRWMS M&O 1996b) and the *Waste Package Off-Normal and Accident Scenario Report* (CRWMS M&O 1996c).

10.3.3 Design Inputs

The following requirements are from the RDRD. Requirements are identified in accordance with the numbering system used in the RDRD.

3.3.6.1 General requirements:

A. All Repository Segment work places shall be designed to be free from recognized hazards that are causing or are likely to cause death or serious physical harm to employees.

B. All Repository Segment work places shall be designed to comply with occupational safety and health standards promulgated under 29 CFR 1910, 29 CFR 1926, and 30 CFR 57.

3.3.6.2 System Safety Precedence

The order of precedence for satisfying system safety requirements and resolving identified hazards shall be as follows:

A. The first priority of design shall be to eliminate hazards. If the hazard cannot be eliminated, the associated risk shall be reduced shall be reduced to an acceptable level through design selection.

B. If identified hazards cannot be eliminated or their associated risks adequately reduced through design selection, that risk shall be reduced through the use of fixed, automatic, or other protective safety design features or devices. when applicable.

C. When neither design nor safety devices can effectively eliminate identified hazards or adequately reduce associated risk, devices shall be used to detect the condition and to produce an adequate warning signal to alert personnel of hazard. Warning signals and their application shall be designed to minimize the probability of incorrect personnel reaction to the signal and shall be standardized within like types of systems.

D. Only where it is impractical to eliminate residual hazards through design selection or adequately reduce the associated risk with safety and warning devices, may procedures and training be used as the only protection.

E. This Section (3.3.6) imposes requirements from 29 CFR 1910, 29 CFR 1926 and 30 CFR 57.

1. 30 CFR 57 shall apply only to underground facilities and equipment and to those mining-related surface facilities and equipment specifically addressed in 30 CFR 57.

2. 29 CFR 1910 and 29 CFR 1926 shall apply to all other surface facilities and equipment. 29 CFR 1910 and 29 CFR 1926 shall also be applied to underground facilities not addressed by 30 CFR 57 and where safety hazards analysis following the precedence in Section 3.3.6.2.A-D deems it necessary.

3.2.5.1.2 Reliability of Equipment

A failure modes and effects analysis shall be performed for all major equipment whose failure can result in personnel injury or illness. Based on this analysis, designs shall be developed to ensure reliability which minimizes safety hazards to the extent possible. Under such design conditions, failures shall not result in personnel injury or occupational illness. If designs cannot be developed to these requirements, then the reliability of systems will be shown by analysis to be such as to minimize the probability of injury or illness to personnel. In demonstrating system reliability, MIL-STD-882B shall be considered in the design, where applicable. (These requirements differ from "items important to safety" and "item important to waste isolation", both of which have very specific meanings for meeting NRC requirements. Further, these criteria do not supplant radiological standards contained in NRC or EPA requirements: e.g., the radiological standards 10 CFR 20).

(MIL-STD-882C is the latest version. The next revision of the RDRD will reflect the latest version.)

10.3.4 Methodology

A general description of the methods used to achieve a high level of industrial safety is contained in the following four activities:

- Establishing precedence
- Conducting and implementing System Safety Analyses
- Complying with regulatory requirements
- Monitoring and verifying.

10.3.4.1 Establishing Precedence (See Subsection 10.3.3)

10.3.4.2 Conducting and Implementing System Safety Analyses

Performing System Safety Analyses and implementing the results is the result of applying the process described in Attachment 9.4 of YAP-30.48, *System Safety Analysis*. The process consists of the following three principal activities:

- Safety Assessment
- Mitigation
- System Safety Working Group.

Safety Assessment: The Safety Assessment activity consists of scenario identification and safety analysis. Safety analysis is comprised of the establishment of system criteria, relevant databases, and application of these criteria to the appropriate design phase. Scenario identification is the detailed description of the identified hazards resulting from Preliminary Hazards Analyses.

Mitigation: Each hazard has one or more mitigations identified which are used to alter the design appropriately or is passed on as a procedural matter to be implemented. The mitigations must reduce the risk to a preselected level of risk.

System Safety Working Group: A System Safety Working group is established for each System Safety Analysis (consisting of designers and safety personnel as a minimum) to establish, review, and evaluate hazardous scenarios prior to sign off.

10.3.4.3 Complying with Regulatory Requirements

Occupational safety and health requirements are primarily derived from compliance with Occupational Safety and Health Administration rules found in Title 29 CFR Part 1900 through 1926. Other standards and regulations are used to supplement the Occupational Safety and Health Administration OSHA rules; their use and application is determined by the DOE Assistant Manager for Environment, Safety, and Health (AMESH) in accordance with the *Safety and Health Plan* (YMP 1995c).

A guiding principle in the use of any selected Occupational Safety and Health Administration standard is as follows: if a particular standard is specifically applicable to a condition, practice, operation or process, it prevails over any other standard that might otherwise be applicable to the same situation.

10.3.4.4 Monitoring and Verifying

Implementation of industrial safety measures is verified through surveillance and inspection of workplaces. Industrial hygiene monitoring is conducted on a continuing basis for workplace environmental agents. Employees are encouraged to bring hazardous conditions or practices to management's attention for correction. Hazardous conditions or practices that are not in compliance with requirements, or accepted safe practices identified in Job Safety Analyses, are corrected by line management. To prevent recurrence, training is conducted on a continuing basis. Regular safety meetings are held to discuss current issues and provide employees with timely information. Trend analysis of injuries and illnesses is performed to determine if the System Safety Analyses and Job Safety Analyses, applicable to the causal conditions, should be reviewed and modified.

10.3.5 Conclusions

The success of the safety efforts for the MGDS will, as in the past require close coordination not only with the design groups but with support analysis groups such as those involved in Waste Package probabilistic evaluations, DBE/DBA analysis, and Performance Assessment/Probabilistic Risk Assessment. At the same time, interfaces need to be maintained between system safety and health and safety to ensure that industrial safety is addressed thoroughly in design as well as operations.

11. OFF-SITE TRANSPORTATION WITHIN NEVADA

The 1995 systems study, *Nevada Potential Repository Preliminary Transportation Strategy Study 2* (CRWMS M&O 1995ax), recommended four rail routes for consideration as alternatives for the transportation of radioactive waste to the proposed repository at Yucca Mountain, Nevada. Routes evaluated in Study 2 were based on previous Study 1 work (CRWMS M&O 1995ay), which had eliminated several other potential routes. During Study 2, the routes were evaluated for fatal flaws primarily from the standpoint of land-use and topographic constraints. All Study 2 routes are currently recommended as reasonable alternatives for further evaluation.

The four rail routes are summarized as follows:

- Valley Modified Route – From a connection with Union Pacific in the Dike/Apex area (northeast of Las Vegas) to the repository via the Indian Springs vicinity, based on a revised Study 1 corridor. Two routing possibilities were considered in the Indian Springs area.

- Jean Route – From a connection with Union Pacific in the Jean/Borax area (south of Las Vegas) to the repository via Pahrump Valley, based on a revised and expanded Study 1 corridor. Key alternate routing possibilities are via Wilson Pass versus State Line Pass and via the northern Pahrump Valley versus Stewart Valley.

- Carlin Route – From a connection with Southern Pacific and Union Pacific at Beowawe (between Carlin and Battle Mountain), via Big Smoky Valley to a point near Mud Lake (southeast of Tonopah), from where part of the Caliente Route is used for the remaining distance to the repository. An alternate route via Monitor Valley was also studied.

- Caliente Route – From a connection with Union Pacific at Caliente to the repository via Mud Lake, based on a preliminary alignment completed by DeLeuw Cather (SAIC 1992).

Study 2 identified current land-use constraints along each rail route through extensive research of land records and field investigation. Using this land-use research data and engineering criteria, pre-conceptual design refined the corridors to a width of one to five miles, and in the process ensured that each corridor supported a feasible route with minimal land-use conflicts.

The following sections summarize the engineering analyses performed in Study 2 for each of the rail routes.

11.1 PREVIOUS WORK

11.1.1 Engineering Analysis

Engineering criteria, as described in the Design Inputs Section, were applied to the various proposed routes to yield a pre-conceptual engineering survey. Key elements of this analysis included:

- Acquiring complete map coverage of corridors and adjacent areas, including United States Geological Survey (USGS) 1:24,000 scale (7.5') topographic maps and U.S. of Land Management (BLM) 1:100,000 scale Surface Management Status maps.
- Establishing approximate locations of feasible alignments according to land-use constraints and engineering criteria. This activity involved extensive topographic map analysis and field investigation.
- Developing quantity estimates, cost estimates, and construction schedules.

Each route was divided into a series of sections, reflecting various alternates studied within each corridor. Route Section Description sheets in Appendix F1 present details concerning the following types of constraints considered:

- Land-use constraints
- Archeological and historical sites
- Road crossings and proximity to population
- Topographic considerations
- Bridges and hydrologic considerations
- Operating considerations.

A state-wide map showing the refined corridor boundaries for the four rail routes is shown in Figure 11-1.

11.1.2 Maps and Profiles

Maps and profiles of the route corridors are included in Appendix F2. A total of 17 map sheets at a scale of 1:250,000 (1" = 4 miles approximately) provide complete coverage of the corridors, illustrating the following key features:

- Proposed rail corridors
- Existing railroads
- Highways
- Topography indicated by contour lines at 200-foot intervals
- Hydrography
- Boundaries of the Nevada Test Site and the Nellis Air Force Range.

Profiles are presented for each section, as delineated in the Route Section Description sheets. These indicate the existing ground line along a likely track alignment; actual track profiles are to

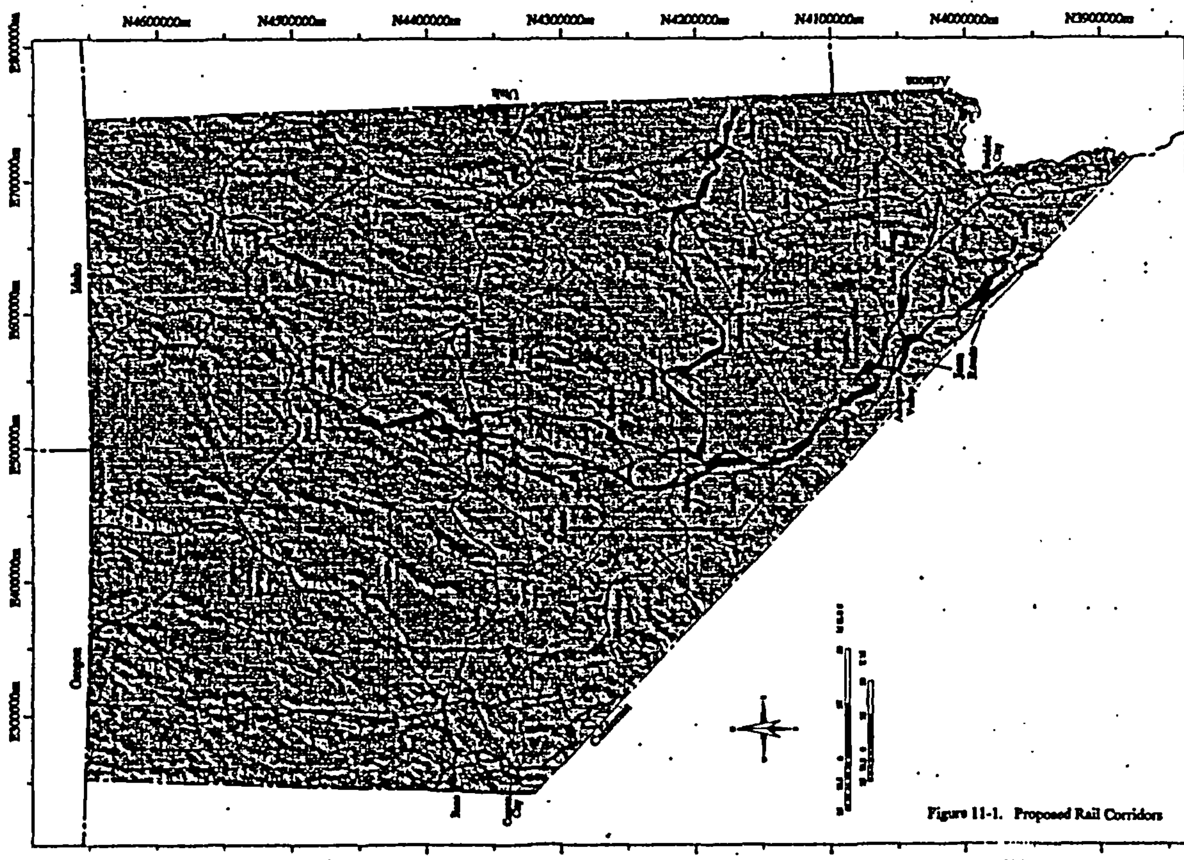


Figure 11-1. Proposed Rail Corridors

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be developed in subsequent design work. Contiguous small-scale profiles covering the entire length of each corridor are also included in Appendix F2 for comparative purposes.

11.1.3 Quantity Estimates

Preliminary quantities for earthwork, bridges, grade separations, tunnels, and track length for each route are presented in the Quantity Takeoff sheets in Volume IV. Key assumptions used in developing these quantities are as follows:

- Right-of-Way – Acreage is based on a total right-of-way width of 400 feet throughout.

- Clearing and Grubbing – Acreage is based on an average of 10.8 acres/track mile.

- Earthwork – Roadbed width is assumed to be 24 feet. Parallel access (maintenance) roads were not considered at this time.

  Earthwork quantities were computed through a cursory survey of 1:24000 scale topographic maps. As shown on the Quantity Takeoff sheets, each route section is divided into a series of subsections at points where significant changes in the nature of the topography is apparent. Within each subsection, an approximate average height of cut or fill was estimated, upon which the average volume of earthwork per mile was based. The volume figure was reduced by up to 30 percent (through the "Balance Ratio") in areas where the proximity of cuts and fills clearly permits use of most excavated material for fills.

  Breakdown of the excavated material into common, rippable, and hardrock quantities is based on rough percentages estimated from field inspection.

- Subballast – Volume is based on 3,200 cubic yards/track mile.

- Track Length – Includes 2,500-foot sidings at 80-mile intervals, plus 1.6 miles of yard trackage.

- Signaled Grade Crossings – Assumed at all roads indicated as "Light-Duty" (typically gravel) on 1:24,000 scale maps.

- Grade Separations – Assumed at all paved public road crossings; the need for separation structures at other public roads will be evaluated during subsequent design. A three-span structure (totaling 130 feet long) was assumed for all grade separations over two-lane roads, while a five-span structure (totaling 230 feet long) was assumed for all four-lane highways.

- Bridges – The width of the watercourse (as shown on 1:24,000 scale maps) was used as the basis for bridge length.

- Major Culverts. Assumed in areas where the required culvert size and/or number of installations per mile would be significantly greater than average.

11.2 DESIGN INPUTS

Basic design criteria were established in Study 2 to govern corridor definition and facilitate consistent evaluation of alternate routes. Prior to conceptual design, these requirements will be reviewed, and applicable standards placed in the *Repository Design Requirements Document* (YMP 1994a).

11.2.1 General

Design must comply with DOE Order 6430.1A, *General Design Criteria*, and the recommendations of the American Railway Engineering Association, as prescribed in the current issue of the *Manual for Railway Engineering* (AREA 1994).

11.2.2 Traffic

Based on the Transportation Cask Arrival Scenario in the CDA Document, Key Assumption 001, (CRWMS M&O 1995a) the rail line will handle up to 600 shipments of spent nuclear fuel and HLW per year along with corresponding return movement of empty transportation casks and canisters. Maximum weight per cask (loaded) will be 125 tons; gross rail load is currently estimated at 194 tons per six-axle car.

The rail line may also handle movement of material and equipment for repository construction, maintenance, and operation, as well as other possible freight traffic. Due to the expected low volume and lighter car weights of such traffic, no design requirements beyond that for the principal traffic are envisioned at this time.

11.2.3 Grades and Curvature

Based on typical U.S. railroad practice for new construction, maximum grade and curvature limits of 2.5 percent and 8 degrees were assumed, respectively.

To the extent feasible, grades in the 1.5 percent to 2.2 percent range were assumed in order to gain a level of operating safety consistent with rail lines used by waste trains prior to reaching Nevada. Grades in tunnels are limited to 75 percent of a route's maximum grade, as recommended by American Railway Engineering Association.

To limit run-times and corresponding quantity requirements for casks, rolling stock and train crews, a design speed of 50 mph was assumed desirable over the majority of each route. Consequently, curves of 2 degrees or less were assumed in corridor development where appropriate.

11.2.4 Corridor Width

A corridor width of one to five miles was considered desirable, allowing for all reasonable alignments which may be considered during subsequent design.

11.3 ROUTE DESCRIPTIONS

Table 11-1 summarizes key characteristics of the rail corridors and significant alternates within each. The corridors are further described in the following pages and in the Route Section Description sheets in Appendix F1. Maps and profiles of the corridors are in Appendix F2.

Table 11-1. General Characteristics of Rail Routes

Route and Alternates	Length (miles)	Maximum		Rise & Fall (feet)	Notes
		Grade	Curve		
Valley Modified Route					
via Indian Hills	98.0	1.5%	6°	2,700	
via Cactus Springs	97.5	1.5%	4°	2,300	
Jean Route					
via Wilson Pass and N. Pahrump	114.0	2.2%	8°	6,200	1
via Wilson Pass and Stewart Valley	118.5	2.2%	8°	6,600	1
via State Line Pass and N. Pahrump	122.0	2.2%	8°	5,400	2
via State Line Pass and Stewart Valley	126.5	2.2%	8°	5,800	2
Carlin Route					
via Big Smoky Valley	331.0	2.4%	8°	6,800	3
via Monitor and Ralston Valleys	338.0	2.4%	8°	8,700	3
via Monitor, Baxter, and Klondike	363.0	2.4%	8°	9,600	3
Caliente Route	338.0	2.4%	8°	16,500	

Notes:

1. Design of Wilson Pass Alternate may increase grade to 2.5 percent and/or increase distance by up to 2.5 miles to reduce tunnel lengths.

2. Design of State Line Pass Alternate may increase curvature to 10 degrees to reduce earthwork.

3. Design of Mud Lake - repository portion (Goldfield Section of Caliente Route) may reduce maximum grade and curvature of Carlin Route to 2.0 percent and 6 degrees, respectively.

11.3.1 Valley Modified Route

Connection of the Valley Modified route with the Union Pacific main line would be between the Dike and Apex sidings. The route proceeds along the north side of Las Vegas Wash to the vicinity of Corn Creek Springs, generally parallels U.S. Highway 95 to Mercury Valley, and passes through Rock Valley and across Jackass Flats to the repository.

Physical characteristics are summarized as follows:

- Of the routes under consideration, the Valley Modified route is the shortest. Total distance from the Union Pacific connection to the repository is 98 miles.

- Compared to the other three routes, the Valley Modified route has the straightest alignment and flattest profile. Few curves require restriction below 50 mph, as most would be 2 degrees or less. Steepest grades are 1.5 percent, the longest of which would be the westbound ascent of the hills south of Indian Springs on the Indian Hills Alternate.

- The connection point is in close proximity to Union Pacific yards at Valley and Arden, at distances of 6 and 26 miles, respectively. This proximity, coupled with the route's short length, would permit flexibility for interchange operations.

As delineated by the Route Section Description sheets in Appendix F1, the route is composed of the Las Vegas Wash Section, either the Indian Hills Alternate or the Cactus Springs Alternate, and the Mercury Section. The following paragraphs summarize the key engineering concerns related to each of these sections.

Las Vegas Wash Section

Corridor location is highly dependent upon land-use constraints, particularly in the eastern half of the section where closest to North Las Vegas. As shown on the maps, a reasonable compromise was achieved between topographic and land-use constraints by locating the corridor on the alluvial fans north of Las Vegas Wash, along the southern border of the Desert National Wildlife Range. Acceptable distances are maintained from areas of critical concern, notably the 7,500-acre BLM parcel to be transferred to North Las Vegas. At the same time, this location provides the opportunity to design an alignment meeting acceptable engineering practices.

Further west, the corridor crosses Las Vegas Wash at a point 4 miles south of Corn Creek Springs where the wash is relatively confined. The corridor then parallels U.S. Highway 95; sufficient corridor width has been allowed to locate the rail line up to three-quarters of a mile from the highway to minimize public visibility and limit grades. Due to the close proximity of the Nellis Air Force Range boundary to the highway (as close as 500 feet), the corridor requires use of a strip of Nellis Air Force Range property up to three-quarters of a mile wide along the boundary for about 7 miles.

Indian Hills Alternate

Of the two routes possible in the vicinity of Indian Springs, the Indian Hills Alternate appears more feasible, as it bypasses both the community of Indian Springs and the Nellis Air Force Auxiliary Field by routing through the hills to the south. This routing requires 11 miles of 1.5 percent grade and separation structures over U.S. Highway 95 (four lanes in this area) at each end of the alternate. Although some curves up to 6 degrees would be required in the hills immediately south of Indian Springs, the balance of the alternate crosses large alluvial fans which permit a relatively straight alignment.

Cactus Springs Alternate

Due its relatively flat profile, the Cactus Springs Alternate is operationally more desirable than the Indian Hills Alternate. However, availability of right-of-way through the Indian Springs area may make this alternate unfeasible. Negotiation with the Air Force would be necessary to define a right-of-way through either the developed area between U.S. Highway 95 and the airfield (involving relocation of Air Force and civilian structures), or through areas immediately north of the airfield now used for target practice. Corridor maps indicate a gap in the corridor through this area, as definition is dependent upon such negotiations.

West of Indian Springs, to the eastern boundary of the Nevada Test Site near Mercury, a route along the north side of Indian Springs Valley is proposed to maximize distance from U.S. Highway 95. Due to the relatively rough topography along the north side of the valley, additional construction costs are expected compared with a possible routing immediately adjacent to U.S. Highway 95.

Mercury Section

The final 34 miles of the route traverses the Nevada Test Site. A steep descent into Mercury Valley is avoided by routing between the community of Mercury and the site of Camp Desert Rock. About 14 miles of the route generally parallels Jackass Flats Road (on the east side), using a less direct route than the road in order to keep grades moderate. Further west, routing via Rock Valley (using a 1.5 percent downgrade) avoids heavy grades that would be required by following Jackass Flats Road over Little Skull Mountain. The route proceeds upgrade across Jackass Flats about two miles southwest of Nevada Test Site facilities. Fortymile Wash is crossed at its narrowest point near the repository.

11.3.2 Jean Route

Various alternates yield four possible configurations of the Jean Route; each configuration is composed of three route sections: over the Spring Mountains (via either Wilson Pass or State Line Pass), around developed areas in the vicinity of Pahrump (via either the North Pahrump or the Stewart Valley Alternate), and across the eastern Amargosa Desert to the repository.

In any case, the physical characteristics of the route may be summarized as follows:

- The route is relatively short, being 114 to 127 miles from the Union Pacific connection to the repository.

- Mountainous territory is traversed over 30 to 40 miles, involving grades up to 2.2 percent and 8-degree curves. Most difficult is the crossing of the Spring Mountains, which will involve major earthwork and tunneling.

- Tangent track and flat curves comprise the balance of the route, permitting 50 mph operation.

- Portions of the route are in close proximity to the communities of Jean, Goodsprings, Sandy Valley, Pahrump, and Crystal.

- Possible connection points at Jean and Borax are in close proximity (21 to 26 miles) to the Union Pacific yard at Arden. This proximity, coupled with the route's short length, would permit flexibility for interchange operations.

Key engineering concerns related to each of the route sections are summarized in the following paragraphs.

Wilson Pass Alternate

Although the corridor map implies a Union Pacific connection site up to three miles north of Jean, grade separations over Interstate 15 and the old highway are more difficult in the northern half of the corridor due to the elevation of the highways relative to Union Pacific track. On the other hand, connection near the southern corridor boundary would be within one-half mile of casinos and industrial buildings in Jean. In Goodsprings, the probable track location is about one mile from the main portion of the town, and about one-half mile from new housing northeast of the community.

Although shorter than the State Line Pass Alternate by approximately eight miles, the Wilson Pass Alternate requires much longer 2.2 percent grades on both the east and west approaches to the Spring Mountains due to the greater elevation gain. Extra distance in the alignment, achieved by looping around the north end of Goodsprings Valley, is instrumental in keeping the grade reasonable on the east side of the range.

Two major tunnels are currently envisioned, approximately 2.0 and 0.5 miles in length, the longer being through the summit of the range. However, in considering tradeoffs involved in raising the elevation of the line (through additional distance or grades up to 2.5 percent), subsequent design may greatly shorten these tunnels.

The Table Mountain Pass Alternate (listed in Study 1), southwest of Goodsprings, has more severe topography than the Wilson Pass Alternate and is not recommended for further consideration as a feasible corridor.

State Line Pass Alternate

Ample space in the vicinity of Borax permits flexibility for connections with Union Pacific, but location of grade separation structures to the west (over Interstate 15) may be dictated by a large archeological site in the vicinity.

As State Line Pass is the lowest summit in the Spring Mountains, the 2.2 percent grades are much shorter than those on the Wilson Pass Alternate. However, California must be entered for about six miles to access the pass, and construction costs will be high due to difficult topography on both approaches.

East of State Line Pass, heavy earthwork will be required through rocky terrain for three miles around the southern tip of the range. A large alluvial fan from a canyon on the north side forms the summit; due to the apparent high runoff, any cut through the summit will require considerable flood protection measures.

The west side of the Spring Mountains will require more difficult construction than the east side. To avoid entering the California Wilderness Area to the southwest, the route follows the north side of the canyon leading from the summit. Slopes are very steep; cuts and fills up to 100 feet high will be required through hard rock and some tunneling may be necessary. In contrast with the 8-degree curvature limit noted in the Design Inputs Section, use of 10-degree curves in this area may have significant construction cost benefits. Over a distance of about three miles to the north of the summit, all washes from the Spring Mountains have the appearance of significant flash flooding.

In the vicinity of Sandy Valley, the probable track location would parallel Cherokee Street and would be less than one mile from some dwellings. A new school on Hopi Street (about one-quarter mile north of Quartz Avenue) is about one mile south of the probable rail line location; some housing to the north is less than one-half mile from the probable location.

North Pahrump Alternate

In the extreme eastern portion of Pahrump, elimination of a short tunnel through a branch of the Spring Mountains is feasible by using an alternate corridor crossing undeveloped private lands in the south one half of Section 2 and the northeast quarter of Section 11.

The route climbs alluvial slopes along the east side of Pahrump to avoid urbanized areas. Closest proximity of the probable track location to developed areas in central Pahrump would be about 1.5 miles in the vicinity of the winery on North Homestead Road.

Proper development of the North Pahrump Alternate would necessitate purchase of right-of-way through private (but largely vacant) lands for about five miles in the northern part of Pahrump Valley. Most critical is a parcel of private land at the summit of the Last Chance Range, upon which a new dwelling is under construction that would be less than one-quarter mile from the probable track location through the summit. Routing to avoid all private lands in northern Pahrump Valley would lengthen the line about three miles, unreasonably increase grade lengths and curvature, and substantially increase earthwork due to rough topography.

The descent from the summit of the Last Chance Range (north of Johnnie) is through very rough topography, requiring 2.2 percent grades and 8-degree curves over a distance of about two miles. Cuts and fills up to 60 feet high and approximately 1,800 feet of tunneling would be necessary.

Stewart Valley Alternate

Longer than the North Pahrump Alternate by 4.5 miles, the Stewart Valley Alternate skirts Pahrump by using the BLM-proposed utility corridor along the state line. This utility corridor minimizes private land acquisition, but a rail line centered in the corridor would pass within 800 feet (0.15 mile) of homes in the developing Homestead Road area near Thorne Drive, making suitability of the BLM corridor for rail line use questionable. A feasible alternate route may be through the north half of Section 25 which, although private land, is undeveloped. A rail line centered through this area would be about 0.3 mile from existing housing.

In the Highway 372 vicinity, the probable track location is within one-half mile of a home under construction in the southeast quarter of Section 26; distance is slightly greater to various other dwellings in the immediate area. Beyond the northern limit of Sections 25 and 26 there are numerous mobile homes, the most southerly of which would be about one mile from the probable track location.

In Stewart Valley, six new homes have been constructed immediately west of Ash Meadows Road in S16 T24N R8E; at least 30 others are planned in the immediate vicinity. Although this development is in California, close proximity to the probable track location (within one-half mile) is a concern. Dwellings present along the west side of Ash Meadows road in Sections 6 and 7 of T20S R52E are within one-half mile of the probable track location.

A short tunnel may be required through the knob in the soutwest quarter of S9 T24N R8E, which appears to be hardrock. Further west, construction of the rail line parallel to, and within 500 feet east of, Ash Meadows Road would be the most economical location, as the road is relatively straight and has little grade. Location further up the hillside would entail significant curvature and earthwork through rocky material.

Amargosa Desert Section

The route through this section is relatively free from land-use and topographic constraints. Private land holdings north of the community of Crystal are easily avoided, although route length is slightly increased in order to do so. The last 14 miles of the route traverses the Nevada Test Site east of Fortymile Wash, crossing the wash at a narrow point near the repository.

11.3.3 Carlin Route

The Carlin Route connects with Southern Pacific and Union Pacific at Beowawe; connection at Palisade (assumed in Study 1) is not considered feasible due to various land-use conflicts. The route traverses the length of Crescent Valley and either Big Smoky Valley or Monitor Valley to Mud Lake, from where the Caliente Route is assumed the remaining distance to the repository. Routing via Monitor Valley connects with the Caliente Route via either the Ralston Valley Alternate or via the southern end of Big Smoky Valley using the combined Baxter Springs and Klondike Alternates.

Physical characteristics are summarized as follows:

- The route is relatively long, being 331 miles from Beowawe to the repository. Routing via Monitor Valley and Ralston Valley would add seven miles of length, while routing via Monitor Valley and the southern portion of Big Smoky Valley would result in a total length of about 363 miles.

- Mountainous territory over 50 miles (65 miles if via Monitor Valley) of the route involves grades up to 2.4 percent (steepest grades are south of Mud Lake on the Caliente Route). Some of these heavy grade areas also include curves up to 8 degrees.

- Tangent track and flat curves comprise the balance of the route, permitting 50 mph operation.

- Beowawe is reasonably close to Southern Pacific and Union Pacific yards at Carlin and Elko (25 miles and 50 miles, respectively). This proximity provides flexibility for interchange operations. However, operations may be complicated by the Southern Pacific/Union Pacific paired-track arrangement, which routes all westbound movements over Southern Pacific and all eastbound movements over Union Pacific. The planned Union Pacific/Southern Pacific merger will likely move Southern Pacific operations in Carlin to Elko, but will not affect the paired-track arrangement.

- Proximity to major mining operations in the Tenabo, Gold Acres, Cortez, and Round Mountain areas may be significant to possible shared-use concerns.

Key engineering concerns related to each of the route sections are summarized in the following paragraphs.

Crescent Valley Section

The primary site under consideration for rail connections is one to two miles east of Beowawe townsite. Alternatively, the most northerly 10 miles of the rail line could be located through the hills east of Crescent Valley (using 1.5 percent grades), making Southern Pacific/Union Pacific connections about four miles east of Beowawe. Connection further east is impractical due to increasing topography. In either case, ample space is available for connecting tracks and other terminal facilities which may be required. The Humboldt River, being north of the Union Pacific main line, would not be crossed.

Much of the eastern portion of Crescent Valley is normally dry lake bed, which may accumulate significant water during periods of runoff. These areas should be avoided by rail construction due to the soft subgrade and resulting maintenance problems. The optimum route appears to be on the western slopes of the valley, about one mile east of the town of Crescent Valley.

The most critical issue in Crescent Valley is the growth of the Cortez and Gold Acres mining operations, particularly the planned "Pipeline" Mine Development. The corridor, as currently envisioned, passes between these mining operations to the south of the growing tailings piles. Additional input from the mining companies may possibly shift the corridor further south in this vicinity.

From the southern end of Crescent Valley, the route climbs to Dry Canyon Summit using a 2.0 percent grade. Grades of up to 2.0 percent characterize the downgrade from Dry Canyon Summit to Grass Valley. The route then follows the west side of the valley, crossing alluvial fans until it passes west of Grass Valley Ranch where a 2.0 percent upgrade begins to the top of Rye

Patch Canyon. An alternate location is possible east of the ranch through more rugged topography. A downgrade of about 1.5 percent brings the route into Big Smoky Valley.

Big Smoky Valley Alternate

North of the Round Mountain/Hadley/Carvers area, there are numerous ranches and privately owned grazing lands along the west side of the valley, between Highway 376 and the approximate valley centerline. The most favorable rail route is therefore along the east side of the valley at the foot of the alluvial fans, thereby avoiding private lands and recreational aspects of the west side, as well as the lakebed and marsh areas of the valley bottom.

Potential land-use conflicts exist in the vicinity of Round Mountain, Hadley and Carvers, which are within 8 miles of each other. The valley narrows significantly in this area, limiting the opportunity to avoid private lands. The most critical point is between the Round Mountain mining properties and the new community of Hadley. The tailings pile for the Round Mountain mine is apparently growing toward Highway 376.

The currently envisioned route crosses Highway 376 north of Hadley and proceeds along the west side of the valley. An alternate route to the east, between the airport and Highway 376, rejoins the other route just south of Hadley. This alternate is closer to the Round Mountain mining operation. From this point south of Hadley the route crosses back to the east side of the valley and parallels Highway 376.

Monitor Valley Alternate

This route traverses Hickison Summit using 2.0 percent grades and proceeds south along the west side of Monitor Valley. Between Highway 50 and Dianas Punch Bowl (approximately 30 miles south of the highway), broad sloping planes on either side of the valley floor permit avoidance of the few private land holdings encountered.

South of Dianas Punch Bowl, the valley floor is so flat that routing directly up the center should be avoided due to accumulation of water during runoff periods. At the time of the field inspection, Dry Lake was filled with water and appeared somewhat larger than shown on the BLM map. Further south, private land holdings in the bottom of the valley can generally be avoided while retaining an acceptable rail alignment. The route leaves Monitor Valley via a short ascent to Horse Heaven Summit.

Ralston Valley Alternate

To keep grades reasonable, additional distance of up to two miles will be required in the descent from Horse Heaven Summit to the Hunts Canyon vicinity. Several routing arrangements, using loops with 6-degree curves, are possible within the proposed corridor.

Considerable development has taken place in the 12 mile stretch of Ralston Valley north of Highway 6, forcing the corridor up onto alluvial slopes along the east side of the valley. These developments include several private land holdings and homesites on the east side of Highway 376 (notably in Section 32 of T5N R44E). South of Highway 6, route length is increased about two miles to avoid the Tonopah Airport.

From Mud Lake, the Goldfield Section of the Caliente Route is used for the remaining distance to the repository.

Baxter Springs Alternate

Routing from Monitor Valley via the Baxter Springs Alternate (and connecting to the Klondike Alternate) provides a reasonable, although very circuitous, option to the Ralston Valley Alternate. Total length of the Carlin Route would be increased by approximately 25 miles. The principal advantage of this alternate is to enable routing via Monitor Valley while avoiding potential conflict with development further south in Ralston Valley.

As with the Ralston Valley Alternate, additional distance will be required in the descent from Horse Heaven Summit to keep grades reasonable. A key routing possibility may involve crossing Toiyabe National Forest land for less than one mile. The balance of the route proceeds in a westerly direction, traversing the southern end of the Toquima Range on a relatively straight alignment. A separation structure will be required over Highway 376 near the point where the alternate enters Big Smoky Valley.

Klondike Alternate

The southern portion of Big Smoky Valley provides a straight, direct route with no significant obstacles to rail line construction. The few private lands in the valley floor can easily be avoided. Sand dunes in Section 24 of T7N R41E appear stable as some vegetation is present, while Crescent Dunes (15 miles to the south) are east of any likely route; blowing sand may therefore not be a significant concern for a rail line in this area.

The route passes west of Tonopah and proceeds southeast to a point west of Mud Lake. Two grade separations over U.S. Highway 95 would be necessary (west and south of Tonopah, respectively). From Mud Lake, the Goldfield Section of the Caliente Route is used for the remaining distance to the repository.

11.3.4 Caliente Route

The Caliente Route is the most mountainous of the routes under consideration, with seven major mountain crossings and three minor summits. The balance of the route generally follows the bottom of large desert valleys, notably Sand Spring Valley, Reveille Valley, Ralston Valley, and Sarcobatus Flat.

Physical characteristics are summarized as follows:

- At 338 miles from Union Pacific connection at Caliente to the repository, the Caliente Route is the longest of all routes considered (except for the Carlin Route using a Monitor Valley/Baxter Springs/Klondike routing).

- Mountainous territory over approximately 80 miles of the route involves grades up to 2.4 percent. Some heavy grade areas include curves up to 8 degrees. As shown in Table 11-1, total rise and fall of the Caliente Route is more than double that of the Carlin and Jean Routes.

- Tangent track and flat curves comprise the balance of the route, permitting 50 mph operation.

- The distance from Caliente to the nearest Union Pacific yards at Milford and Las Vegas (Valley and Arden) is over 115 miles. Coupled with the route's long length, this distance may limit interchange possibilities.

- The Caliente route is unique in that it is by far the most circuitous of the routes studied; more than 100 miles of additional length are required to keep the route out of the Nellis Air Force Range.

As indicated by the Route Section Description sheets, the route is divided into two key sections at Mud Lake. The Reveille Section (from Caliente to Mud Lake) is exclusive to the Caliente route, while the Goldfield Section (from Mud Lake to the repository) is common to the Caliente and Carlin routes.

Reveille Section

Most of the heavy grade areas are in the eastern portion nearest Caliente; the two most difficult mountain crossings are Bennett Pass and Timber Mountain Pass. Significant extra distance in the form of large loops is necessary to achieve acceptable grades in these and other cases. Further engineering work may find that the heavy grades may be reduced to 2.0 percent with some construction cost penalty. Such reduction would be most difficult in the case of Timber Mountain Pass due to the rough topography of the east slope of the Seaman Range and its close proximity to White River.

A significant route option is indicated on the corridor maps by a split corridor between Coal Valley and Garden Valley. The route may use either Water Gap or a somewhat higher pass through the Golden Gate Range about four miles to the north. The key advantage of routing through Water Gap is the avoidance of 3.5 miles of grades over 2.0 percent.

In the more westerly portions of the Reveille Section, the route traverses the length of Sand Spring Valley, Reveille Valley, and Stone Cabin Valley through a series of long tangents and relatively little grade. The north-south orientation of much of Reveille Valley, however, results in over 30 miles of circuity.

The Reveille Section is notable in being more isolated than any other route section in the study; Caliente and Panaca are the only communities along this part of the route, and access from paved public roads is very limited.

Goldfield Section

Heavy grade areas (up to 2.4 percent) extend over both the Goldfield Hills and the western portion of Yucca Mountain near Beatty Wash. Further engineering work may find that these grades may be reduced with some construction cost penalty.

Due to the depth of the canyon encompassing Beatty Wash and the rugged nature of the adjacent branch of Yucca Mountain, negotiating this area will be one of the more difficult portions of the Caliente (or Carlin) Route. However, DeLeuw Cather's proposed route leading to this area, through the northern portion of Crater Flat, is clearly far more circuitous than necessary. The corridor has therefore been widened sufficiently to permit investigation of improved alignments through both the Crater Flat and Beatty Wash areas.

Significant route options are indicated on the corridor maps by split corridors in two key areas:

- In the vicinity of Goldfield, a route through part of the Nellis Air Force Range (over a distance of about 14 miles) would greatly improve the route by using a much lower summit and avoiding mining patent areas. Grades would be less than 1.5 percent versus 2.4 percent required for the higher summit near Espina Hill. Curvature would likewise be greatly reduced.

- Across Sarcobatus Flat (in the vicinity of Scottys Junction), two options are available to avoid private lands and housing in the area. These options parallel U.S. Highway 95 to the west and east, respectively.

Routing on the west side will require three highway grade separations; a route east of the highway would have, at most, two grade separations. However, this route would require penetration of the Nellis Air Force Range to bypass the private lands. A third possible routing would be via the alignment abandoned by the Las Vegas & Tonopah Railroad further west through Bonnie Claire; such routing would lengthen the line at least two miles.

In the event that routing is kept east of the highway, it may be feasible to avoid the two grade separations over U.S. Highway 95 proposed by DeLeuw Cather near Tolicha Wash; routing higher on the alluvial fan of the wash is possible, although some heavy earthwork may be required through the hills to the south.

Crestline Alternate

Pending further investigation of land status, the Crestline Alternate may be a potential option at the extreme eastern end of the Caliente Route. Currently, land ownership data is incomplete concerning the portion of the route which uses the abandoned 200-foot wide right-of-way of the former Union Pacific Pioche branch between Caliente and a point near Panaca (a distance of approximately 10.5 miles).

In the event that the former Union Pacific right-of-way is unavailable for rail use, another origin point for the Caliente route may be justified. DeLeuw Cather evaluated a route from Crestline with the following general characteristics:

- 15 miles additional length
- Heavy grades and sharp curvature
- Extensive earthwork
- Approximately $88 million additional cost
- Additional operating and maintenance cost.

This alternate was originally eliminated from the study due to the additional cost. However, it may be an attractive option if land ownership becomes an obstacle to routing from Caliente.

11.4 OPERATING PLANS

The typical dedicated train is assumed to be two 3,000-horsepower diesel-electric locomotives with a maximum of three spent nuclear fuel transportation cask cars or five high-level waste transportation cask cars, with two or more buffer cars (gondolas) and an escort car (CRWMS M&O 1995a, Key Assumption 001). Trailing train weight would probably not exceed 2,500 tons, and train lengths would not likely exceed 800 feet.

Locomotive power should be ample to maintain speeds of 50 mph, with excellent braking and train handling characteristics. Projected tonnages suggest that frequencies could vary from one train each way every ten days (1,000 ± net metric tons of uranium per year) to two trains each way per week under peak conditions (3,000 ± net metric tons of uranium per year).

Operating plans depend upon route lengths and corresponding run times from the junction point to the repository. Run times indicated in the following sections are based on the train assumed above, the individual route's physical characteristics, and a maximum speed of 50 mph.

For both the Carlin and Caliente Routes, the "hours of service" 12-hour limit (required by 49 CFR 228, Subpart B) is a major operating consideration. Due to the length of these runs, crews would have a programmed layover (a least 10 hours) at the repository before returning to the home terminal. Transporting crews between the repository and the home terminal would be impractical due to the distance involved. The length of these routes therefore introduces disadvantages in the form of layover costs and the necessity of carefully scheduling train movements to avoid extended layovers.

11.4.1 Interchange with Line-Haul Carriers

A key operating issue to be determined is whether dedicated trains or general freight service is to be used in interchanging with Union Pacific (or Southern Pacific). Dedicated trains would offer greater opportunity to schedule and control movement of cask cars and may result in cost benefits through enhanced use of crews and equipment. "Run-through" motive power would also be possible, simplifying interchange and enabling the use of Union Pacific locomotives. Trains arriving at the connection point would then stop only to secure movement authority and change crews.

If general freight service is used, cask cars would be set out at the junction point by Union Pacific (or Southern Pacific) trains and subsequently assembled into a train for movement to the repository. The more random nature of general freight service would likely result in shorter, more frequent trains than in the case of dedicated train service.

A conceptual layout of the interchange yard and connecting trackage is applicable to any of the possible connection sites, but should be modified depending on the specific site and the selection of interchange via either dedicated or general freight service.

In the case of Jean, Borax, or Caliente, the existing main line passing siding would serve as the siding shown on the drawing adjacent to the main line. Two storage tracks are included for interchange of loaded and empty cars with general freight service; these tracks may be unnecessary if dedicated trains are used with motive power run-through. The "Y" track enables run-through movements from either direction, as well as turning of any captive locomotives. One leg of the " Y" may therefore be unnecessary if all interchange is to be accomplished using run-through service from one direction only.

11.4.2 Valley Modified Route

Close proximity to North Las Vegas makes Dike suitable as a home terminal for Yucca Mountain crews; Union Pacific crews would terminate at the Union Pacific Arden yard, traveling to and from Dike by motor vehicle.

Run times between Dike and the repository should be under three hours in each direction. Speed would be limited to about 25 mph upgrade and restricted to 40 mph downgrade on the steepest grades of 1.5 percent. A crew could operate from Dike to the repository and return within the 12-hour limit, allowing two hours at the repository for switching and make-up of the outbound train.

In the event that a return movement is not available when switching is completed at the repository, the crew could return to their home terminal by motor vehicle, leaving the motive power idle at the repository until needed. The crew would be recalled when required and transported back to the repository to operate the empty train to Dike. Depending upon the length of delay at the repository, this may be less costly than requiring the crew to remain at the repository until a return movement is available.

11.4.3 Jean Route

Jean's proximity to Goodsprings (7 miles) and Las Vegas (30 miles) makes it acceptable as a home terminal for Yucca Mountain crews. Union Pacific crews would terminate at the Union Pacific terminal at Arden, travelling to and from Jean by motor vehicle.

Normal run times between Jean and the repository should be under four hours in each direction. Speed would be limited to 15 to 20 mph upgrade and restricted to 25 mph downgrade on the steepest grades of 2.2 percent. A crew could operate from Jean to the repository and return within the 12-hour limit, allowing two hours at the repository for switching and make-up of the outbound train.

As described for the Valley Modified route, transporting the crew to the home terminal may be appropriate when a return movement is not immediately available at the repository.

11.4.4 Carlin Route

Beowawe's proximity to Crescent Valley (10 miles) and Carlin (25 miles) makes it acceptable as a home terminal for Yucca Mountain crews. Southern Pacific and Union Pacific crews would terminate at their respective yards in Carlin and Elko, travelling to and from Beowawe by motor vehicle.

Normal run times between Beowawe and the repository should be under nine hours in each direction. Speed would be limited to 15 to 20 mph upgrade and restricted to 25 mph downgrade on the steepest grades of 2.0 to 2.4 percent. A crew could operate from Beowawe to the repository (or return) within the 12-hour limit, allowing over an hour at the repository for switching.

11.4.5 Caliente Route

Caliente would serve as a home terminal for train crews, as well as a layover point for Union Pacific crews operating the trains between Caliente and Milford, the next Union Pacific crew-change point.

Normal run times between Caliente and the repository should be under 10 hours in each direction. Speed would be limited to 15 to 20 mph upgrade and restricted to 25 mph downgrade on the steepest grades of 2.4 percent. A crew could operate from Caliente to the repository (or return) within the 12-hour limit, allowing over an hour at the repository for switching.

12. DEVELOPMENT TASKS AND ISSUES

At the completion of the repository advanced conceptual design (ACD), major design issues and development tasks have been identified. The report provides feasible concepts to most of these issues through assumptions or engineering judgment and acknowledges that some of these issues remain to be resolved as design and site characterization move forward. A discussion of issues related to the repository design is presented in this section.

Some of these issues encompass more than repository design; an example of this is the thermal loading issue which spans repository design, Engineered Barrier System design, site characterization program, and pre- and postclosure performance assessment. However, the impact of this issue on repository design only is discussed here. Some issues are confined to repository design. For example, the issue of the disposability of spent nuclear fuel assemblies. Each major design issue is discussed as shown below:

- Description of the issue
- Assumption used for ACD
- Risk considerations, including a qualitative description of cost and design impact
- Tasks required to resolve the issue (e.g., substantiate the assumption).

12.1 SURFACE DESIGN ISSUES

Issues that are expected to pose the greatest risk to the repository surface facilities design are described below. None of the issues is expected to be unsolvable (i.e., adequate facilities can be designed and constructed regardless of how the issue is resolved). These issues present program risk in that the cost of construction or operations could be significantly affected.

12.1.1 Disposability of Spent Fuel Assembly Canisters

12.1.1.1 Description

The repository may receive spent fuel assemblies (SFAs) in a variety of configurations, including bare fuel in GA-4 and GA-9 legal weight truck casks, disposable canisters in rail casks, and non-disposable canisters in rail casks (e.g., dual purpose canisters). The primary issue involves whether the SFA canisters, which are used to deliver 98 percent of the SFAs (70 percent of the waste), will be disposable. A disposable canister can be transferred directly to a disposal container as a sealed unit and subsequently emplaced in the repository. Nondisposable canisters would need to be opened and the 12 to 40 SFAs, depending on the canister capacity, would be individually removed and transferred to a disposal container. The residual nondisposable canister would require processing as a solid low-level waste and disposal off site.

12.1.1.2 Assumption Used for ACD

The repository ACD is based on receiving 8,593 disposable SFA canisters. The detailed waste form arrival scenario is provided as a controlled design assumption (Key Assumption 002, Waste Form Arrival Scenario) and is provided in Table 7.1.2-3.

12.1.1.3 Risk Considerations

If the canisters are not disposable, the following Waste Handling Building (WHB) design changes would be required: two hot cells would be added to open the canisters and transfer the SFAs; the single ACD hot cell dedicated to disposable canister waste transfers would be deleted; the number of shipping cask preparation stations would increase by two receipt and two exit stations; and the cask unloading ports would increase from two to five. These collective changes to the major features of the WHB configuration would increase the size of the facility footprint by about 45 percent.

Transfers of uncanistered SFAs inherently lead to more contamination being dispersed within the confinement zones as opposed to transfers of canistered SFAs. For this reason it is estimated that the liquid low-level waste generated from more frequent decontamination operations would increase approximately threefold. The solid low-level waste generation rate would therefore also increase threefold because the liquid low-level waste is mixed with grout, solidified in drums, and disposed of as a solid low-level waste. The amount of solid low-level waste drums requiring disposal would increase from approximately 32,000 cubic feet per year to 90,000 cubic feet per year. The unloaded nondisposable canisters would conservatively generate approximately 1.75 million cubic feet of additional solid low-level waste. The increases in secondary waste generation would result in expanding the Waste Treatment Building size and numbers of process equipment, or operating the present facility for an additional shift, or both.

The projected increases to the WHB and Waste Treatment Building (WTB) life cycle costs are estimated to be about $570 million and $345 million, respectively. The WTB life cycle costs include all solid low-level waste disposal costs. Based on the design impacts described above, the use of non-disposable canisters will have a significant impact on repository cost.

There is a high probability that in the future the repository waste form arrival scenario will be predominantly based on nondisposable canisters (i.e., dual purpose canisters licensed for storage and transportation) due to a number of recent programmatic decisions that favor the adoption of existing nondisposable canister technologies.

12.1.1.4 Tasks Required For Resolution

A revised basis for the repository waste form arrival scenario must be developed by Waste Acceptance and incorporated in the *Repository Design Requirements Document* (RDRD) (YMP 1994a). The WHB, WTB, and portions of the Cask Maintenance Facility (CMF) will need to be updated in order to develop a defensible design and a sufficiently accurate cost estimate in support of the next design phase.

12.1.2 Waste Form Assay for Measurements

12.1.2.1 Description

The repository design assumes SFA burn-up credit will be achieved based on accurate records taken at the reactor sites prior to shipment. Without this credit it is expected that the current waste package design would need to be resized and/or redesigned. The current program position is that it will not be necessary to perform additional measurements of SFA burn-up; although measurements to verify the existing spent fuel burn-up records may be considered in the future to mitigate the risk of the program position acceptance by the U.S. Nuclear Regulatory Commission (NRC).

It is expected that other waste forms, such as severely degraded SFA and/or other U.S. Department of Energy- (DOE) owned waste, may need to be assayed at the repository. Industry currently provides assay measurement technology that may be suitable for performing an assay that will be acceptable to the NRC. Certain technology operates underwater on uncanistered individual fuel assemblies. Other technologies may be available but have not been identified.

12.1.2.2 Assumption Used for ACD

The repository ACD does not include provisions for conducting SFA burn-up or other waste form assay measurements. The bulk of the SFAs are transferred to disposal containers in sealed canisters, which does not accommodate operations requiring access to uncanistered SFAs. Also, the SFA and other waste form transfer operations are conducted dry, in a hot cell, which would not directly accommodate current underwater assaying technologies without some modification for shielding background radiation and/or local neutron scatter in air.

12.1.2.3 Risk Considerations

Three different alternatives should be considered, depending on the requirements of the selected assaying technology. The impact of each technology alternative is described below:

- *Dry Technology Operating on Sealed Canisters* – If this type of technology is used, assay equipment and hot cell assay stations would need to be added to the WHB. There would be an impact on the waste throughput due to the additional time required for set-up, calibration, maintenance, and conducting the assay measurements. These changes would result in a moderate increase in the cost of the WHB construction and operation. Sealed SFA canisters are not expected to be suitable for assaying due to the probable use of internal borated materials. Other DOE-owned waste forms, however, may arrive at the repository sealed in specially designed canisters.

- *Dry Technology Operating on Individual SFAs* – If this type of technology is used, burn-up measurement equipment and hot cell stations would need to be added to the WHB. In addition, hot cells and equipment would need to be added to cut open canisters and handle/transfer individual SFAs, as described for the alternative in Section 12.1.1. The additional time required for equipment set-up, calibration, maintenance and conducting the burn-up measurements would impact the facility size based on maintaining the same waste throughput. These changes would result in a significant increase in the cost of the WHB construction and operation. Other impacts are described in Section 12.1.1.

- *Wet Assay Technology Operating on Individual SFAs* – If this type of technology is used, burn-up measurement pools and equipment would need to be added to the design. In addition, hot cells and/or fuel handling pools and equipment would need to be added to cut open canisters and handle/transfer individual SFAs. With this alternative, consideration should also be given to using a wet transfer system for all fuel handling operations and integrating this system with the wet system provided for conducting cask maintenance. The impacts on cost are unknown because the design would be radically different from the design provided in the ACD.

Of the 19 buildings in the North Portal area, the WHB, WTB, and CMF contribute approximately 64 percent to the construction cost and 59 percent to the operating cost of the repository surface facilities. The potential impacts described above are significant drivers to the repository cost.

There is a low probability that in the future some burn-up measurement capability for SFAs would become a requirement for the repository design based on the current program position. There is a moderate probability that some DOE-owned waste form assay capability would become a functional repository requirement. There is also a high probability that the selected technology would operate on individual SFAs and other non-SFA waste form canisters. There is a high probability that a technology exists or could be developed to perform the SFA assays in a dry environment.

12.1.2.4 Tasks Required for Resolution

Assay and/or burn-up measurement technologies need to be identified, possibly modified, and approved. A technology needs to be selected, and the facility and equipment requirements need to be established. The major repository nuclear facilities would need to be redesigned and the total system life cycle cost would need to be updated.

12.1.3 Repository Collocation with Interim Storage

12.1.3.1 Description

Congress is currently considering amending the Nuclear Waste Policy Act of 1982 to allow, or require, interim storage of spent nuclear fuel (SNF) and defense high-level waste (DHLW) near the repository. Interim storage (referred to as monitored retrievable storage) involves receiving shipping casks, transferring the waste to a storage mode, and transferring the storage mode to a storage pad. When the repository begins operation, the waste is transferred from the storage mode to a disposal container for emplacement.

It is expected that most of the facilities required to conduct repository operations would also be required to conduct interim storage operations. It is also expected that the repository could conduct all the interim storage operations if a storage pad were added and a storage mode loading capability were added to the WHB. Due to space limitations adjacent to the North Portal, the storage pad may need to be remote.

12.1.3.2 Assumption Used for ACD

The repository ACD does not include considerations for collocation with interim storage operations.

12.1.3.3 Risk Considerations

Adding the interim storage mission to the MGDS (i.e., collocation) would significantly impact the current repository design scope, as well as planned schedules, budgets and program milestones. Project redirection to a phased licensing and construction approach would be considered to promote early receipt of waste forms at lowest initial cost. The repository surface waste handling designs would be impacted by the added functional requirement to accommodate handling of the waste storage modes and interface with the storage mode transporters. A suitable location for the storage pad would also need to be identified, and the complexities of licensing a single facility under both 10 CFR 60 and 10 CFR 72 would need to be addressed.

The design impacts described above will increase the construction and operating cost of the repository surface facilities, although a collocated design will also be significantly more cost efficient for the overall waste management system as compared to providing separate (i.e., non-collocated) facilities.

There is a moderate probability that interim storage will be collocated with the repository in the future. A determination that the Yucca Mountain site is not suitable for a repository would likely deter a decision to provide interim storage within the Nevada Test Site. However, there has been no indication to date that the Yucca Mountain site would not be suitable for a repository. Interim storage collocated with the repository is an attractive waste management option because the waste would not need to be transported twice, it accommodates early receipt of waste, and it has a relatively small impact on the repository construction cost. Another advantage of this alternative is that the storage pad could likely be used to support a repository retrieval mission or accommodate surface waste cooling (aging).

12.1.3.4 Tasks Required for Resolution

Congressional action is required to revise the current Nuclear Waste Policy Act of 1982 to allow interim storage at the proposed repository site. The repository surface facilities design would then need to be modified to incorporate disparate interim storage features from the monitored retrieval storage design. A phased construction approach would need to be addressed in the design so that early waste receipt and minimum initial construction costs may be achieved.

12.1.4 Integrated Nuclear Operations

12.1.4.1 Description

Surface nuclear operations at the repository include waste handling operations, cask maintenance operations, and waste treatment operations. These major operations are performed in separate structures, each with unique individual systems and components. Each major operation also requires a variety of support systems. Many of these support systems are common to all three of the major operations and could be combined in an integrated facility design that serves all operations more efficiently and economically. Integrating these operations into a single facility could take advantage of economy of scale by using fewer large facilities, eliminating multiple like support systems, increasing facility utilization, promoting the sharing of staff, and facilitating personnel and materials movement.

12.1.4.2 Assumption Used for ACD

The repository ACD provides separate structures (i.e., WHB, CMF, and WTB) for conducting the nuclear material handling operations. Each building contains common support areas such as offices, tool and equipment storage, maintenance shops, health physics areas, and change rooms. This non-integrated approach was selected for the ACD because the repository surface facilities design, schedule, and budget were inadequate to develop integrated facility designs.

12.1.4.3 Risk Considerations

Integrating the facilities for waste handling operations, cask maintenance operations, and waste treatment operations is expected to reduce the quantity of construction (i.e., total building area) and optimize the operating staff.

Of the 19 buildings in the North Portal area, the WHB, WTB, and CMF contribute approximately 64 percent to the construction cost and 59 percent to the operating cost of the repository surface facilities. Integrating the operations should moderately reduce the capital and operating cost.

There is a high probability that future design optimizations will select an integrated approach for the nuclear operations.

12.1.4.4 Tasks Required for Resolution

Design integration of these facilities is currently planned for FY 1997.

12.1.5 Frequency of Waste Package Disassembly for Performance Confirmation

12.1.5.1 Description

Performance confirmation is a program of baseline data acquisition and ongoing monitoring which will ensure that assumptions made during the repository licensing process are correct. This program will provide confidence that the repository system is functioning, and will continue to function, as it was presented at the time of licensing.

Requirements to guide the development of a performance confirmation program are not yet in place. Uncertainties exist as to the types of data to be collected and how often this data needs to be collected. The program is expected to rely on some combination of in situ monitoring, in situ experiments, and laboratory and/or field testing of seals, barriers, and waste packages.

12.1.5.2 Assumption Used for ACD

The repository WHB is designed to support the retrieval and disassembly of one disposal container (waste package) every 10 years, starting ten years after the first waste package is emplaced.

The WHB design includes one hot cell that is expected to be adequately sized to conduct disposal container disassembly operations specifically in support of a performance confirmation program. This cell would also be used to add filler material to SFA canisters and to help mitigate off-normal situations with canisters, disposal containers and fuel assemblies.

During the caretaker phase, the repository maintains a skeleton crew of about 32 full-time employees to secure and maintain the facilities and conduct in situ performance confirmation monitoring. When a disposal container internals are to be examined, the staffing level for the surface operations increases to 195 full-time employees, the crews are retrained, and the affected buildings and support systems are restarted. A disposal container is brought to the WHB from the emplacement drift and transferred to the performance confirmation cell. In this cell the disposal container is opened, waste is removed, and testing and sampling activities are conducted. After examination and testing, the waste is repackaged and then returned to the emplacement area. When the above-ground performance confirmation operations are complete, the staff is reduced to 150 full-time employees, and the WHB and other affected facilities are decontaminated. Following decontamination, the repository is returned to a standby caretaker mode (i.e., maintenance and monitoring) and the staffing level reduces again to 32 full-time employees. The durations for each operating period is as follows: seven years for standby, two years for restart and waste package disassembly, and one year for decontamination. During the emplacement phase, performance confirmation activities can be performed without an increase in staffing levels.

12.1.5.3 Risk Considerations

Three options for performance confirmation are considered below:

- *Disposal Containers Do Not Require Opening* – There is no impact on the size of the facilities or construction cost because the same hot cell will be provided to support off-normal operations. The operating cost during the caretaker phase would be reduced approximately 65 percent. There is a moderate probability that this approach will ultimately be selected for the repository because other in situ methods of monitoring may be adequate to confirm system performance.

- *Disposal Containers Must Be Opened More Frequently* – There is no impact on the size of the facilities or construction cost, if the available cell can accommodate the higher throughput without impact to other functions this cell performs. It is expected that rates of approximately two disposal container openings per year or fewer could be accommodated with the present design. The operating costs during caretaker phase could double. There is a moderate chance this alternative will be selected. If it is decided that disposal containers need to be opened to collect data, it may also be decided that more openings are required because of the variety of waste forms emplaced at the repository.

- *Disposal Containers Must Be Opened So Frequently That More Cells Are Required* – The cell configurations and overall size of the WHB, construction cost, and the staff during emplacement and caretaker phases would increase. There is a low probability that this alternative will be selected.

12.1.5.4 Tasks Required For Resolution

Data are being collected from the Exploratory Studies Facility (ESF) and the Surface Based Testing programs that will provide much of the baseline information needed to initiate the formal performance confirmation program once it is developed.

A systems study concerning performance confirmation is underway during FY 1996. The objective of the study report is to provide the technical bases for recommendations for performance confirmation program-related updates to the RDRD (YMP 1994a) and/or *Engineered Barrier Design Requirements Document* (EBDRD) (YMP 1994c), with primary emphasis on the identification of the key drivers. The report will also contain an overview of the performance confirmation approach in the form of a draft performance confirmation plan. This study is the first step in defining requirements for the performance confirmation program.

When the performance confirmation disposal container opening rates are selected, the number of cells required would need to be calculated, and the WHB may require redesign.

12.2 SUBSURFACE DESIGN ISSUES

12.2.1 Thermal Loading – Emplacement Area Required

12.2.1.1 Description

Thermal loading has a great potential to impact the reference design. Section 8.2 contains a description of thermal loading and the different ways in which it can be expressed. The magnitude of the potential impact of the thermal loading decision on the subsurface repository is best defined by showing the range of repository sizes that would result from thermal loads at the opposite ends of the possible range. A repository having a low thermal loading of 25 MTU/acre would require emplacement area totaling approximately 1,134 hectares (2,800 acres) in order to emplace the 70,000 MTU waste inventory. This is approximately three times the area available in the current primary area being characterized at Yucca Mountain. At the other end of the range, a thermal load of 100 MTU/acre requires only 283 hectares (700 acres) to emplace 70,000 MTU. A repository of this size would fit entirely within the upper block of the primary area with additional space remaining.

Figure 12-1 shows these bounds. The primary area and all optional areas are required for a 25 MTU/acre loading. In contrast, only the cross-hatched area in the upper block of the primary area is needed for a high loading of 100 MTU/acre.

12.2.1.2 Assumption Used in ACD

As discussed in Section 8, a loading of 83 MTU/acre was used to develop the ACD reference design layout. This loading requires 341 hectares (843 acres) of usable emplacement area. This can be accommodated within the primary area, using the upper and lower blocks, with approximately 10 percent extra space available.

12.2.1.3 Risk Considerations

As can be seen by the wide range of possible areal requirements, the thermal loading decision has the potential to make the repository area large or compact. Potential impact is greater with a low loading because the primary area cannot accommodate the 70,000 MTU inventory at less than approximately 72 MTU/acre. If the loading were to be lower than 72 MTU/acre, additional space outside the primary area would have to be characterized and developed. A high loading would allow development of a very compact subsurface repository. Approximately 324 hectares (800 acres) is available in the upper block of the primary area. Loadings of 88 MTU/acre and above could be placed completely within the upper block.

12.2.1.4 Tasks Required for Solution

The selection of the thermal load is driven by multiple factors including long-term performance and preclosure operational needs. Field data from thermal testing in the Exploratory Studies Facility combined with long-term performance modeling will provide the primary information from which the thermal loading decision will be made. Volume I, Section 9.1, contains a discussion of the thermal loading issue. A description of the thermal strategy is contained in Section 8.2.3.

12.2.2 Thermal Loading – Maintaining Flexibility

12.2.2.1 Description

An issue related to the question of thermal loading is that of maintaining the flexibility to change thermal load if the need to do so is indicated by performance confirmation testing or modeling. Changes in the thermal loading strategy can be accommodated with relative ease prior to the receipt of NRC construction authorization and the start of repository subsurface construction. After the start of construction, however, such changes may impact both the cost of the facility and the schedule of emplacement.

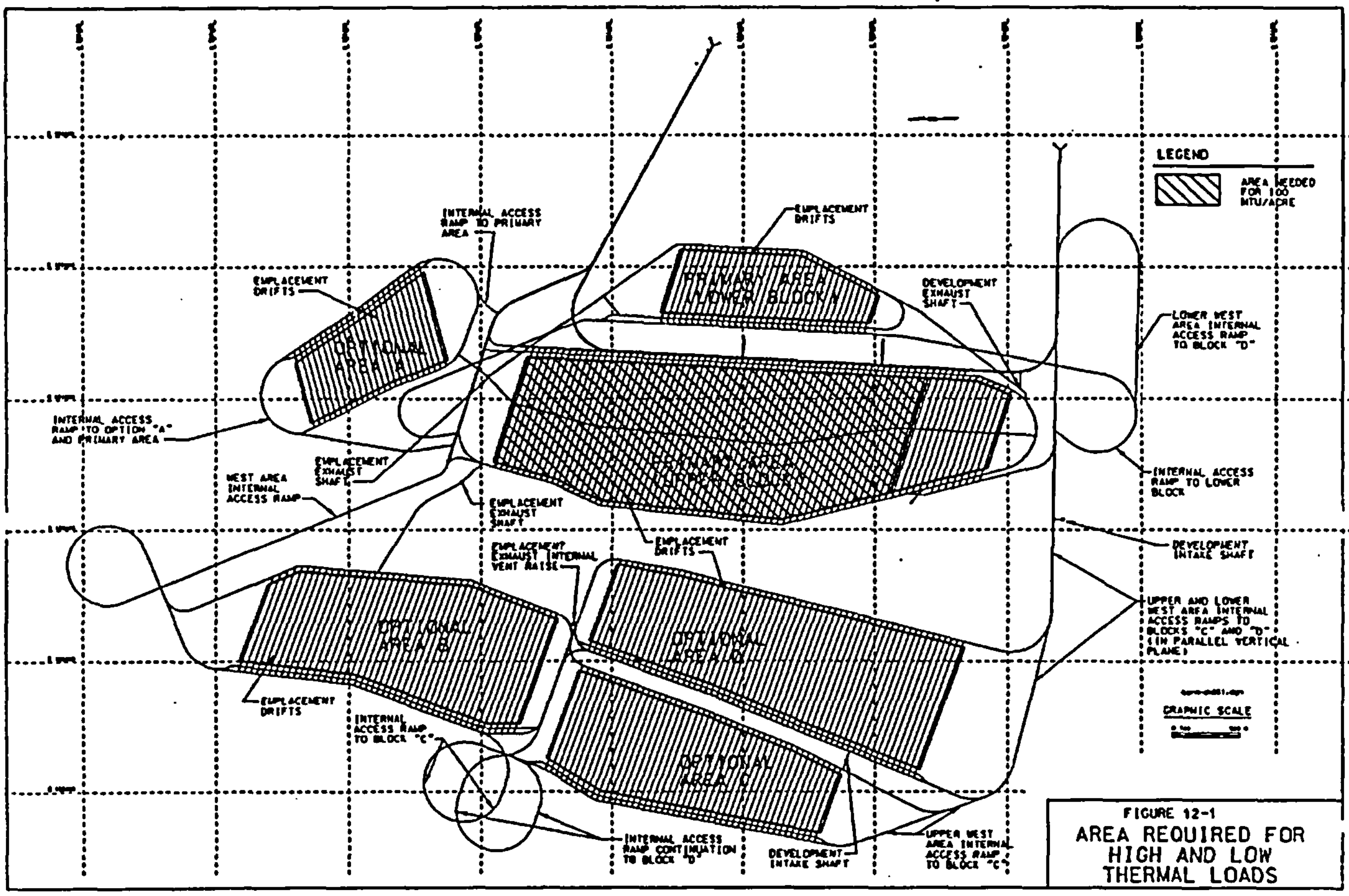

Figure 12-1. Area Required for High and Low Thermal Loads

The primary factor causing the impact is that the spacing between the emplacement drifts would not be the same for high and low thermal load strategies. A high thermal load requires emplacement drifts on relatively close spacings to achieve the waste package density needed for a high thermal load without placing the waste packages too closely together within the emplacement drifts (placing the waste packages too closely together could cause them to overheat, potentially degrading long-term performance). A low thermal load does not require such close drift spacing but, as noted in the previous section, requires significantly more total area to be developed.

A potential strategy that would allow the program to begin the emplacement process at a low thermal loading while maintaining the option to switch to a high thermal load is described the *Waste Emplacement Management Evaluation Report* (CRWMS M&O 1995at). This strategy is summarized here.

Development of the repository would be started with an emplacement drift spacing needed for a high thermal load. Waste emplacement, however, would be done at a low areal load. Two possible waste package arrangements are shown in Figures 12-2 and 12-3. Figure 12-4 shows the waste package arrangement for the high thermal loading case. As can be seen by comparing the figures, the emplacement drifts are under-used in the low loading cases, with some drifts having no waste packages, and others having packages on larger-than-minimum spacings. This does, however, maintain the option to change to a high thermal load by simply emplacing in the empty drifts and decreasing the waste package spacing in those drifts containing waste.

A downside to this strategy is that, because there is a logistical limit to the number of tunnel boring machines (TBM) that can be operated from a single service main, the development operation could not excavate emplacement drifts at a high enough rate to support the currently planned annual waste receipt and emplacement schedule. This schedule is shown in Section 8.2. As long as the emplacement drifts are being developed on close spacing, and the waste emplaced at a low loading, the annual emplacement rate would be constrained to well below the currently planned rate of 3,400 MTU/year.

Once the final thermal loading decision is made, high or low, the waste emplacement rate could be increased to the planned level. If the decision is for high thermal load, the emplacement drifts would simply be fully used. If the decision is for low thermal load, the spacing of the subsequently developed emplacement drifts would be increased, reducing the amount of under-used emplacement drift space. Figure 12-5 indicates how the primary area would appear under a scenario in which the decision was made to stay with a low thermal loading after approximately half of the upper block had been developed to maintain a high thermal loading option.

12.2.2.2 Assumption Used in ACD

The ACD reference layout is developed with closely spaced emplacement drifts, providing the ability to begin emplacement at any loading up to approximately 100 MTU/acre. As discussed above, the selection of a low loading would constrain the annual waste emplacement rate until a final loading decision was in place.

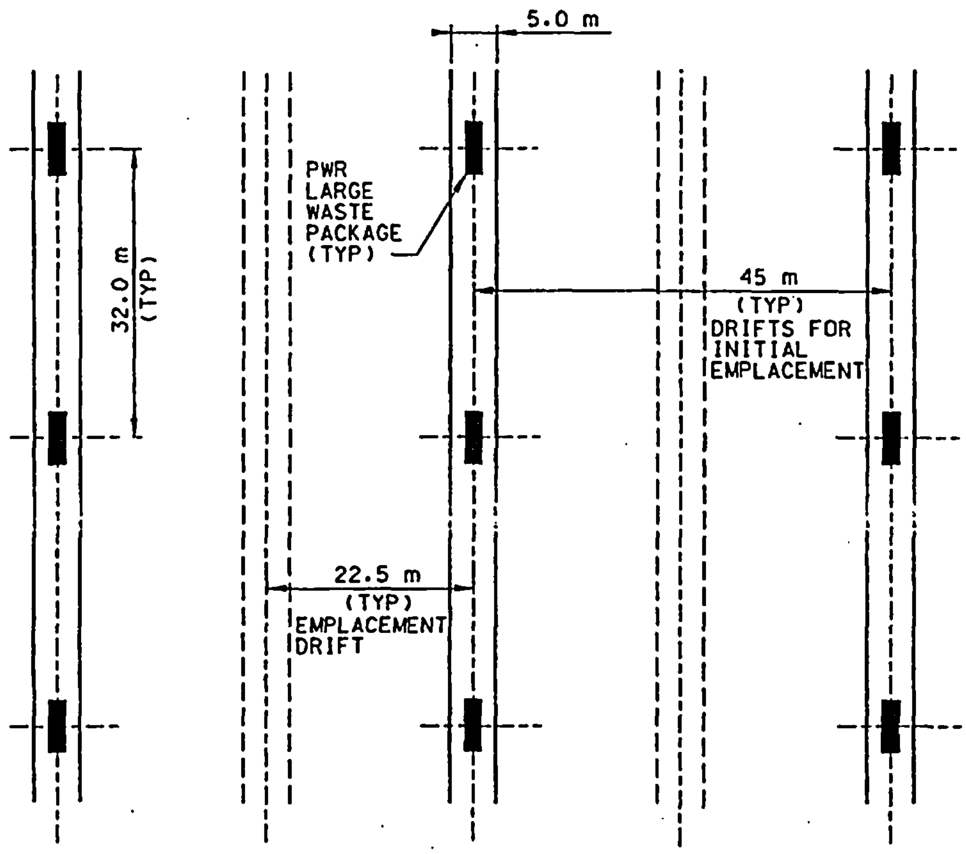

Figure 12-2. Minimal Disturbance Emplacement Pattern

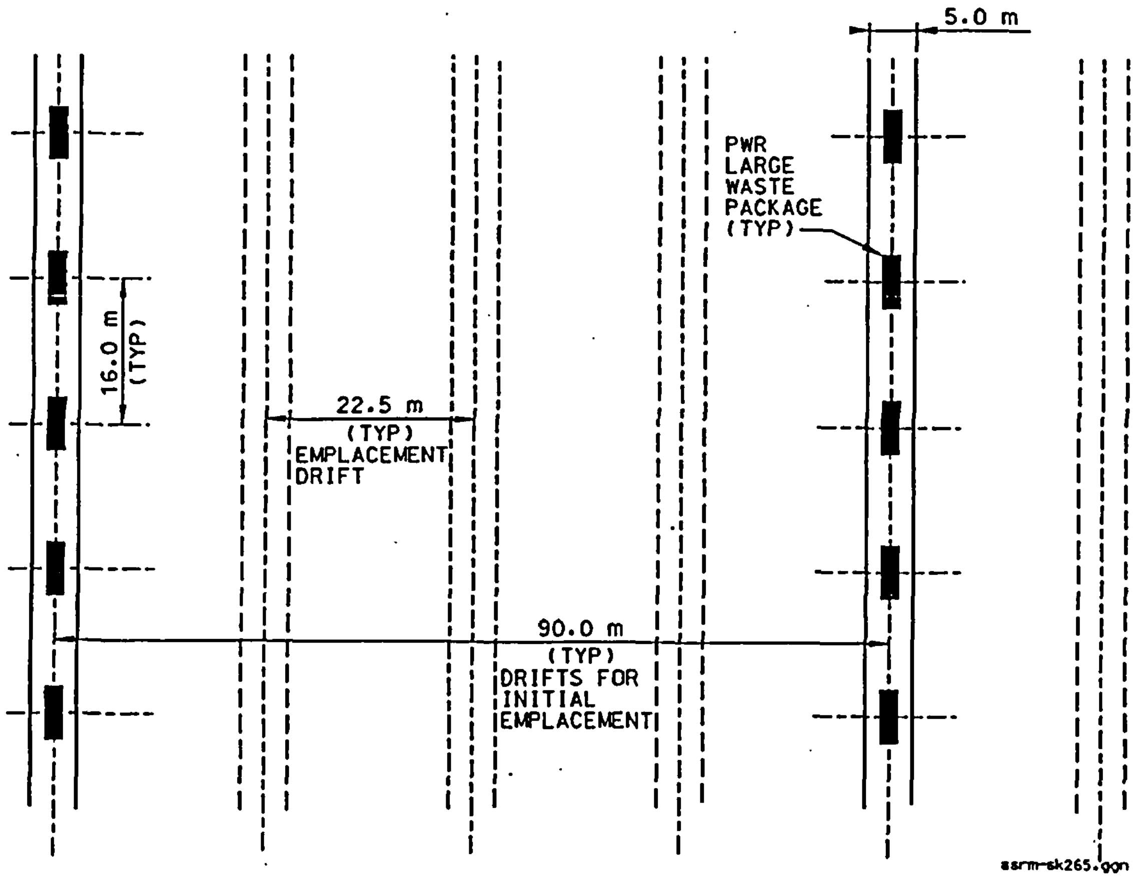

Figure 12-3. Localized Disturbance Emplacement Pattern

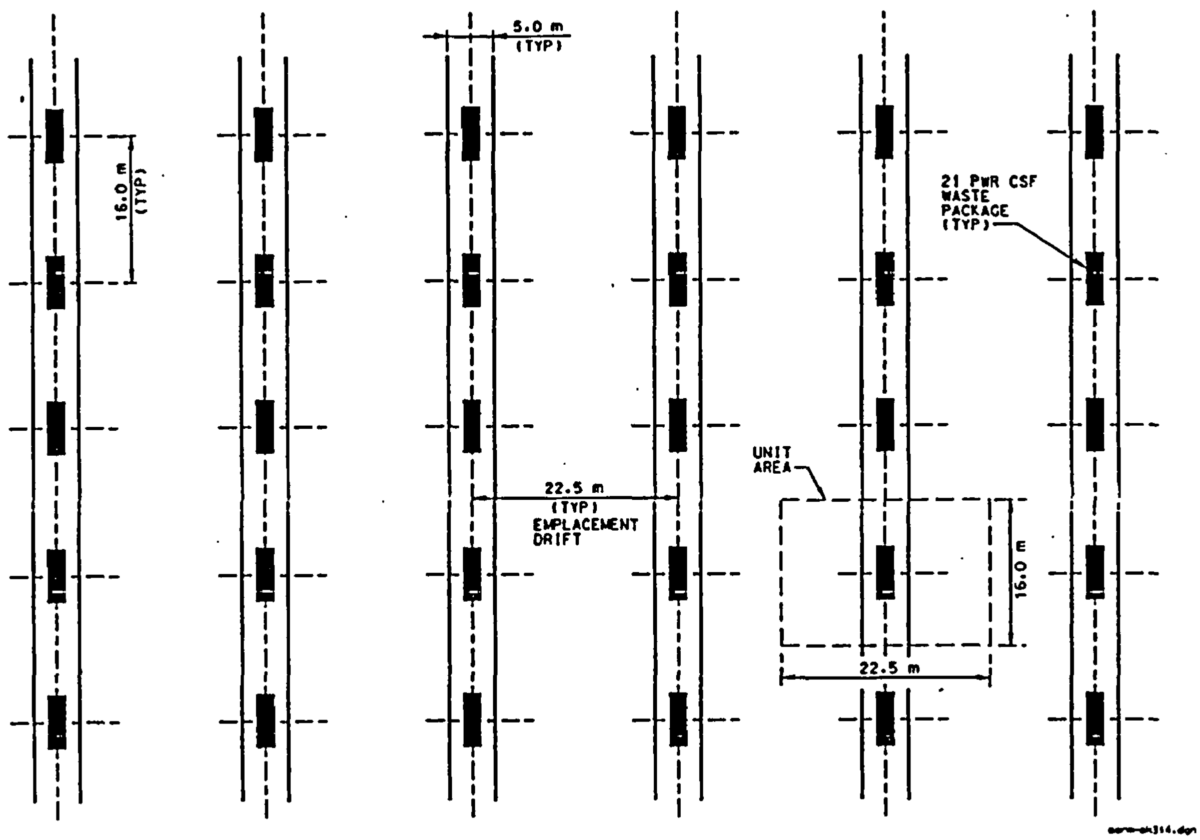

Figure 12-4. 100/MTU Emplacement Pattern

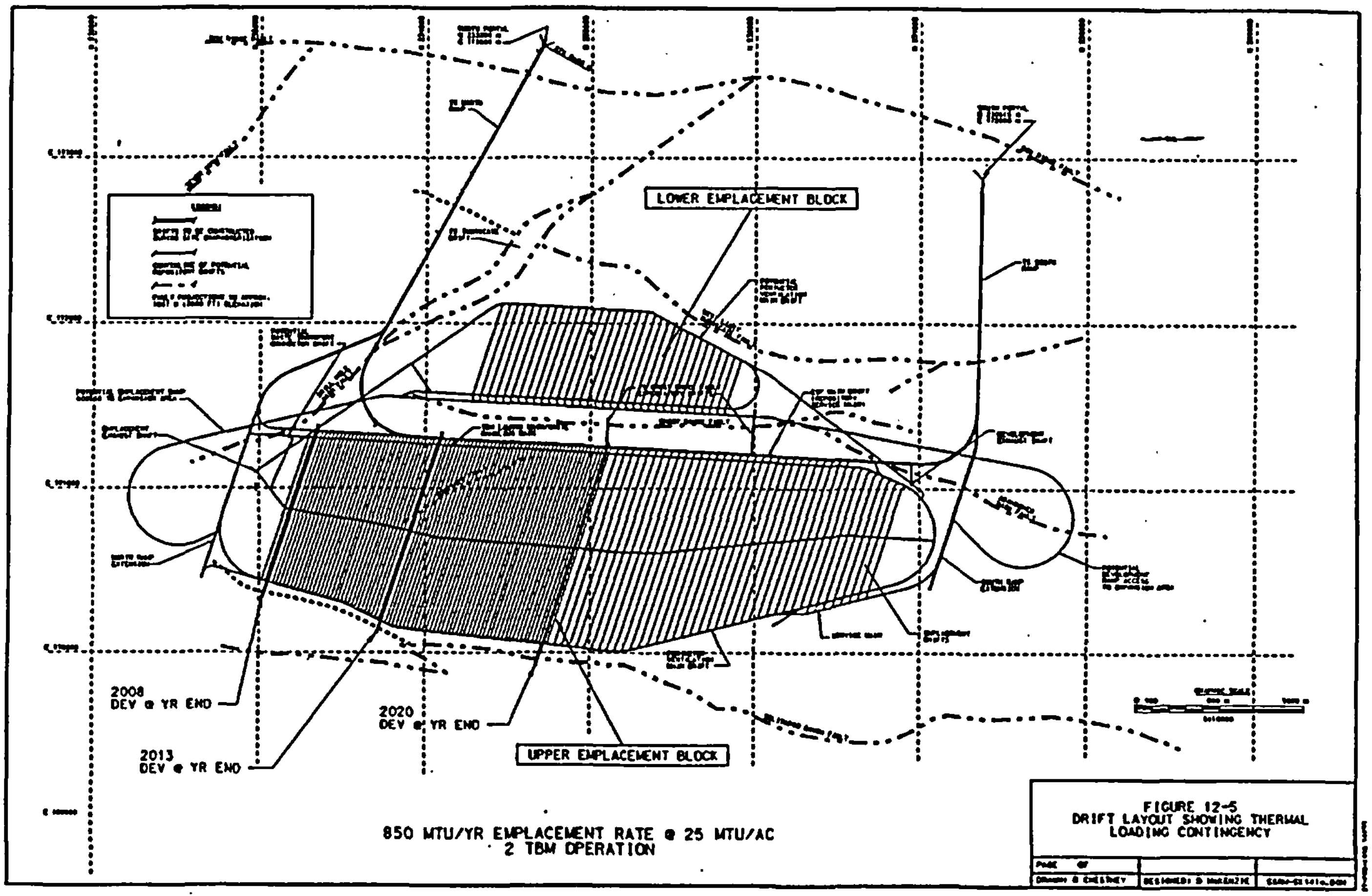

Figure 12-5. Drift Layout Showing Thermal Loading Contingency

12.2.2.3 Risk Considerations

The risk of pursuing this strategy is that some emplacement drift excavation could be wasted if the decision is made to stay with a low thermal load. Additionally, the annual waste emplacement rate would be constrained until the final decision is made. This constraint would begin in approximately the fourth year of emplacement operations. The waste receipt rate is sufficiently low in the first three years that it can be accommodated. The longer the decision is delayed, the larger the potential impact. It is preferable, therefore, to have the thermal loading decision in place prior to, or immediately following, the start of construction.

12.2.3 Thermal Loading – Thermal Goals

12.2.3.1 Description

A number of thermal goals have been developed to minimize the possible effects of increased temperature on the repository host rock and over- and underlying units. Thermal goals are discussed in Volume II, Section 8.2. Although these goals are tentative, some have become important to the repository design as their application influences repository configuration. Confirmation or revision of these goals is needed because a change in one or more of the goals may have a sizable impact on subsurface design.

12.2.3.2 Assumption Used in ACD

As described in Section 8.2, the three thermal goals influencing the current design are:

- Limit maximum temperature of the TSw3 unit to 115°C
- Limit maximum emplacement drift wall rock temperature to 200°C
- Limit maximum temperature of main access drift wall rock to 50°C.

The impacts on the layout of observing these limits are summarized below.

Limiting TSw3 temperature to 115°C involves maintaining an approximate 30 m vertical separation between the top of the TSw3 and the nearest emplaced waste packages, thus impacting the layout in the southwest area of the upper block. An area of approximately 100 acres is lost to emplacement in order to maintain the 30 m vertical separation.

The limit of 200°C for emplacement drift wall rock does not currently introduce any major limitation due to the selection of a thermal load of 83 MTU/acre for the reference design. At the reference thermal load, this temperature limit would be constraining only for large waste packages containing young (i.e., just over ten years out of reactor) fuel. The peak wall rock temperature estimated for emplacement of waste having the average characteristics of an oldest fuel first acceptance strategy (Volume II, Section 8.2) is in the 150 to 160°C range. The 200°C wall rock goal would become more important under a 100 MTU/acre scenario because more waste packages would have the potential to cause wallrock temperatures in excess of the goal.

The goal of limiting main access wall rock temperatures to 50°C involves the use of thermal buffer zones. These thermal buffers are areas of the emplacement drifts immediately adjacent to the main drifts which are left empty. This results in loss of potential emplacement area of the repository and an increase in cost. The empty areas allow the mains to remain cool because the process of thermal conduction through the rock takes many years to result in a rise of the rock temperature in the main. The fact that ventilation is maintained in the mains also tends to reduce the temperature rise of the main drifts.

12.2.3.3 Risk Considerations

The primary risk to the reference design of these goals is that a significant change in one or more of the goals could cause a change in the layout. If the TSw3 temperature limit were to be eliminated, additional emplacement space would be available in the primary area. Conversely, if it were lowered, the available space would be further reduced. Similarly, a change in the peak emplacement drift wall rock temperature goal could impact the allowable level of thermal loading and therefore change the size of the repository. A change in the main drift thermal goal could involve alteration of the width of the thermal buffers, again changing the repository size and resulting in loss or gain of emplacement area.

12.2.3.4 Tasks Required for Solution

Thermal goals are tied to the overall thermal loading strategy and will be defined (or eliminated) as a part of the final thermal loading decision.

12.2.4 Retrievability

12.2.4.1 Description

As discussed in Section 9.2, the ability to retrieve any or all of the emplaced waste must be maintained for 100 years after the start of emplacement. This retrieval operation would have to be conducted under adverse initial conditions including high temperature and radiation levels, and may have to contend with inoperative rail systems, areas of collapsed emplacement drift, and radioactive contamination from breached waste packages. Considerable effort will be required to demonstrate that retrieval is possible under the most adverse credible conditions that might be encountered. The retrievability issue encompasses issues related to long-term ground stability, including the longevity of material used for ground control. The issues related to long-term ground control requiring further investigation during the post-ACD are discussed below.

12.2.4.1.1 Materials Behavior

Information is needed to understand the potential for chemical and structural degradation of engineered materials at temperatures up to about 200°C and for time periods up to at least 150 years. Evaluation should consider the effects of site geochemistry, moisture, temperature (including temperature-induced mechanical loads), and time on construction materials (e.g., steel, concrete, shotcrete, and grout). Such data collected from in situ and laboratory tests and literature analysis are considered to have applicability to the assessment of preclosure as well as postclosure conditions.

12.2.4.1.2 Rock Mass Performance Parameters

The in situ measurement of rock and ground support deformation, stress, and temperature during ESF excavation and thermal testing (e.g., heater tests) is needed to develop criteria for the design of repository structures and operations. In addition to verification of design and the further development of acceptance criteria for subsurface openings, these data provide input to a database as the first step in a performance confirmation program as described in Subpart F of 10 CFR 60.

12.2.4.2 Assumption Used in ACD

A thermal load of 83 MTU/acre, near the lower end of the high range (80 to 100 MTU/acre), was used in the reference design. This should result in peak wall rock temperatures in the 150 to 160°C range in the emplacement drifts during the preclosure period. This is well below the current thermal goal of 200°C.

Emplacement drifts will not be ventilated after they are fully emplaced. However, the emplacement ventilation system is sized to be able to provide adequate airflow to emplacement drifts on a sequential basis to cool the drifts sufficiently for retrieval equipment to enter the drift.

No backfilling of emplacement drifts is planned. The emplacement drifts will remain unobstructed throughout the preclosure period. Retrieval equipment will have unimpaired access after ventilation is re-established to cool the drift.

The waste emplacement mode of in-drift emplacement of waste packages on railcars makes retrieval a straightforward operation under normal conditions. Retrieval would be accomplished in the reverse of the emplacement sequence.

12.2.4.3 Risk Considerations

If a determination is made that retrieval is not possible under the reference design conditions described above, the repository design would require change in order to preserve the retrieval option. The changes could involve altering certain design parameters such as the thermal loading; or basic changes to primary concepts, such as in-drift emplacement; the use of long parallel emplacement drifts; or the practice of not ventilating emplacement drifts after emplacement.

12.2.4.4 Tasks Required for Resolution

Prior to license application, the retrievability of waste under the conditions expected for the repository design must be shown to be feasible. Tasks required will include investigation of the behavior and longevity of the manmade materials that will be relied upon to preserve the retrievability option. These items are listed below.

- Ground Control – The behavior of both the subsurface openings and their installed ground control measures will be important. Field test information, primarily from ESF-based heater testing, coupled with numerical analyses of potential ground control measures and rock conditions, will help provide confidence that the drifts will remain stable. Investigation of the longevity of various construction materials should help in selecting those with projected long service lives and avoidance of those exhibiting rapid deterioration.

- Drift Invert and Rail System – The drift invert material and its installed rail haulage system must remain stable and functional in order to accommodate normal retrieval. As with ground control above, the issues of selecting proper construction materials, and in developing designs appropriate for the expected conditions, will be central to issue resolution.

- Waste Package Railcar – Retrieval under normal conditions will require that emplacement railcars remain functional throughout the preclosure period. An additional issue is that of metallurgical compatibility between the railcar and the waste package. The railcar must not detract from the long-term performance of the system. Design is needed to help ensure continued operability of the railcars, to provide compatibility, and to investigate potential enhancement of performance by the use of favorable materials and/or configurations.

12.2.5 Performance Confirmation

12.2.5.1 Description

A program of performance confirmation must be executed throughout the life of the repository. As discussed in Section 9.3, requirements for this program have not yet been defined. The eventual form that this program takes may have significant impact on the reference design. If requirements are developed that involve continuous monitoring of emplacement drifts, a significant research and development program will be needed to develop instrumentation capable of withstanding the emplacement drift environment for long time periods. Permanent in situ monitoring areas, if required, would involve changes to the subsurface layout.

12.2.5.2 Assumptions Used in ACD

While no special accommodation has been made for performance confirmation monitoring, it is felt that the layout could accommodate a reasonable program without major re-work. A combination of intermittent mobile remote monitoring and accessible in situ monitoring stations could be incorporated into the design as it now exists.

12.2.5.3 Risk Considerations

The primary risk to the design lies in the degree to which emplacement areas must be monitored. Continuous monitoring of all emplacement areas would be extremely impactive and would require a vast program of monitoring, data collection, and maintenance. Programs involving lesser levels of monitoring would have less impact on the design.

12.2.5.4 Tasks Required for Resolution

A systems engineering study currently underway is the first step in the process of defining performance confirmation program requirements. This study should produce a listing of requirements related to parameters of interest, proposed sampling frequencies, and proposed monitoring methodologies. A draft performance confirmation plan is also expected to result from this work. Subsequent repository design work will incorporate these recommendations.

12.2.6 Definition of the Repository Block

12.2.6.1 Description

The reference design presented in this MGDS ACD Report is based on the best mapping and geologic information available from ESF, surface mapping, drilling, and laboratory testing. While it is not expected that major changes will result from additional information, it is desirable to base the geologic model and, therefore, the subsurface design on the most complete information base possible.

12.2.6.2 Assumptions Used for ACD

The three-dimensional stratigraphic model described in Section 8.1 forms the basis for the reference layout, and is based on the best available geologic information.

12.2.6.3 Risk Considerations

The primary risk to the reference design of failing to acquire sufficient geologic information is that, if the design is well advanced, or construction is started, when a major feature (fault or large zone of fractured ground) is discovered, the layout may have to undergo significant modification, or even a complete change of approach. The impact of this degree of change is more severe when the design has reached its final stages, especially if construction has already begun.

12.2.6.4 Tasks Required for Resolution

The obvious solution in this situation is to continue gathering site information. Specific needs can be addressed by:

- Developing one or more cross-block drifts during site characterization to discover any major unknown north-south trending geologic features, and to explore the lower sub-units in the TSw2. The current Topopah Spring Main Drift remains in the upper part of the TSw2 along its entire length and traverses the east edge of the upper emplacement block. Such cross-block drifting is described in *Description and Rationale for Enhancement to the Baseline ESF Configuration* (CRWMS M&O 1993d).

- Performing some drilling in the southwest part of the block where geologic information is lacking to define the boundary of the block in that area.

12.2.7 Seismic Design Issues

12.2.7.1 Description

The design of the subsurface openings and ground control system must take into account ground motion from credible seismic events. A seismic design methodology has been developed and reported in two topical reports: *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain* (CRWMS M&O 1994t), and *Topical Report – Seismic Design Methodology for a Geologic Repository at Yucca Mountain* (YMP 1995d).

12.2.7.2 Assumptions Used in ACD

The reference design described in the MGDS ACD Report was developed using the methodology described in the above-referenced topical reports. The emplacement drifts were designed using the parameters for Performance Category 3.

12.2.7.3 Risk Considerations

The design of the ACD ground support systems could be affected if either of two events occur: a change in the magnitude of the design seismic event, or a change in the performance category in which repository subsurface openings have been placed.

12.2.7.4 Tasks Required for Resolution

A series of three topical reports was originally planned to be developed to address the seismic design issue. The first two reports, cited above, have been completed. A third report was originally planned for FY 1996, but has been deferred due to funding limitations. The completion of the third topical report is fundamental to the development of a robust licensing argument in the seismic design area. The first report dealt with the concept and methodology by which probabilistic estimation of the magnitude of the potential ground motion and fault displacement hazards at Yucca Mountain would be done. The second report contains a design methodology for estimating the design loads on subsurface openings, given a design seismic event. The third report is to contain definition of the magnitude of the design seismic event and corresponding ground motion parameters which can be used, in conjunction with the design methodology, to design the subsurface openings. The reference ACD design is based on the information used in the ESF design. This information can be found in *Seismic Design Inputs for the Exploratory Studies Facility at Yucca Mountain* (CRWMS M&O 1994d). The completion of the third topical report in the series is recommended to conclude the design for seismic hazards.

12.2.8 Secondary Excavation

12.2.8.1 Description

Approximately 20,000 m of the repository subsurface layout shown in this report will require excavation by means other than TBM. It is a stated assumption that mechanical excavations will be used when practical, as stated in Key Assumption 027 and Design Concept Subsurface (DCSS) 005 in the CDA Document (CRWMS M&O 1995a). There are currently no proven non-TBM mechanical excavation methods available to excavate rock having the compressive strength of the repository emplacement horizon rock, the TSw2. This unit has an unconfined compressive strength of approximately 179 megapascals (MPa) (SNL 1995a). Numerous concepts exist and have been conceptually evaluated (CRWMS M&O 1995aj). None have been proven via long-term operation in underground applications in rock of the strength of the TSw2.

12.2.8.2 Assumption used for ACD

The mobile miner, a hardrock excavation system based on disc cutter technology similar to TBMs, has been assumed for secondary (non-TBM) mechanical excavation. It is recognized that the mobile miner does not have a long history of proven use, but it has had three versions that have been used in actual mining and construction applications with varying degrees of success.

12.2.8.3 Risk Considerations

The risk to the ACD subsurface design is primarily in the operational methodology. The subsurface configuration shown can be excavated by numerous secondary excavation methods, should they prove feasible. In addition, drill and blast is an option. If drill and blast is used, some features of the design may need to be adapted to account for the movement, storage, and initiation of explosives, and the effects of blasting induced pressure waves on subsurface installations.

12.2.8.4 Tasks Required for Resolution

Further investigation into these methods, and field trials of the methods showing the most promise, would be required to base subsequent design work on any particular concept. Drill and blast excavation is the alternative to mechanical excavation and would likely be used if no non-TBM mechanical excavation methods prove feasible.

12.2.9 Emplacement Drift Backfill

12.2.9.1 Description

The use of backfill in emplacement drifts is not currently anticipated as indicated by Key Assumption 046 in the CDA Document (CRWMS M&O 1995a). However, the use of backfill as an enhancement to waste isolation is being evaluated, along with other Engineered Barrier System enhancements, in an ongoing systems engineering study. A decision to employ backfill in emplacement drifts could have the following potential effects on the design:

- If excavated tuff is to form some or all of the backfill material, the excavated rock storage area may have to provide protection of the rock to reduce the likelihood of deleterious changes over a 100-year period while stored on the surface.

- The closure period would be reconsidered because there would be approximately 250 km of drift to backfill as opposed to 25 to 30 km if only the main drifts and ramps are filled.

- A method would have to be developed to emplace backfill remotely in the emplacement drifts. A concept is discussed in Section 8.8, but significant additional work would be needed to prove the concept.

12.2.9.2 Assumption Used for ACD

As noted above, it is assumed in the ACD that no backfilling of emplacement drifts is required. However, it was considered inappropriate to present a design that did not support at least some form of emplacement drift backfill. The currently ongoing systems engineering study and the draft waste isolation strategy, which discusses backfill in numerous places, prompted the repository designers to consider adjusting the emplacement mode from a center in-drift mode, that may not support backfill, to an off-center in-drift mode which supports the placement of some types of backfill. The off-center in-drift mode also possesses other favorable attributes, including flexibility in potential retrieval actions and access for performance confirmation.

12.2.9.3 Risk Considerations

With the off-center in-drift emplacement mode, the risk to the design of changing to a backfill scenario is reduced. The closure phase of repository operations would have to be addressed again, as would the cost of construction of emplacement drifts. Additional design activity would be needed to more fully develop the concept of backfilling via a remote operation.

12.2.9.4 Tasks Required for Solution

The long-term performance of the site must be further evaluated to assess the potential benefits of backfill. Such performance assessment activity would, if backfill proves necessary or desirable, ultimately result in the development of requirements concerning backfill that would then be incorporated in subsequent design activity.

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13.2 LAWS, CODES, AND STANDARDS

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APPENDIX A
ACRONYMS

A.1 DOCUMENT ACRONYMS

AC	Alternating Current
ACD	Advanced Conceptual Design
ACGLF	Automatic Center of Gravity Lift Fixture
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ALARA	As Low As Reasonably Achievable
AML	Areal Mass Loading
ANS	American Nuclear Society
ANSI	American National Standards Institute
AREA	American Railway Engineering Association
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASTM	American Society of Testing and Materials
B&W	B&W Fuel Company
BLM	U.S. Bureau of Land Management
BOP	Balance of Plant
BWR	Boiling Water Reactor
CDA	Controlled Design Assumptions
CFR	Code of Federal Regulations
CHn	Calico Hills Nonwelded Thermal/Mechanical Unit
CI	Configuration Item
CIG	Configuration Item Group
CID	Center-In-Drift
CMAA	Crane Manufacturers Association of America, Inc.
CMF	Cask Maintenance Facility
CRD	Civilian Radioactive Waste Management System Requirements Document
CRWMS	Civilian Radioactive Waste Management System
CSCI	Computer Software Configuration Item
CSF	Canistered Spent Fuel (see canistered fuel, Vol. III)
CSI	Construction Standards Institute
CSS	Carrier Staging Shed
DB	Dry-Bulb
DBA	Design Basis Accident
DBE	Design Basis Event
DBT	Design Basis Tornado
DCS	Design Concept Assumption Surface
DCSS	Design Concept Assumption Subsurface

DHLW	Defense High-Level Radioactive Waste
DOE	U.S. Department of Energy
EBDRD	Engineered Barrier Design Requirements Document
EBS	Engineered Barrier System
ESF	Exploratory Studies Facility
ESFAS	Exploratory Studies Facility Alternatives Study
ESFDR	Exploratory Studies Facility Design Requirements
FLAC	Fast Lagrangian Analysis of Continua
FY	Fiscal Year
GROA	Geologic Repository Operations Area
HE	Human Error
HEPA	High Efficiency Particualte Air
HLW	High-Level Waste
HLWC	High-Level Waste Canister
HVAC	Heating, Ventilation and Air Conditioning
HW	Hazardous Waste
IOC	Interoffice Correspondence
ITEL	International Tunnel Equipment Limited
LLNL	Lawrence Livermore National Laboratory
LLW	Low-Level Radioactive Waste
LYNX	Lynx Geoscience Modeling Software System
M&O	Management and Operating Contractor
MGDS	Mined Geologic Disposal System
MGDS-RD	Mined Geologic Disposal System Requirements Document
MPC	Multi-Purpose Canister
MRS	Monitored Retrievable Storage
MTIHM	Metric Tons of Initial Heavy Metal
MTU	Metric Tons of Uranium
MW	Mixed Waste
N/A	Not Applicable
NEPA	National Environmental Policy Act
NNWSI	Nevada Nuclear Waste Storage Investigations
NRC	U.S. Nuclear Regulatory Commission
NTS	Nevada Test Site
NUREG	Nuclear Regulatory Commission Regulation (or position preface)

NWPA	Nuclear Waste Policy Act of 1982
NWPAA	Nuclear Waste Policy Amendments Act of 1987
NWTRB	Nuclear Waste Technical Review Board
OCID	Off-Center In-Drift
OCRWM	Office of Civilian Radioactive Waste Management
OFF	Oldest Fuel First
ORNL	Oak Ridge National Laboratory
PTn	Paintbrush Tuff Nonwelded Thermal/Mechanical Unit
PWR	Pressurized Water Reactor
QARD	Quality Assurance Requirements and Description
RCA	Radilogically Controlled Area
RCRA	Resource Conservation and Recovery Act
RDRD	Repository Design Requirements Document
RW	Radioactive Waste
SCP	Site Characterization Plan
SCP-CD	Site Characterization Plan Conceptual Design
SCP-CDR	Site Characterization Plan Conceptual Design Report
SD&TRD	Site Design and Test Requirements Document
SFA	Spent Fuel Assembly
SFC	Spent Fuel Canister
SNF	Spent Nuclear Fuel
SNL	Sandia National Laboratories
SRB	Sulfate-Reducing Bacteria
SSC	Structures, Systems, and Components
TBD	To Be Determined
TBM	Tunnel Boring Machine
TBR	To Be Resolved
TBV	To Be Verified
TCw	Tiva Canyon Welded Thermal/Mechanical Unit
TDPP	Technical Document Preparation Plan
TDS	Technical Data Assumption Surface
TDSS	Technical Data Assumption Subsurface
TMB	Transporter Maintenance Building
TS	Topopah Spring Tuff Geologic Unit
TSw	Topopah Spring Welded Thermal/Mechanical Unit
UCF	Uncanistered Fuel
UDEC	Univeral Distinct Element Code
UE	Underground, exploratory (drill hole designation)

USC	United States Code
USF	Uncanistered Spent Fuel (also see Uncanistered Fuel -UCF)
USGS	U.S. Geological Survey
USW	Underground, southern Nevada waste (drill hole designation)
VNETPC	Ventilation Network Simulation Program for Personal Computer
V-TOUGH	Computer program
WHB	Waste Handling Building
WTB	Waste Treatment Building
YMP	Yucca Mountain Site Characterization Project
YMSCO	Yucca Mountain Site Characterization Office

A.2 DEFINITIONS OF UNITS

BTU/hr	British Thermal Unit per hour
°C	degree Celcius
°C/m	degree Celcius per meter
CF	cubic feet
cfm	cubic feet per minute
cm/millenium	centimeter per millenium
cm/ka	centimeter per thousand years
cm/yr	centimeter per year
cu. m	cubic meter
dpm/cm^2	disentigration per minute per square meter
°F	degree Farenheit
ft	foot
ft^2	square foot
ft^3	cubic foot
ft-lb	foot-pound
g	gram
gals	gallons
g/cm^3	grams per cubic centimeter
GHz	gigahertz
GJ/m^2	gigajoules per square meter
GPa	gigapascal
gpd	gallons per day
gpm	gallons per minute
GWd/MTU	gigawatt-day per metric tons of uranium
hr	hour
HP	horsepower
in	inch
J/m^3K	joule per cubic meter-degree Kelvin
kg	kilogram
kg/m	kilogram per meter
kg/m^3	kilogram per cubic meter
kJ/m^3K	kilojoule per cubic meter-degree Kelvin
km	kilometer
km/h	kilometer per hour
km/hr	kilometer per hour
kN	kilonewton
kPa	kilopascals
kV	kilovolt
kW	kilowatt
kW/acre	kilowatt per acre
kWh	kilowatt-hour
kW/Pkg	kilowatt per waste package
lb	pound

lbs/ft^3	pounds per cubic foot
m	meter
m^3	cubic meter
MB	megabyte
mbar	millibar
Mbps	megabits per second
Mbtu/hr	million British Thermal Unit per hour
$\mu Ci/cm^2$	microcuries per square centimeter
MeV	(10.2.2.2)
m^3/hr	cubic meter per hour
MHZ	megahertz
m^3/min	cubic meter per minute
min	minute
mm	millimeter
mm/millenium	
μm	micrometer or micron
MPa	megapascal
mph	miles per hour
mR/Hr	millirem per hour
mrem	millirem
m/s	meter per second
$(m^3/s)/kW$	cubic meter per second per kilowatt
m^3/s	cubic meter per second
mSv	millisievert
MT	metric tons
MTU	metric tons of uranium
MTU/acre	metric tons of uranium per acre
MTU/WP	metric tons of uranium per waste package
MVA	megavolt-ampere
MW	megawatt
MWd/IHM	(10.2.2.2)
Pa	pascals
psi	pounds per square inch
rem/hr	rem per hour
R/Hr	rem per hour
rpm	revolutions per minute
VAC	(7.2.2.5.9)
V	volt
W/mK	watt per meter-degree Kelvin
W/m^2	watt per square meter
wt %	percent weight by volume
yr	year

APPENDIX B

ANALYSIS OF GROUND STABILITY AND SUPPORT

CONTENTS

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FIGURES

FIGURES (Continued)

Page

FIGURES (Continued)

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TABLES

ANALYSIS OF GROUND STABILITY AND SUPPORT

B.1 PREVIOUS WORK

Documents providing background information applicable to repository ground control include reports by Sandia National Laboratories (SNL) and the Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) documents on Exploratory Studies Facility and repository design. These reports are discussed in Section 8.5, Ground Control.

B.2 ANALYSIS INPUTS

Modeling inputs include geologic information, thermal/mechanical properties, repository layout design parameters, ground support types, in situ stress, thermal loads, dynamic loads, and temperature histories. Sources for this information, mainly CRWMS M&O and CRWMS M&O/Sandia reports, are referenced. Some of these data are qualified sources and some are not; however, these data are considered the most appropriate data for the modeling that was performed.

B.2.1 Loading Conditions

B.2.1.1 In Situ Stress

Components of the in situ-stress state at the approximate depth of the repository are given in Table B-1. These stresses, caused by the weight of the overlying geologic units, lateral confinement, and past stress history, are the initial stress condition for modeling. The vertical normal stress σ_v is considered equal to the weight of the overlying rock and is expressed as

$$\sigma_v = -\sum_{i=1}^{n} \rho_i g Y_i \tag{1}$$

where ρ_i = the average density of ith layer rock, kg/m^3
g = the gravitational acceleration, m/s^2
Y_i = the average thickness of ith layer rock, m
n = number of overlying rock layers

The magnitude of the horizontal stress σ_h is expressed as a function of the vertical stress and given as the horizontal-to-vertical stress ratio K, which is

$$K = \frac{\sigma_h}{\sigma_v} \tag{2}$$

Values for the ratio K are given in Table B-1 and show that horizontal stresses are expected to be lower than the vertical stress. Minimum and maximum horizontal stress ratios are close in value and indicate a weak horizontal stress anisotropy. A value of $K = 0.5$ has been assumed to be representative of initial horizontal repository stress and is used for this analysis. As shown in Table B-1, in situ stress at the proposed repository horizon is an average vertical stress of 7.0 MPa and a horizontal stress of 3.5 MPa.

Table B-1. Rock In Situ Stress at Proposed Repository Horizon

Parameter	Average Value	Range
Vertical Stress (MPa)	7.0	5.0 - 10.0
Minimum Horizontal/Vertical Stress (MPa)	0.5	0.3 - 0.8
Maximum Horizontal/Vertical Stress (MPa)	0.6	0.3 - 1.0
Bearing - Minimum Horizontal Stress	N57W	N50W - N65W
Bearing - Maximum Horizontal Stress	N32E	N25E - N40E
Source: *Controlled Design Assumptions*, TDSS-001 (CRWMS M&O 1995a)		

B.2.1.2 Thermal Load and Heat Transfer

A thermal load of 83 metric tons of uranium (MTU)/acre is used as the reference design load based on a programmatic decision. Drift spacing and waste package spacing associated with this thermal load are listed in Table B-2, based on the horizontal in-drift emplacement mode and the areal mass loading (AML) approach. Heat transfer in an emplacement drift involves thermal conduction, convection, and radiation. A detailed description regarding these three heat transfer mechanisms is given in Thermomechanical Analyses (CRWMS M&O 1995b).

Table B-2. Drift and Waste Package Spacings Used in Analysis

	Spacing (at 83 MTU/acre)
	83
Drift (m)	22.5
Waste Package (m)	19.12

B.2.1.3 Seismic Loads

Following the seismic design methodology described in a topical report, *Seismic Design Methodology For a Geologic Repository at Yucca Mountain* (YMP 1995b), a peak ground velocity (PGV) of 23 cm/second was selected as being appropriate for the analysis of the emplacement drifts. This PGV value corresponds to performance category 3, of the performance-goal-based seismic design method proposed in the topical report (YMP 1995b). The corresponding peak ground acceleration (PGA) is 0.37g where "g" is the gravitational acceleration. Dynamic loads on the underground repository openings have been analyzed by idealizing the seismic ground motion as a sinusoidal wave. Peak wave values are based on peak ground accelerations, and a typical earthquake frequency range has been used.

In carrying out numerical simulation using FLAC models, both PGV and PGA values were further assumed to be the same for horizontal and vertical directions. Furthermore, depth attenuation of ground motions was not considered. Seismic loading was expressed in terms of a combination of sinusoidal pressure and shear waves with an amplitude equal to 23 cm/second, frequency varying between 0.2 to 10 Hz, and duration of 0.5 to 2 seconds. At present, a frequency of 5 Hz was chosen along with a duration time of 0.5 seconds. In addition, a PGV value of 46 cm/sec and a frequency value of 10 Hz were used as an upper bound to examine the dynamic response of drift and ground support.

B.2.2 Thermal and Mechanical Rock Properties

Thermal and mechanical properties for the TSw2 thermal/mechanical unit are listed in Tables B-3 through B-6. As shown in Table B-6, mechanical properties are given for rock mass quality categories (RMQ) ranging from 1 to 5. The RMQ categories, first presented by Hardy and Bauer (SNL 1991) and used for Exploratory Studies Facility analyses (CRWMS M&O 1995e) represent the distribution of rock properties for a given rock unit. Each category is associated with a frequency of occurrence of a certain range of Q-values. For example, category RMQ=3 for rock unit Tsw2 has a typical Q-value of 1.91 for which rock properties have been derived and ground support categories have been developed (Table B-6). Also, category RMQ=3 is considered representative of the most frequently occurring range of Q-values (see Table 8.5-1 and Table 8.5-3) and is thus used as a reference case for the numerical modeling.

B.2.3 Layout Parameters

Emplacement drift orientation is a feature of the layout design that has a potential impact on ground control. Typically, a stable drift orientation is one that minimizes the occurrence of open joints or faults parallel to the drift axis, especially in rock with low horizontal stresses. As stated by DCSS 001 and explained in the *Initial Summary Report for Repository/Waste Package Advanced Conceptual Design* (CRWMS M&O 1994a, Section 8.2.1.3), emplacement drifts will be oriented at least 30 degrees from the dominant strike of vertically-dipping joints, and maintainable drifts and accesses will be oriented, if practicable, to have intersections of 70-90 degrees with the dominant strike of the joint systems. However, in situ lateral stresses at Yucca Mountain are expected to be low (CRWMS M&O 1994, Section 5.1.3), resulting in low confining stress and reduced joint strength during excavation. This condition is expected to be improved as thermally-induced horizontal stress increases following emplacement of waste packages. Both the excavation stress condition and the post-emplacement stress condition are examined by numerical stress analysis.

Horizontal center-in-drift emplacement is the reference emplacement mode, based on preliminary assessments of waste package design and repository criteria and requirements (CRWMS M&O 1995a Key 011). The current conceptual layout shows emplacement drift excavation by TBMs, which produce drifts with a circular cross section. The 5.0-m-diameter drift used in the stability analyses was chosen based on waste package size, emplacement equipment size, and invert and ground support considerations. Waste package length and diameter are assumed to be 5.68 m and 1.80 m, respectively, based on the CDA (EBDRD 3.7.1.J.1). These two parameters were used in numerical modeling with ANSYS to determine rock-mass temperature distributions.

Table B-3. Contact Depths, Thermal Conductivity, and Capacitance for TSw2 Thermal/ Mechanical Unit

Units	Upper Contact (m)	Lower Contact (m)	Thermal Conductivity (W/m·°K)	Thermal Capacitance (J/cm^3·°K) (averaged over temperature range)		
				T≤94°C	94°C≤T≤114°C	T>114°C
TSw2	204.2	393.5	2.10	2.1414	10.4786	2.1839
Source: RIB, Rev. 3, Sections: 1.1326a (YMP 1995a)						

Table B-4. Thermal Expansion Coefficient for TSw2 Thermal/Mechanical Unit

Temperature Range (°C)	Thermal Expansion Coefficient (10^{-6}/°C)
25 - 50	5.07
50 - 100	7.30
100 - 150	8.19
150 - 200	8.97
Source: SNL 1995	

Table B-5. Rock In Situ Density for TSw2 Thermal/Mechanical Unit (g/cm^3)

Thermal/Mechanical Unit	At In Situ Saturation
TSw2	2.274
Source: YMP 1995a, Sec. 1.1325a	

Table B-6. Rock Mass Mechanical Properties for TSw2 Thermal/Mechanical Unit

Rock Mass Mechanical Properties		Rock Mass Quality Category				
		1	2	3	4	5
Q		0.3	0.65	1.91	3.75	8.44
Average RMR		42	48	54	59	65
Elastic Modulus (GPa)		6.37	8.95	12.55	17.11	23.51
Poisson's Ratio		0.21	0.21	0.21	0.21	0.21
Mohr-Coulomb Strength Parameters	Cohesion (MPa)[1]	1.3	1.6	2.2	2.8	3.8
	Friction Angle (degrees)[1]	49	49	50	50	50
	Dilation Angle (degrees)[1]	25	25	25	25	25
Tensile Strength (MPa)[2]		0.65	0.8	1.1	1.4	1.9
[1] Data not qualified. [2] Assumed to be one half of cohesion.						
Source: CRWMS M&O 1995c						

B.2.4 Candidate Ground Support

Ground support materials considered for emplacement drifts consist primarily of rock bolts, welded wire mesh (WWM) (not modeled), shotcrete, and structural steel sets. Three ground support types were assumed for these analyses and are used as examples to provide guidance in determining likely support behavior:

- Type I: Fully grouted rock bolts (30 mm outside diameter), 2.5 m long on a 1.0-m-square pattern plus 100 mm of shotcrete
- Type II: Shotcrete lining, 150 mm thick
- Type III: Structural steel sets, W5×19, spaced at 1.2 m intervals

Parameters and properties used to characterize the ground support elements include cross-sectional area, elastic modulus, tensile strength, bond stiffness, bond strength of the grout annulus for steel bolts, and moment of inertia for both shotcrete and steel sets. (Formulations and additional information on bond stiffness and strength are provided in Itasca 1993). Values for these parameters, grouped by ground support type, are listed below in Table B-7.

Table B-7. Ground Support Parameters and Values

Parameter	Value
Steel Rock Bolt (30-mm outside diameter):	
• Length (m)	2.5
• Cross-Sectional Area (m^2)	4.39×10^{-4}
• Elastic Modulus (GPa)	200.0
• Tensile Strength (kN)	267.0
• Bond Stiffness of Grout Annulus (GN/m/m)	10.62
• Bond Strength of Grout Annulus (MN/m)	0.556
Shotcrete (100-mm thick):	
• Cross-Sectional Area (m^2/meter of drift)	0.10
• Moment of Inertia (m^4/meter of drift)	8.33×10^{-5}
• Elastic Modulus (GPa)	27.58
• Compressive Strength (MPa)	34.5
Steel Set (W5x19):	
• Cross-Sectional Area (m^2)	3.57×10^{-3}
• Moment of Inertia (m^4)	1.09×10^{-5}
• Elastic Modulus (GPa)	200.0
• Strength (MPa)	248.0
Sources: CRWMS M&O 1995d; AISC 1989	

B.3 NUMERICAL MODELING

B.3.1 Computer Programs

Two commercially available computer programs, ANSYS and FLAC (described below), were used for the numerical analysis of rock temperature and opening stability. The ANSYS program is installed on a SGI Indigo^2 Power Extreme workstation with 320 MB RAM, and the FLAC code runs on 90-MHz Pentium microcomputers. The release of the ANSYS program used in the thermal analysis is Revision 5.2. ANSYS Revision 5.1 has been verified and validated according to the QAP-SI-series of CRWMS M&O *Computer Software Quality Assurance* procedures, but Revision 5.2 has not been verified and validated. The FLAC code, Version 3.22, on the other hand, is approved for design use in accordance with the Quality Assurance procedures and carries the appropriate CSCI number (given below), its installation on the machines used for these analyses, however, has not been documented. Additional documentation would be required before these computer results would be considered qualified.

ANSYS, introduced in 1970 by Dr. John Swanson and Swanson Analysis Systems, Incorporated (SASI), is a general-purpose program, meaning that the program can be used in many disciplines of engineering, that deal with topics including structural, geotechnical, mechanical, thermal, and fluids. The ANSYS Revision 5.2 is a menu-driven computer program and uses the Graphical User Interface (GUI) of the Unix X Window System (ANSYS 1995).

FLAC (Fast Lagrangian Analysis of Continua) is a two-dimensional explicit finite difference code that simulates the behavior of structures built of soil, rock, and other materials that are subjected to static, dynamic, and thermally induced loads (Itasca 1993). Modeled materials respond to applied forces or boundary restraints according to prescribed linear or non-linear stress/strain laws, and undergo plastic flow when a limiting yield condition is reached. FLAC is based on a Lagrangian calculation scheme, especially suited for modeling large displacements, and has several built-in constitutive models that permit the simulation of highly non-linear, irreversible responses typical of many geologic materials. The FLAC program was initially developed by Dr. Peter Cundall and Itasca Consulting Group, Inc. in 1986. The program version used to analyze opening stability is Version 3.22 (CSCI # 20.93.3001-AAu3.22), which has been verified and validated in accordance with applicable CRWMS M&O procedures.

The FLAC code computes fully-dynamic responses to seismic loadings on an explicit finite different solution scheme of the full equations of motion. Displacement and load changes brought out by ground shaking on ground support systems are calculated in the same way. A seismic event is translated into the dynamic input by one of the following four ways: (1) an acceleration history, (2) a wave velocity history, (3) a stress or pressure wave history, and (4) a dynamic force history. The history data are expressed either in a table or in functions. Different damping can be introduced into the run during the program execution to help rapidly mobilize the ground vibration after the seismic waves have passes through the model. The velocity history approach was adopted for analysis.

B.3.2 Features of the Model

B.3.2.1 Yield Criterion

The Mohr-Coulomb yield criterion was used in the analysis to judge whether or not the rock mass experiences failure. The criterion is defined as

$$\tau = c - \sigma_n \tan\phi \tag{3}$$

where τ = shear stress on a failure or yield plane, Pa
σ_n = normal stress on a failure plane (tensile stress is positive), Pa
c = cohesion, Pa
ϕ = friction angle, degrees

The yield criterion is used to represent the rock mass strength in FLAC. The ratio of Mohr-Coulomb strength to rock stress (strength/stress ratio) is evaluated for every element and is especially useful in assessing rock mass stability in the vicinity of the drift. An element is considered to perform satisfactorily when its strength/stress ratio is larger than 1.0 and is thought to fail structurally if the strength/stress ratio is equal to or less than 1.0.

The concept of factor-of-safety was used as the criterion to assess ground support performance under in situ stress, thermal and seismic loads. The factor-of-safety for ground support components is defined as the ratio of material strength to stress or force. A ground support component is in a stable state when its strength/stress (or force) ratio is larger than 1.0 and is of structural failure if the strength/stress ratio is equal to or less than 1.0.

B.3.2.2 Initial and Boundary Conditions

Initial Conditions

Initial stress condition in the analysis is assumed to be consistent with the in situ stress given in Table B-1. Initial temperature in the TSw2 thermal/mechanical unit is based on a rock temperature at the ground surface of 18.7°C and a rock thermal gradient as listed in Table B.8.

Table B-8. Rock Mass Thermal Gradient

Depth (m)	Thermal Gradient (°C/m)
0 - 150	0.019
150 - 400	0.018
400 - 541	0.030
Source: CRWMS M&O 1995a, TDSS-002	

Boundary Conditions for Thermomechanical Model

Boundary conditions for the thermomechanical model with FLAC are illustrated in Figure B-1. The half-drift-spacing geometry is appropriate for the thermomechanical model because the model is symmetric along a vertical plane through the center of the drift. The model dimension in the vertical dimension is the entire thickness of the TSw2 unit. As shown by the bar-and-roller symbols along the sides and bottoms of the models (Figure B-1), displacements in the horizontal direction on two vertical boundaries and in the vertical direction at the TSw2 lower boundary are zero (or fixed). Overburden stress is applied to the TSw2 upper contact, which is free to move vertically. The surface of the drift is stress and constraint free.

Rock temperatures after waste emplacement are time-dependent and were evaluated with the ANSYS program. Due to limitations of the thermal options in the FLAC code, rock temperature distributions are calculated based on the boundary temperature histories obtained from the thermal analyses with ANSYS. Based on thermal symmetry, the vertical model boundaries are prescribed as adiabatic, or zero heat flow, boundaries.

Boundary Conditions for Seismic Model

Boundary conditions for the seismic model with FLAC are shown in Figure B-2, and differ from those for the thermomechanical model. Symmetrical conditions for stress, displacement and velocity fields of the seismic model do not exist because the direction of seismic wave propagation varies with time. In addition, the model dimensions should be large enough to minimize wave reflection and achieve free-field conditions at boundaries so that seismically-induced response can be corrected simulated.

As illustrated in Figure B-2, the horizontal and vertical dimensions for the seismic model are 202.5 and 189.3 meters, respectively. For the 5-meter-diameter-drift with 22.5-meter-drift-spacing, the model contains 9 emplacement drifts. The center drift is reinforced with ground supports, while its neighboring drifts are not supported in order to examine the maximum influence of multiple drift excavation and waste package emplacement on the center drift. The underlying rationale is that any ground support systems which work for the center drift will automatically work for all the adjacent drifts. Figure B-3 illustrates the mesh refinement near the emplacement drifts for the seismic model.

Viscous boundary conditions are used at the base and top of the seismic model to prevent the outward propagating waves from reflecting back into the model at those boundaries, and free field conditions are set on two vertical boundaries. Seismic loads, which are in the form of sinusoidal velocity waves (P-wave and S-wave), are imposed on the model after the equilibrium has been reached under both in situ stress and thermal loads. Therefore, the initial velocity for each grid point prior to the application of seismic loads is zero. The sinusoidal velocity waves (P-wave and S-wave) are applied at the bottom of the model and propagate upwards. The S-wave, or shear wave, causes ground vibration (shaking) in the horizontal direction. The P-wave, on the other hand, causes ground oscillation in the vertical direction and results in variations of compression and tension. As was the case for the thermomechanical model, all other displacement and stress boundary conditions are still applied for the seismic model.

B.3.2.3 Sign Convention

In the FLAC program, the sign convention for stress and strain is "tension is positive and compression is negative" (as indicated in Figure B-4). For shear stress, also shown in Figure B-4, a positive shear stress points in the positive direction of the coordinate axis if the shear stress acts on a surface with the outward normal in the positive direction. Conversely, if the outward normal of the surface is in the negative direction, then the positive shear stress points in the negative direction of the coordinate axis. All stresses shown in Figure B-4 are positive. For displacement or seismic velocity, positive displacement or velocity is upward and to the right. Axial forces in ground support elements are negative in tension and positive in compression, as shown in the figures of Appendix B of the *Repository Ground Control Evaluation* report (CRWMS M&O 1995ad). For consistency, the sign of axial forces and stresses of structural members discussed in this section are reversed to positive for tension and negative for compression, unless otherwise specified.

B.4 OPENING AND GROUND SUPPORT BEHAVIOR

Numerical modeling for emplacement drifts has been carried out with Version 3.22 of FLAC. This computer program allows only two-dimensional thermomechanical analysis. Thermally-induced displacements and stresses in the rock mass and in ground support elements were calculated for up to 150 years after waste emplacement.

B.4.1 Pre-emplacement Behavior

Pre-emplacement behavior of openings discussed in this section is referred to as drift closure and rock mass yield during excavation before installation of ground support components. The pre-emplacement behavior of drifts was modeled by assuming that the rock stresses had fully relaxed prior to installation of ground supports. This is considered a conservative overestimation of the drift closures and rock mass yield for supported openings, but may result in an underestimation of the ground support load induced by in situ stress.

Drift Closure

Vertical closure, defined as the relative vertical displacement between the floor and crown, varies from less than 3 mm for RMQ=5 to about 10 mm for RMQ=1. Horizontal closure, defined as the relative horizontal displacement between the drift walls, ranges from less than 1 mm for RMQ=5 to about 2 mm for RMQ=1. Deformations for supported cases are similar due to the assumption of 100 percent stress relaxation in modeling. The values of closure shown by these results are relatively small elastic deformation resulting from the response of drift excavation to the in situ stress field.

Rock Mass Yield

As an indication of potential rock mass yield, contours of Mohr-Coulomb strength-to-stress ratios have been determined for cases of unsupported drifts (Figures B-5a, b, and c). These plots show that the factor of safety contour of 1.0, below which value yield occurs, is at a shallow depth, less than a meter, around the drift for all three RMQ categories, indicating that the drift is in stable elastic conditions following stress redistribution, and apparently self-supporting.

Ground Supports

Loads in ground support components, rock bolts, shotcrete, and steel sets, induced by the response of drift excavation to the in situ stress field, are extremely low due to the assumption of full rock stress relaxation before installation of ground support components in modeling. Higher loads may be anticipated in ground support components before waste emplacement, and to better understand the response of ground supports to the in situ stress field, a different magnitude of percentage of the rock stress relaxation, such as 50 percent, should be assumed in modeling. A previous study for the repository ground control evaluation (CRWMS M&O 1995d) indicated that with 50 percent of the rock stress relaxation before installation of ground support components, all three types of ground supports, rock bolts, shotcrete, and steel sets, appear to perform satisfactorily for the three RMQ categories, 1, 3 and 5, under excavation-induced loads.

B.4.2 Emplacement Behavior

Temperature histories of the drift wall and TSw2 boundary contacts due to a thermal load of 83 MTU/acre from waste emplacement, as shown in Figure B-6, were calculated with the ANSYS code. The heat transfer mechanism in modeling with ANSYS involves both radiation and conduction, and the thermal radiation process is simulated explicitly. Thermal analyses for FLAC models calculate time-dependent temperature distributions resulting from boundary temperature inputs, and the heat transfer mechanism involved is limited to conduction only. Coupled thermomechanical analyses with FLAC have been performed for a period of 150 years after waste emplacement. This period of time, called the overall thermal time, is divided into a number of thermal time steps. At each thermal time step, the temperature distributions are determined first, and stress and displacement fields around the supported drift opening, strength-to-stress ratios, and axial forces or moments if applicable in ground supports are then obtained by conducting a quasi-static mechanical analysis. Owing to temperature dependence of thermomechanical properties of rock, such as specific heat and thermal expansion coefficient, each thermal time step has been further divided into a number of sub-thermal time steps. At the beginning of each sub-thermal time step, the values of specific heat and thermal expansion coefficient are updated for every zone based on its corresponding temperature and the temperature dependence of the properties, as illustrated in Tables B-3 and B-4.

Depending upon mechanical properties and the magnitude of thermomechanical loads, the continuous rock model used in FLAC may behave elastically or elasto-plastically. The Mohr-Coulomb failure criterion is used in the analysis to judge whether or not the stress level reaches the yield limit, which varies with the rock mass quality (RMQ) categories.

Rock Temperature

Two-dimensional analysis with ANSYS shows that average peak temperature experienced on the drift wall for a thermal load of 83 MTU/acre, as shown in Figure B-6, is about 146°C, which occurs at about 64 years after waste emplacement. Due to decay of the heat output from waste packages and thermal conduction within the rock mass, temperatures of the drift wall undergo a slight decrease, even though drift heating by the waste packages lasts for the entire 150-year modeling time. The average wall temperature drops only 2°C to about 144°C at 150 years after waste emplacement.

Three-dimensional analysis, presented in Section 8.2.4, gives somewhat higher temperatures for both in-center and off-center emplacement modes. Maximum sidewall temperatures for in-center emplacement, for example, are about 155°C. Note that temperatures used for FLAC models are from two-dimensional analysis, rather than from three-dimensional ANSYS analysis.

Drift Closure

Thermally-induced vertical closures, as illustrated in Figure B-7a and on Table B-9 for 83 MTU/acre and ground support Type I, are in the opposite direction to closures induced by in situ loads at excavation. Maximum vertical closures induced by thermal load are about 8 mm outward for all rock mass quality (RMQ) categories. Combined in situ and thermal loads result in net vertical closures of about 1 mm inward for RMQ category 1, and about 4 and 6 mm outward for RMQ categories of 3 and 5, respectively. Maximum thermally-induced horizontal closures, as shown in Figure B-7b, are inward and are about 10 mm for RMQ category 1, 9 mm for RMQ categories 3 and 5. Combined in situ and thermal loads result in net horizontal closures of about 12 mm for the RMQ category of 1, and 10 mm for RMQ categories of 3 and 5.

As can be seen from these results, horizontal closures for the 83 MTU/acre case are about 5 to 24 times those for the in situ case. Vertical closures, on the other hand, are relatively small and are about 0.9, 1.8 to 3.4 times the in situ values for three RMQ categories of 1, 3 and 5, respectively.

It is also indicated that thermally-induced vertical and horizontal closures, as shown on Tables B-10 and B-11, for 83 MTU/acre and ground support Types II and III for three RMQ categories of 1, 3 and 5 are about the same magnitude as those for ground support Type I.

Rock Mass Yield

Time histories of major and minor principal stresses at the drift crown are shown in Figure B-8a and b for the thermal loading of 83 MTU/acre, ground support Type I, and RMQ categories of 1, 3 and 5. At 50 years following waste emplacement, the major principal compressive stress (tangential to the crown) is close to its maximum value of -30 MPa (RMQ=3) and the minor principal stress is close to its maximum value of -3 MPa. These values are about 9 and 6 times the in situ case values, respectively.

Rock mass yield is indicated by Figures B-9a, b, and c, which give strength-to-stress-ratio contour plots and failure surface envelopes at 10, 50 and 150 years after emplacement (ground support Type I and RMQ= 3). The plots of strength-to-stress ratios indicate potential rock yield to a depth of about one meter from the periphery of the drift (Figures B-9a through c). In addition, Figures B-9b and c show an increasing strength-to-stress ratio into the rock away from the drift wall, then a decrease, then a constant value as the line of symmetry (i.e., the center of the pillar) between the drifts is approached. Strength also decreases as the confining stress in the pillar decreases. Beyond 50 years, the strength-to-stress ratio in the majority of the pillar is at or above a value of 4.0 for all cases. The decrease in strength-to-stress ratio within the pillar apparently results from a stress decrease or "stress shadow" effect that occurs between multiple parallel drifts that are subjected to a high horizontal stress field perpendicular to the drifts (see for example Hoek and Brown 1980, p. 124). It is also indicated according to the analyses that the strength-to-stress ratios in the pillar are dependent on the variation of RMQ categories, decreasing with the increase of the RMQ categories under the thermal load of 83 MTU/acre.

Maximum major and minor principal stresses at the drift crown for 83 MTU/acre and ground support Types II and III, as shown on Tables B-10 and B-11, are about the same magnitude as those for the ground support Type I for three RMQ categories, 1, 3 and 5, which means that the strength-to-stress ratios of rock mass with the ground support Types II and III are similar to those with the Type I, as illustrated in Figures B-9a through c.

The analysis also shows that the vertical and horizontal closures, major and minor principal stresses, and strength-to-stress ratios of the drift opening without ground supports at 83 MTU/acre are about the same magnitude as those for the supported opening due to the flexibility of ground supports used in modeling.

Results of the analysis of loads induced in ground support components by thermal stress are given in the following:

Rock Bolts

Axial forces in rock bolts at 83 MTU/acre vary with RMQ categories, as shown in Figure B-10a and on Table B-9. Rock bolt loads reach about 267 kN, 196 kN, and 185 kN, which is approximately 100 percent, 73 percent, and 69 percent of the bolt tensile strength of 267 kN, at about 150 years after waste emplacement for the RMQ categories of 1, 3 and 5, respectively. It is indicated that at 83 MTU/acre, maximum axial forces in rock bolts are dependent of the variation of RMQ categories, decreasing with the RMQ categories. Plots of factors of safety for rock bolts at 83 MTU/acre, as shown in Figure B-10b, indicate that the factors of safety drop to or below 1.5 at about 50 years following waste emplacement for three RMQ categories, and a potential rock bolt yield may occur for the RMQ category of 1. The distribution of bolt axial force, for bolts at the crown, can be observed in Figures B-11a through c, for ground support Type I for RMQ=3 at 10, 50 and 150 years after waste emplacement. Note that not all bolts have such high axial loads; only bolts near springline have high loads, about 30 percent, 22 percent and 26 percent higher than those at crown at about 10, 50, and 150 years, respectively, after emplacement for the RMQ category of 3.

Shotcrete

Axial forces in shotcrete, for 83 MTU/acre, at 10, 50 and 100 years after waste emplacement, are presented in Figures B-11a through c for ground support Type I with RMQ=3. Axial forces increase with time; depending on location shotcrete may be in tension or compression. All shotcrete begins in compression, but the portion along the sidewalls quickly changes to tension and remains in tension. Figures B-12a and b show time histories of maximum shotcrete compressive axial stresses and its factors of safety for three RMQ categories. It is indicated that at 83 MTU/acre, the stresses in shotcrete are dependent of the variation of RMQ categories, increasing with the RMQ categories. Maximum compressive axial stresses in 100-mm thick shotcrete, as shown in Table B-9, occur at about 150 years after emplacement and are about 29 MPa for RMQ=1, 36 MPa for RMQ=3, and 40 MPa for RMQ=5. Axial stresses in the shotcrete for both rock categories of 3 and 5 exceed the compressive strength of 34.5 MPa at about 70 years after waste emplacement. Maximum compressive axial stresses in 150-mm thick shotcrete, as shown in Figure B-13a and Table B-10, are about 73 percent, 92 percent and 106 percent of the compressive strength of 34.5 MPa for the RMQ categories of 1, 3 and 5, respectively. Only axial stresses in the shotcrete for the RMQ category of 5 exceed the compressive strength at about 50 years following waste emplacement.

Both tensile and compressive stresses are developed in shotcrete at thermal loads of 83 MTU/acre. Though compressive stresses are below the strength of 34.5 MPa for the RMQ category of 1, tensile stresses for all RMQ categories are of a similar magnitude and may result in tensile failures.

Steel Sets

Time histories of axial stresses in steel sets (W5×19) are illustrated in Figure B-14a for three RMQ categories, 1, 3 and 5. Maximum compressive axial stresses at 83 MTU/acre, as shown in Table B-11, are 309 MPa, 340 MPa and 368 MPa for the RMQ categories of 1, 3 and 5, respectively, exceeding the yield limit of 248 MPa. Factors of safety for steel sets, as shown in Figure B-14b, drop to or below 1.0 at about 20 years after emplacement for three RMQ categories.

Table B-9. Results from FLAC Analysis for Thermal Load for Ground Support Type I

Ground Support Type I: 1.0 m Spacing Pattern Steel Bolt Plus 100 mm Thick Shotcrete			
Items	Thermal Load: 83 MTU/acre		
	RMQ=1	RMQ=3	RMQ=5
Horizontal Closure (mm)	12.3 (150)[1]	10.0 (150)[1]	9.5 (150)[1]
Vertical Closure (mm)	1.3 (150)[1]	-3.7 (150)[1]	-6.0 (150)[1]
Max. Major Principal Stress at Crown (MPa)	-16.8 (150)[1]	-31.1 (150)[1]	-55.8 (150)[1]
Max. Minor Principal Stress at Crown (MPa)	-2.1 (150)[1]	-3.2 (150)[1]	-5.0 (150)[1]
Max. Bolt Axial Force (kN)	267 (150)[1]	196 (150)[1]	185 (150)[1]
Bolt Strength to Axial Force Ratio	1.0 (150)[1]	1.4 (150)[1]	1.4 (70)[1]
Max. Tensile Axial Stress in Shotcrete (MPa)	20.8 (150)[1]	32.8 (150)[1]	36.2 (150)[1]
Ratio of Shotcrete Tensile Strength to Tensile Axial Stress	0.2 (150)[1]	0.1 (150)[1]	0.1 (150)[1]
Max. Compressive Axial Stress in Shotcrete (MPa)	-29.4 (150)[1]	-35.5 (150)[1]	-40.4 (150)[1]
Ratio of Shotcrete Compressive Strength to Compressive Axial Stress	1.2 (150)[1]	1.0 (150)[1]	0.9 (150)[1]

[1] Time in years after emplacement to reach a maximum value during preclosure.

Table B-10. Results from FLAC Analysis for Thermal Load for Ground Support Type II

Ground Support Type II: 150 mm Thick Shotcrete or Concrete Liner			
Items	Thermal Load: 83 MTU/acre		
	RMQ=1	RMQ=3	RMQ=5
Horizontal Closure (mm)	12.9 (150)[1]	10.5 (150)[1]	9.7 (150)[1]
Vertical Closure (mm)	1.5 (150)[1]	-3.6 (150)[1]	-6.1 (150)[1]
Max. Major Principal Stress at Crown (MPa)	-16.1 (150)[1]	-30.1 (150)[1]	-55.6 (150)[1]
Max. Minor Principal Stress at Crown (MPa)	-2.2 (150)[1]	-3.3 (150)[1]	-5.0 (150)[1]
Max. Tensile Axial Stress in Shotcrete (MPa)	12.9 (150)[1]	24.8 (100)[1]	31.6 (150)[1]
Ratio of Shotcrete Tensile Strength to Tensile Axial Stress	0.3 (150)[1]	0.1 (150)[1]	0.1 (150)[1]
Max. Compressive Axial Stress in Shotcrete (MPa)	-25.1 (150)[1]	-31.7 (150)[1]	-36.7 (150)[1]
Ratio of Shotcrete Compressive Strength to Compressive Axial Stress	1.4 (150)[1]	1.1 (150)[1]	0.9 (150)[1]

[1] Time in years after emplacement to reach a maximum value during preclosure.

Table B-11. Results from FLAC Analysis for Thermal Load for Ground Support Type III

Ground Support Type III: 1.2 m Spacing W5x19 Steel Sets			
Items	Thermal Load: 83 MTU/acre		
	RMQ=1	RMQ=3	RMQ=5
Horizontal Closure (mm)	11.8 (150)[1]	9.8 (150)[1]	9.4 (150)[1]
Vertical Closure (mm)	1.3 (150)[1]	-3.4 (150)[1]	-5.5 (150)[1]
Max. Major Principal Stress at Crown (MPa)	-17.7 (150)[1]	-31.1 (150)[1]	-52.6 (150)[1]
Max. Minor Principal Stress at Crown (MPa)	-1.6 (150)[1]	-2.7 (150)[1]	-4.5 (150)[1]
Max. Steel Set Axial Stress (MPa)	-308.8 (150)[1]	-339.5 (150)[1]	-368.4 (150)[1]
Steel Set Strength to Axial Stress Ratio	0.8 (150)[1]	0.7 (150)[1]	0.7 (150)[1]

[1] Time in years after emplacement to reach a maximum value during preclosure.

B.4.3 Seismically-induced Behavior

Numerical results for seismic load cases are given according to the type of ground support systems. Primary focus is on stability response of the drift and load response of ground supports to the seismic loads. The maximum change in ground stress, support load and displacement due to seismic loads is expressed in terms of the percentage increase or decrease in the parameter following application of seismic load.

B.4.3.1 Drift Reinforced with Rock Bolts and Shotcrete

Figure B-15 illustrates 2.5 m long, fully-grouted rock bolts and a 100 mm thick shotcrete layer in the drift. Seismic loads are applied to the model after the completion of computer simulation of thermal loads for 10, 30 and 50 years after waste package emplacement. The rock temperature nearly reaches its peak at the drift wall after 50 years. As was the approach for static and thermal loading, three different rock mass quality categories (RMQ=1, 3 and 5) were used to represent the rock mass, with case RMQ=1 being the poorest rock and RMQ=5 being the most competent.

Figure B-16 shows input velocity profiles for P- and S-waves at the base of model and the output velocity profiles at the top of model as the wave propagates through the 189-meter-thick TSw2 rock unit. Figure B-17 shows additional drift closures produced by seismic loads. Both ground vibration and drift closure diminish rapidly after the specified duration time for seismic waves, indicating that the ground remains primarily within the elastic range of deformation. The maximum dynamic drift closure caused by seismic loads is 1.6 mm between crown and invert and 0.8 mm along the springline. Figure B-18 illustrates contours of Mohr-Coulomb strength to stress ratios near the center drift under three different rock mass categories and shows no development of yielding near the drift.

As tabulated in Table B-12, fully-grouted rock bolts experience a maximum increase in axial load of 10 percent, and the shotcrete liner shows a load increase of up to 8.4 percent. The increase is not considered significant. These results are realistic because underground drifts are confined and are therefore less sensitive to earthquake-induced ground shaking than surface structures. In addition, the seismic wave is characterized by a long wave length and low frequency. The dimension of the drift is a fraction of the typical seismic wave length, consequently the rock mass and the drift tend to move together rather than undergo differential movements. Seismic-induced load maximums can occur at any point within a ground support system.

To further examine the dynamic response of the drift to seismic loadings, two more computer runs were made: one increased the input frequency for P- and S-waves from 5 to 10 Hz, and the other doubled the peak ground velocity (PGV) value to 46 cm/second as an upper bound loading case. Both runs were for RMQ=3 rock conditions. In comparison with the numerical results obtained using the PGV value of 23 cm/second, frequency of 5 Hz and duration of 0.5 seconds, doubling the frequency only slightly changed loads on bolts and shotcrete. The maximum increase in bolt loads is less than 2 percent while the maximum increase in shotcrete load is 3 percent. The strength-to-stress ratio near the drift changed noticeably during the seismic loading, however, no failure zone developed. On the other hand, doubling the PGV value caused greater change in ground support load, but did not significantly change the strength-to-stress ratio near the drift. The maximum increase detected is nearly 10 percent in bolt force and 12 percent for the compressive load in shotcrete. Figures B-19 and B-20 further illustrate these comparisons.

Table B-12. Summary of Numerical Results for Seismic Load and/or Ground Support Type I (Rock bolts plus 100 mm of shotcrete)

	Rock Mass Quality (RMQ) Category		
Item	RMQ = 1	RMQ = 3	RMQ = 5
Change in Horizontal Closure (mm)	+0.3 or -0.4	+0.4 or -0.2	+0.8 or -0.6
Change in Vertical Closure (mm)	+1.6 or -1.4	+1.2 or -1.0	+1.0 or -1.2
Change in Major Princ Stress at Crown (%)	1.5	2.5	4.5
Change in Minor Princ Stress at Crown (%)	5.0	5.2	7.0
Change in Max. Axial Bolt (%)	10.0	5.6	8.3
Change in Max. Tensile Shotcrete stress (%)	2.0	5.0	8.4
Change in Max. Compressive Shotcrete stress (%)	-18.5	-10.8	-19.2

B.4.3.2 Drift Supported by Shotcrete Liner

A shotcrete liner, as in the case for Ground Support Type II, was numerically represented by elastic beam elements bonded onto the drift wall. The liner has a thickness of 150 mm and is uniformly continuous along the drift wall. Figures B-21 and B-23 and Table B-13 summarize some of numerical results due to the seismic loads.

Table B-13. Summary of Numerical Results for Seismic Load and/or Ground Support Type II

	Rock Mass Quality (RMQ) Category		
Item	RMQ = 1	RMQ = 3	RMQ = 5
Change in Horizontal Closure (mm)	+0.3 or -0.5	+0.4 or -0.3	+0.8 or -0.6
Change in Vertical Closure (mm)	+1.8 or -1.5	+1.3 or -1.1	+1.1 or -1.2
Change in Major Princ Stress at Crown (%)	1.1	2.6	3.8
Change in Minor Princ Stress at Crown (%)	6.7	7.4	7.5
Change in Max. Tensile Load in Shotcrete (%)	2.1	6.3	7.3
Change in Max. Compre Load in Shotcrete (%)	-27.8	-10.0	-21.8

These results are similar to the results shown in Table B-9. In general, the additional effect of seismic loads on drift stability and ground support systems is insignificant.

B.4.3.3 Drift Supported with Steel Sets

Dynamic results obtained for a drift supported with full-circle steel sets are shown in Figures B-24 and B-26 and in Table B-14. Changes due to the addition of seismic load are small. An exception is the relatively high 16.5 percent change in axial load due to the high rock stiffness for category RMQ=5. Steel sets, which are not specified for use in such good ground, show initial overstress by thermally-induced mechanical loads and would experience some additional stress, although not significant, due to seismic loads.

Table B-14. Summary of Numerical Results for Seismic Loads for Ground Support Type III (Steel Sets)

	Rock Mass Quality (RMQ) Category		
Item	RMQ = 1	RMQ = 3	RMQ = 5
Change in Horizontal Closure (mm)	+0.3 or -0.5	+0.4 or -0.3	+0.8 or -0.6
Change in Vertical Closure (mm)	+1.8 or -1.5	+1.4 or -1.1	+1.1 or -1.2
Change in Major Princ Stress at Crown (%)	0.5	3.0	4.1
Change in Minor Princ Stress at Crown (%)	4.0	4.1	5.1
Change in Max. Axial Load in Steel Set (%)	2.2	6.1	16.5

B.5 SUMMARY

Uniformly-spaced emplacement 5-meter-diameter drifts have been analyzed using both ANSYS and FLAC codes under combinations of static, thermal and seismic loading conditions. Three sets of material properties, simulating poor to good rock mass states, were considered. Fully-grouted rock bolts, shotcrete and steel sets were incorporated in numerical models as candidate ground support for the drift. The main objective of the analysis is to examine the response of emplacement drifts to the addition of long-term thermal loading and potential earthquake events, so that the drift stability can be assessed.

Input data to numerical analyses reflect the best documented information currently available on elastic properties, strength parameters, thermal properties, in situ stresses, thermal loads, and seismic loading. These properties and their time dependent behavior, if any, have been considered in modeling as realistically as possible. Careful attention was also given to mesh refinement and boundary conditions in order to minimize the effect of mesh dimensions on numerical output.

Numerical results indicate that upon excavation, prior to waste emplacement, the unsupported drift will experience no failure of rock mass surrounding the drift. The maximum closure between crown and invert is about 10 mm. However, numerical results does indicate a potential overstressed zone which extends about 1 m into the rock where block loosening along discontinuities could occur. No discontinuities were explicitly considered in numerical models at present.

Under the thermal load of 83 MTU/acre, the drift experiences higher horizontal closure than vertical closure. In fact, the drift will elongate vertically for RMQ = 3 and RMQ = 5. The maximum horizontal closure detected is 12.8 mm while the maximum vertical elongation is 5.9 mm. These values for closure indicate that rock mass behaves essentially elastically, though the normal components of the stress state have increased significantly. Load development in fully-grouted rock bolts is below the yield capacity of the bolt, except for the bolt closest to the springline for RMQ=1 where the bolt has reached its yield strength. For fully-grouted steel bolts, yielding in steel will not substantially reduce their effectiveness. For the shotcrete lining, tension occurs in the side walls while compression occurs at the crown and invert. Regardless of the rock mass category, tensile load in shotcrete liner is high enough for tensile cracks to develop, eventually reducing the effectiveness of the shotcrete. Light steel sets are also shown to exceed their yield strength in tension and in compression. In this respect, high thermal loads indicate the need for structurally flexible support systems.

In general, underground drifts are confined and are therefore less sensitive to earthquake-induced ground shaking than surface structures. In addition, the typical seismic wave is characterized by a long wave length and low frequency. The dimension of the drift is a fraction of the typical seismic wave length, consequently the rock mass and the drift tend to move together rather than undergo any significantly differential movements. However, seismic-induced load maximums can occur at any location within the ground support system as compressional and shear waves propagate through the drift. Such a dynamic feature is important to the design of ground support connections such as shotcrete to invert and steel set to invert connection.

The seismic loading, characterized by a combination of sinusoidal P- and S-wave of velocities, was superimposed onto FLAC models after 50 years of thermal loading generated from waste packages in the emplacement drift. These seismic waves of long wave length and low frequency propagate upwards. The dynamic response of the drift and associated ground support systems to seismic loading is best described in terms of the change by percentage in stress, displacement and loads in ground support systems. Drift closure and elongation caused by seismic loading is less than 2 mm regardless of ground support types and RMQ categories. Fully-grouted rock bolts experience a maximum increase of 10 percent in axial load. Shotcrete shows a maximum tensile load increase of 8.4 percent and a compressive load decrease of 27.8 percent at different locations along the lining. Steel sets show a 16.4 percent increase in axial load in one case. These changes are noticeable but are not considered significant from the standpoint of ground control aspects.

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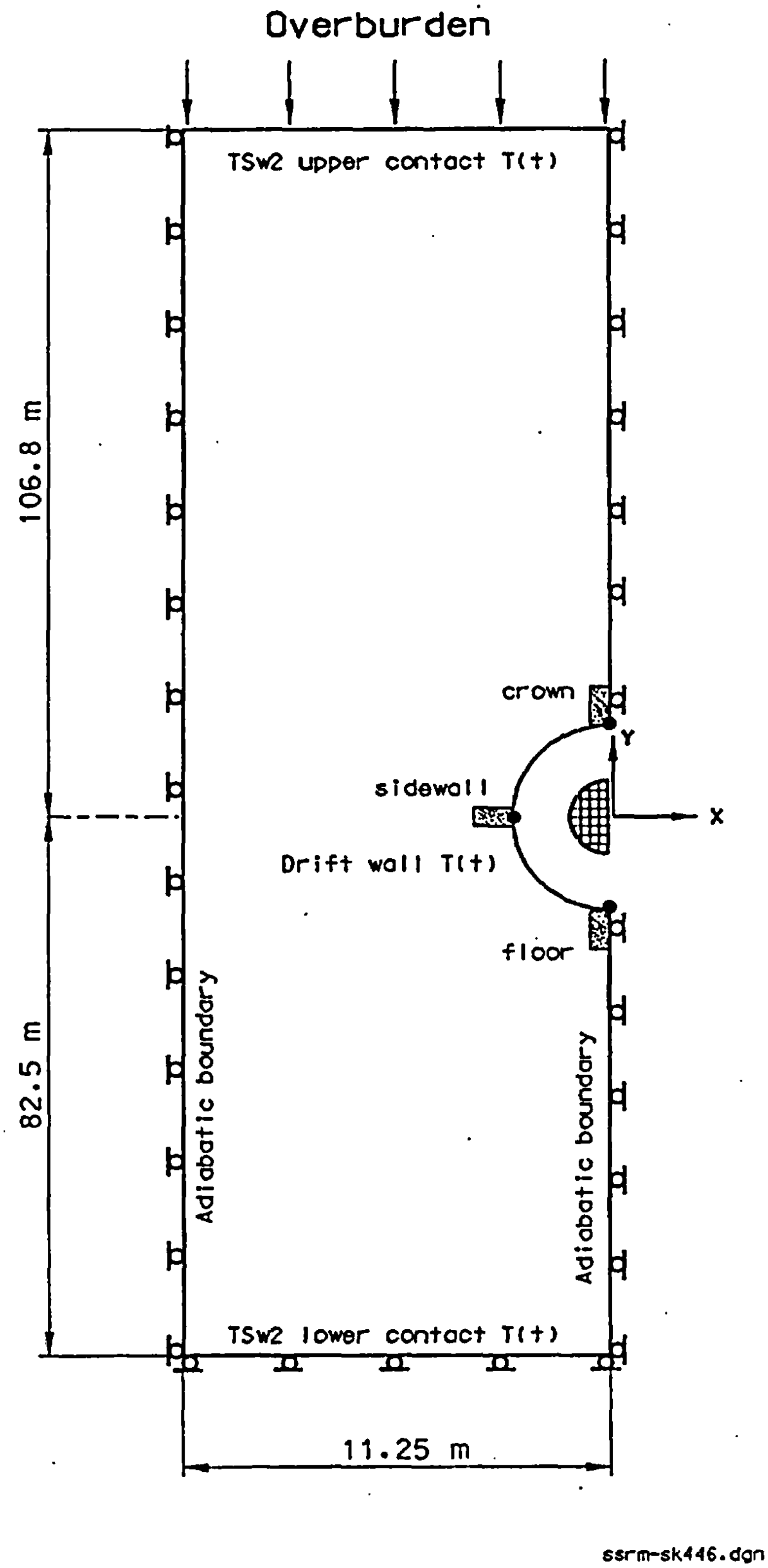


Figure B-1. Geometry and Boundary Conditions for Thermomechanical Modeling Using FLAC

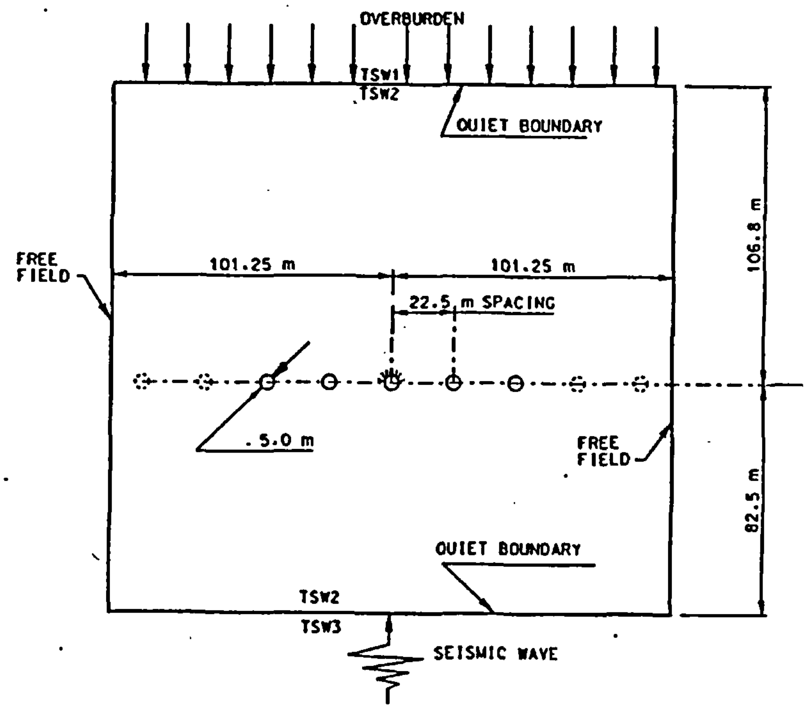


Figure B-2. Mesh Dimensions and Boundary Conditions of The FLAC Model for Seismic Analysis

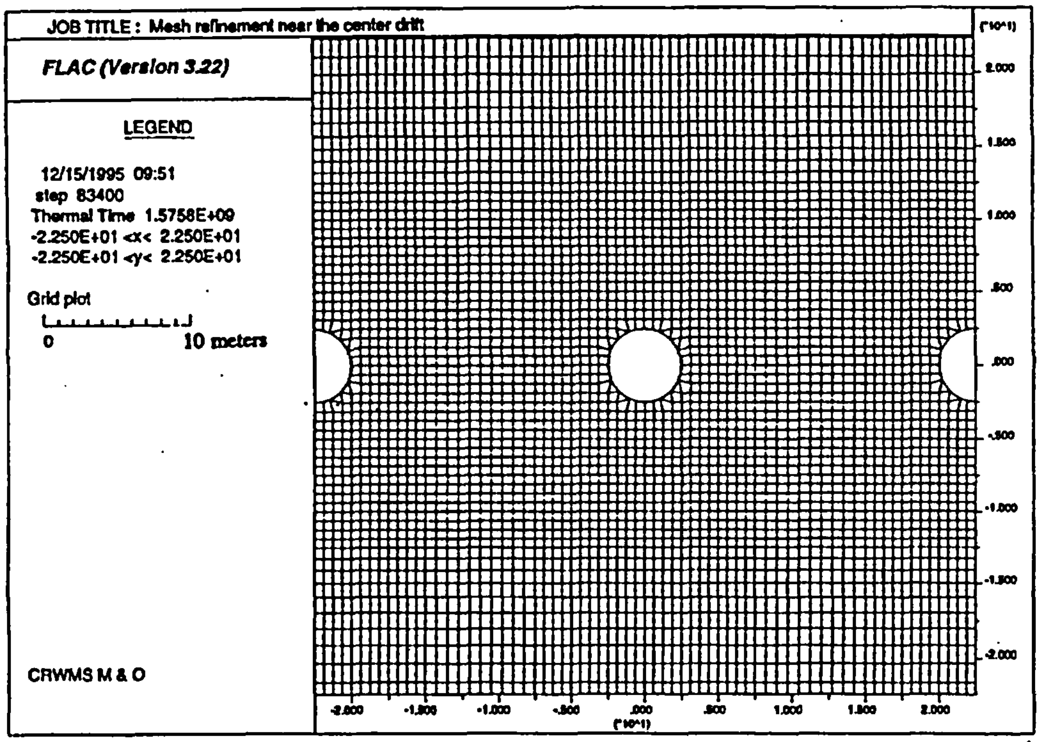


Figure B-3. Mesh Refinement Near the Center Drift

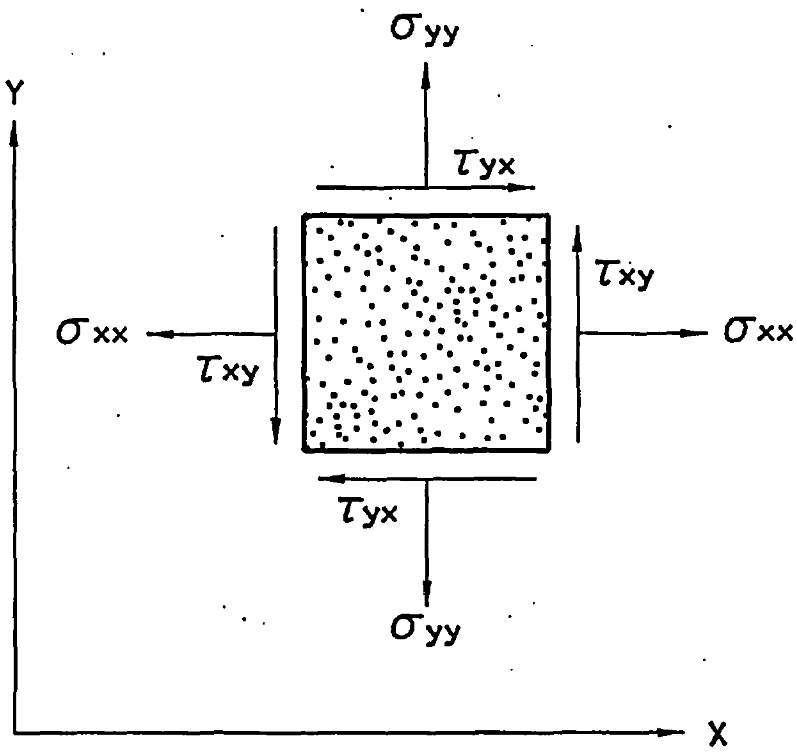


Figure B- 4. Sign Convention for Positive Stresses

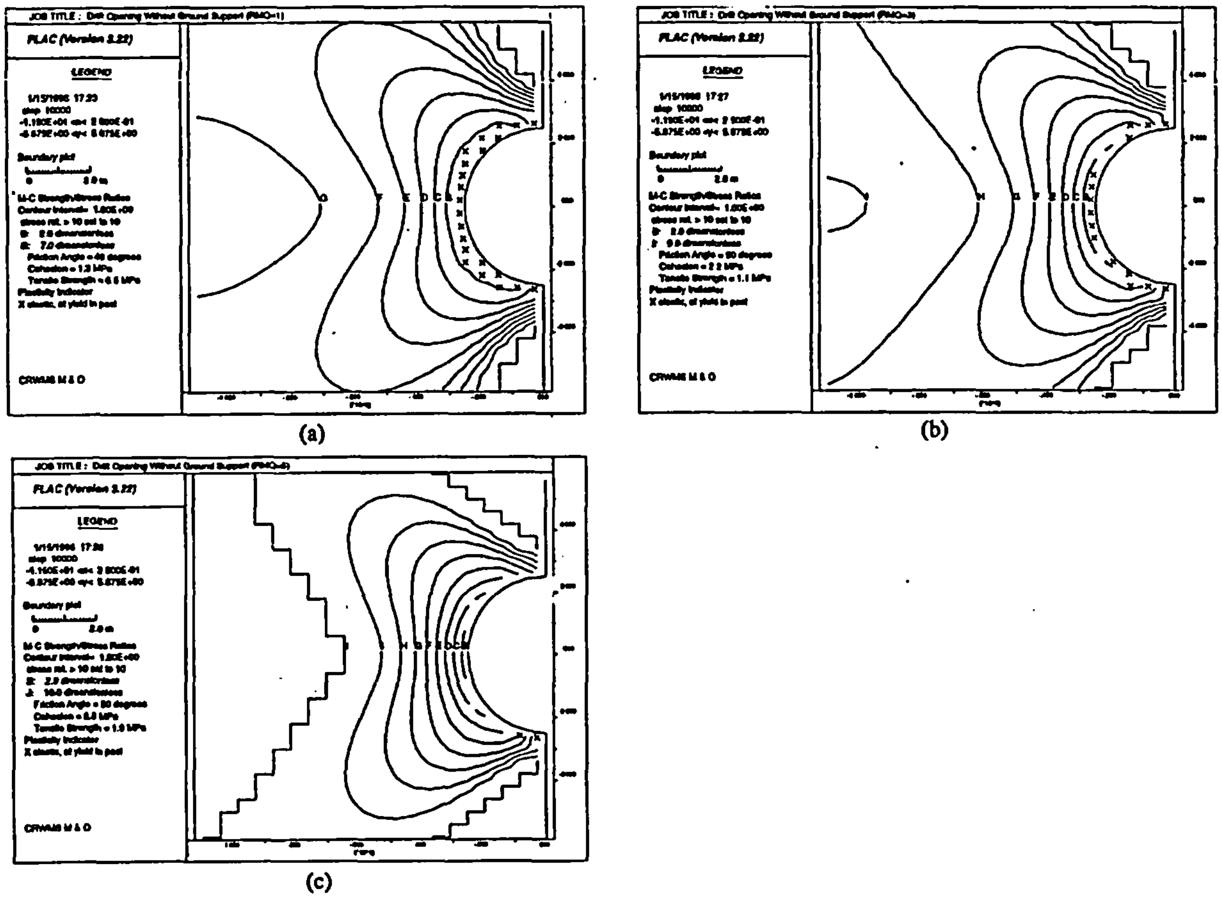


Figure B-5. Strength/Stress Ratio Contours and Plasticity Indicators around Opening without Ground Support: (a) RMQ=1; (b) RMQ=3; (c) RMQ=5

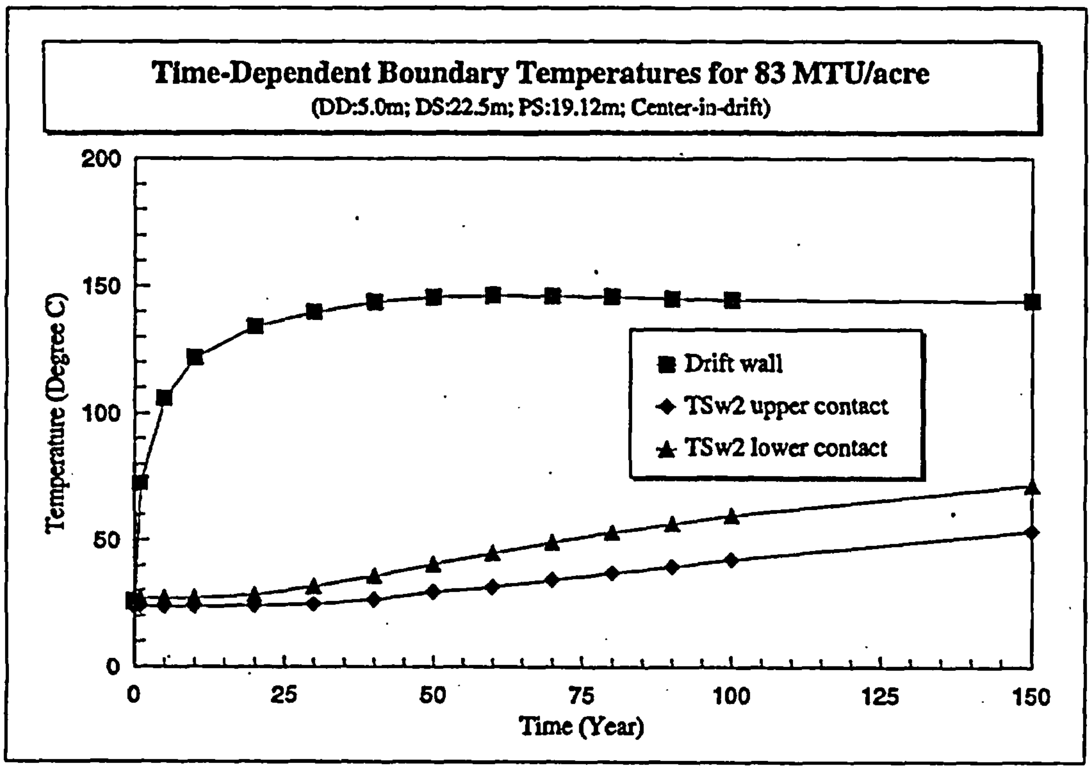
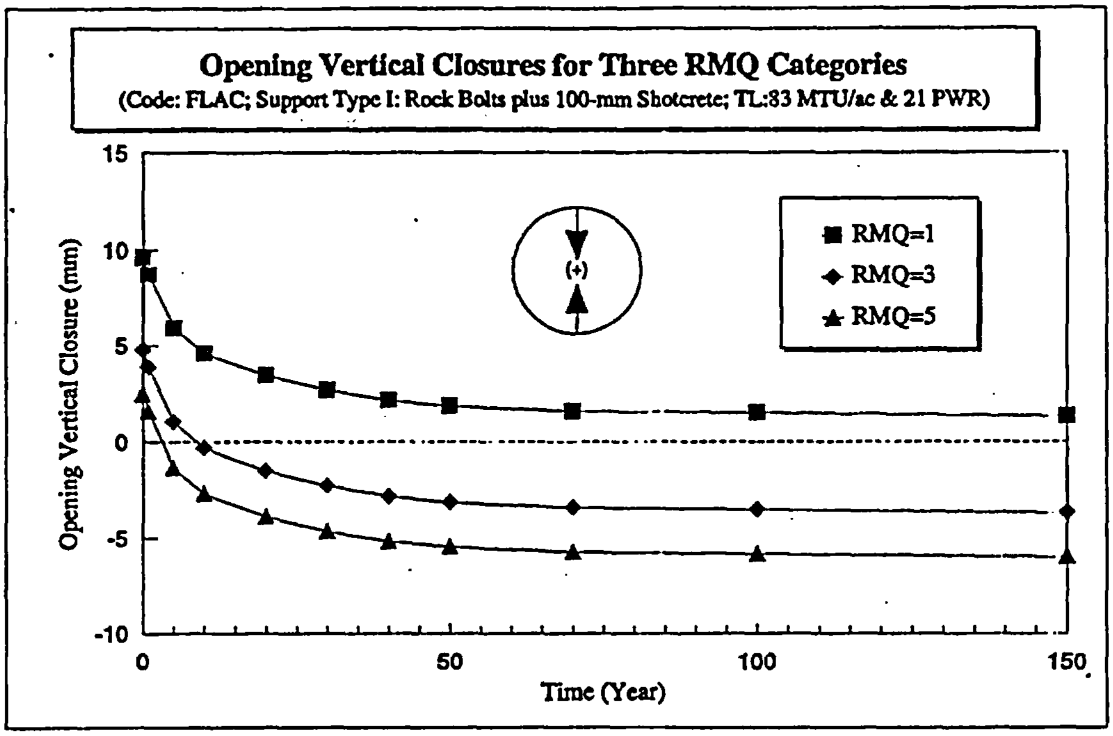
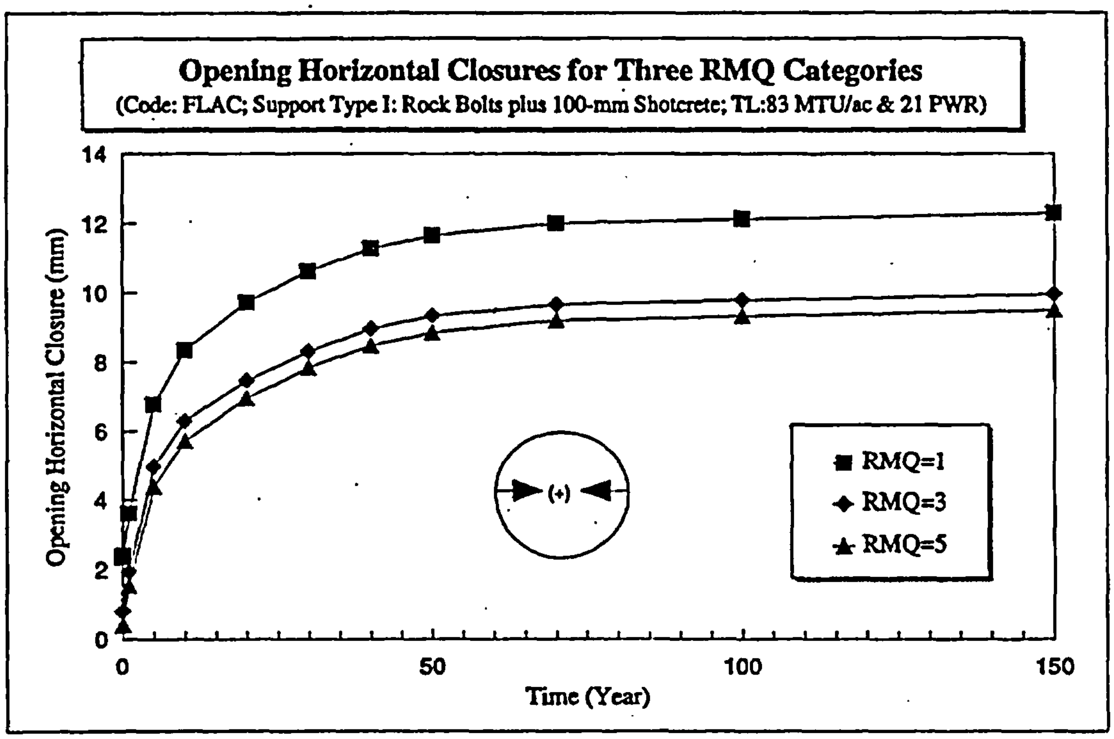


Figure B-6. Temperature Histories of TSw2 Upper and Lower Contacts and Drift Wall for 83 MTU/acre

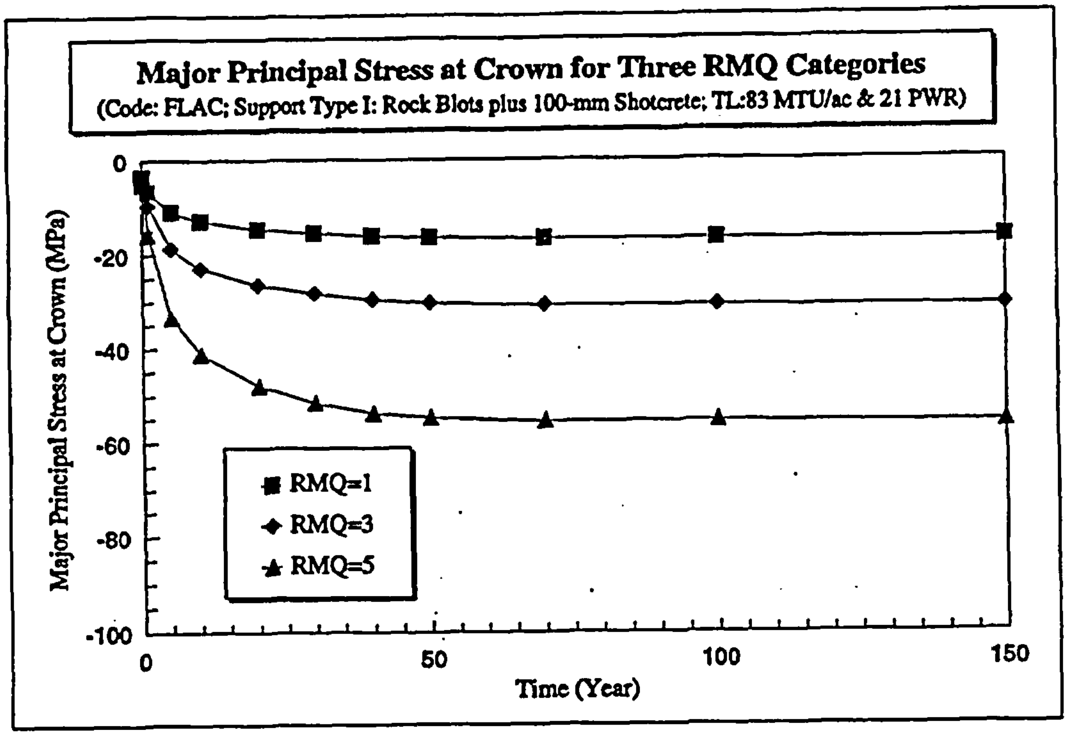


(a)

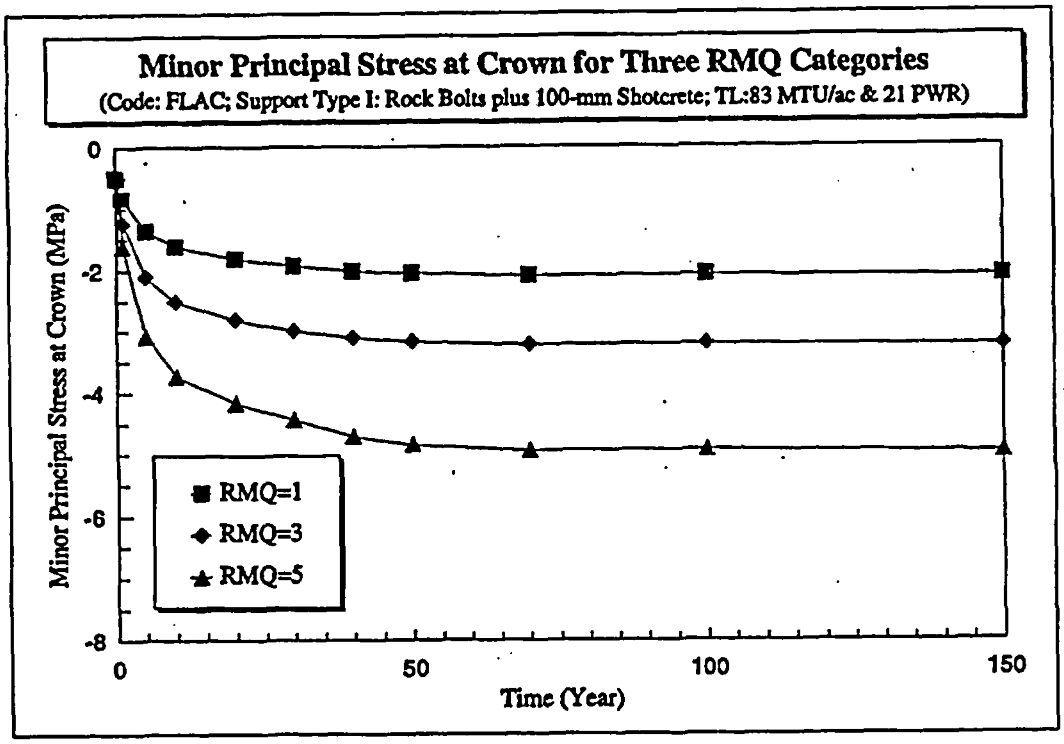


(b)

Figure B-7. Time Histories of Opening Closures for Different RMQ Categories for 83 MTU/acre: (a) Vertical Closures; (b) Horizontal Closures



(a)



(b)

Figure B-8. Time Histories of Principal Stresses at Crown for Different RMQ Categories for 83 MTU/acre: (a) Major Principal Stress; (b) Minor Principal Stress

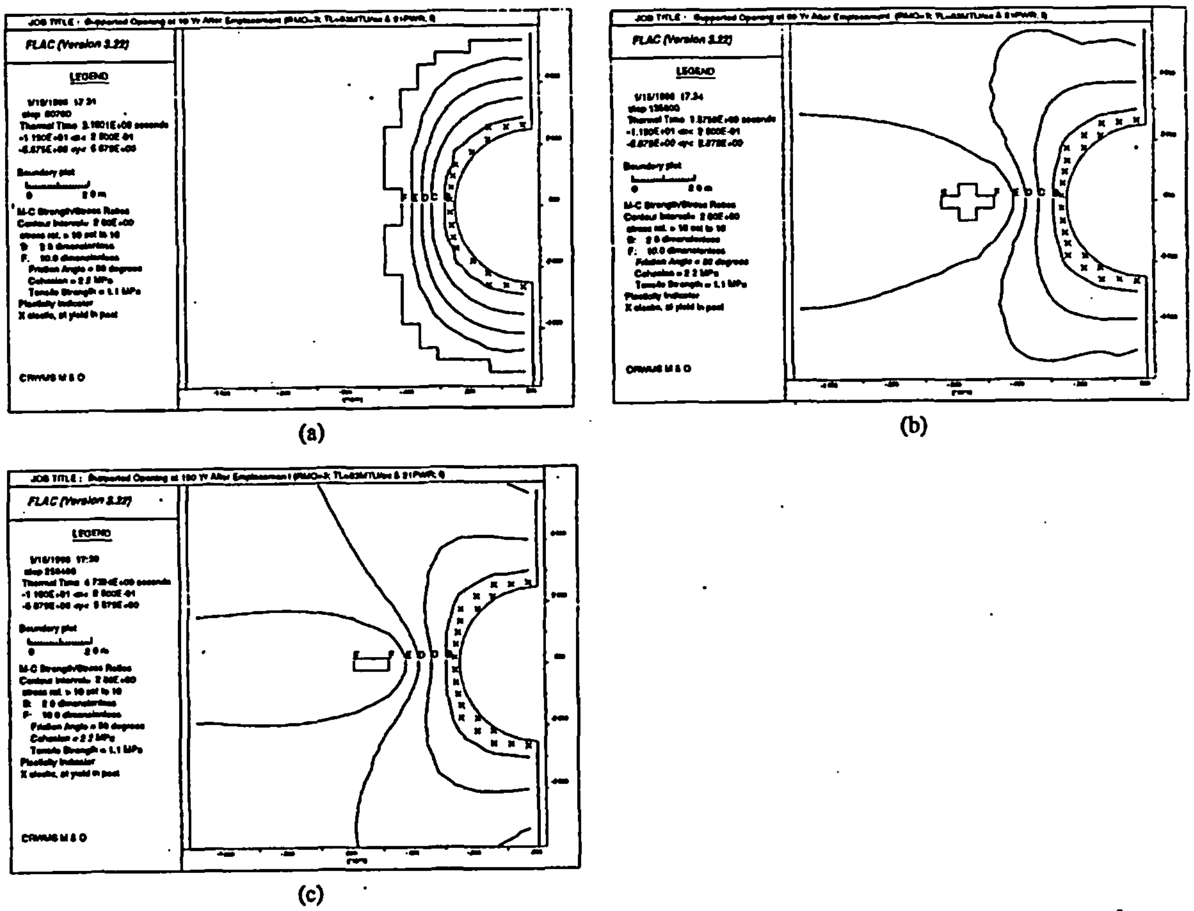
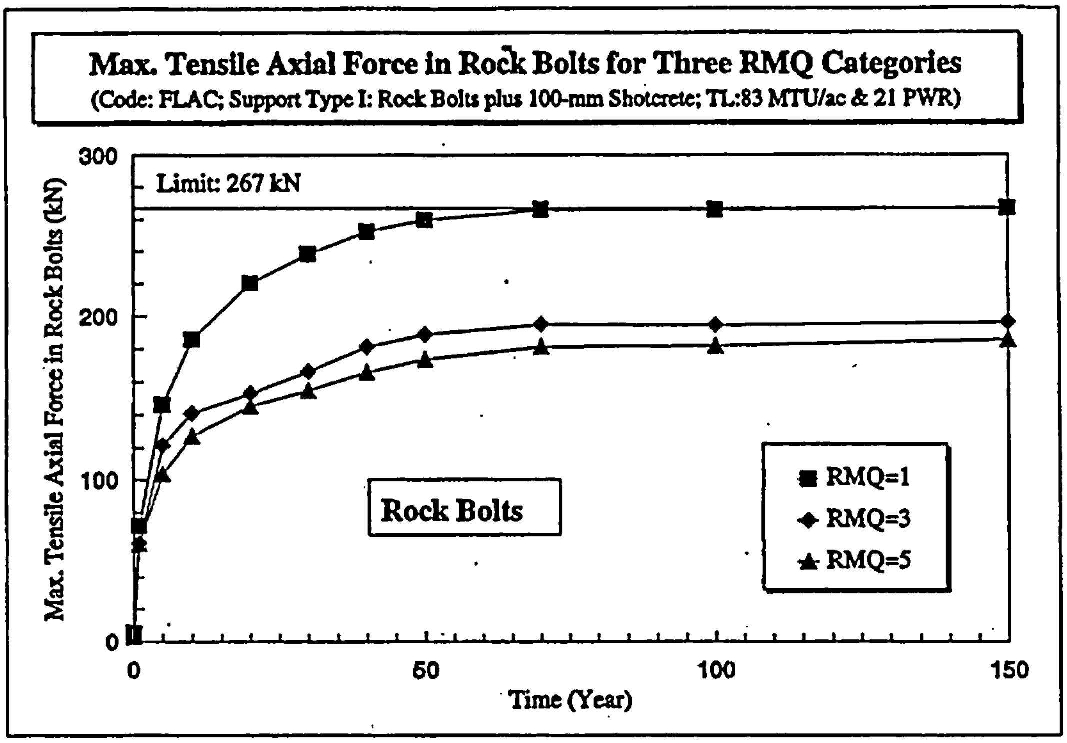
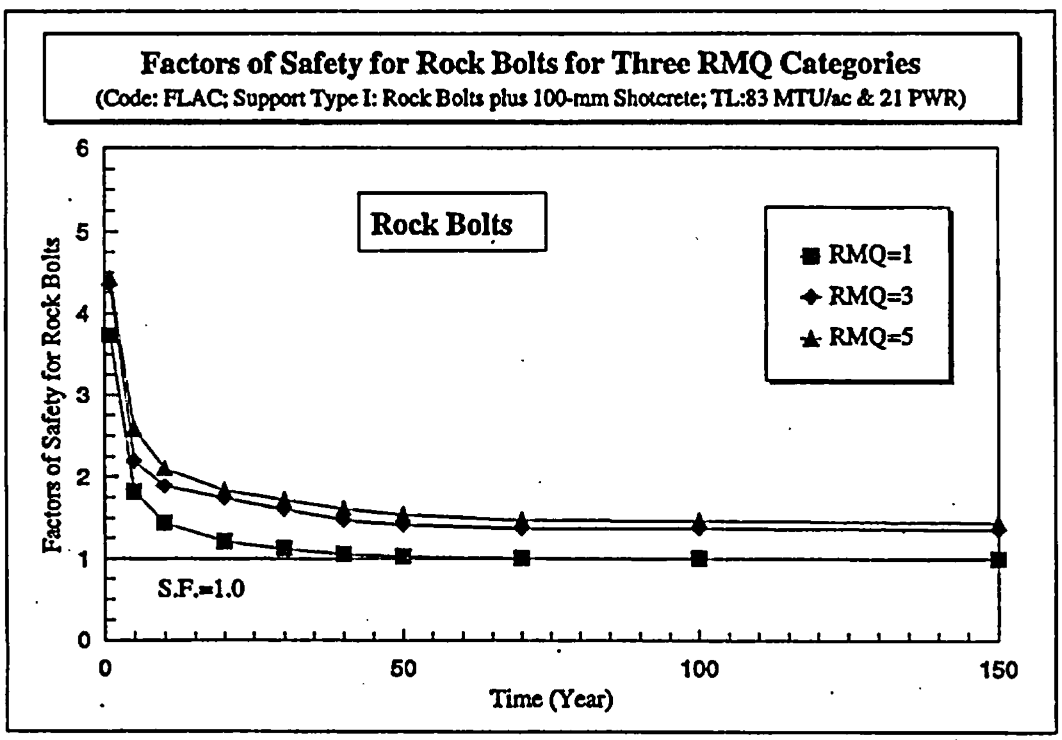


Figure B-9. Factors of Safety Contours and Plasticity Indicators around Opening with Ground Support Type I for RMQ=3 and 83 MTU/acre: (a)10 Years after Emplacement; (b) 50 Years after Emplacement; (c)150 Years after Emplacement



(a)



(b)

Figure B-10. Time Histories of Max. Axial Forces in Rock Bolts and Their Factors of Safety for Different RMQ Categories for 83 MTU/acre: (a) Max. Axial Forces; (b) Factors of Safety

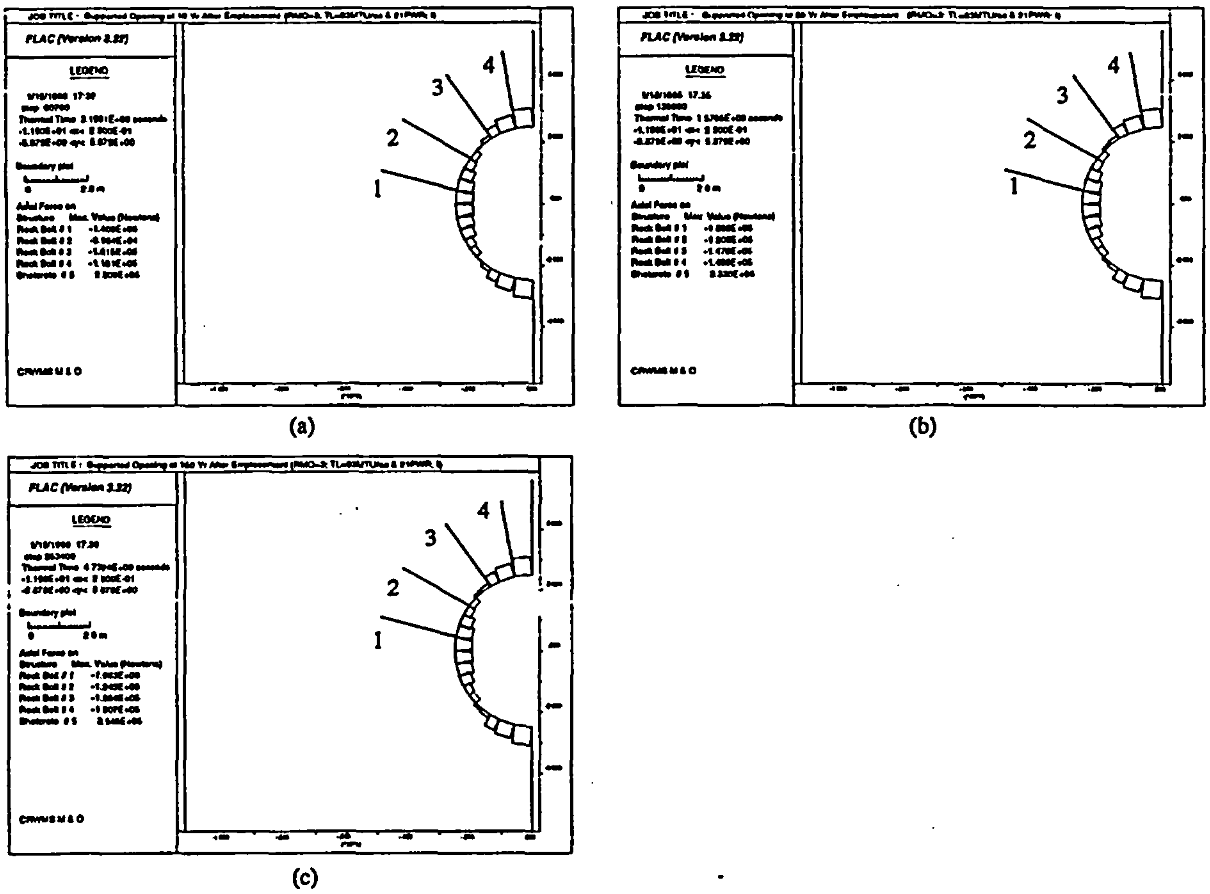
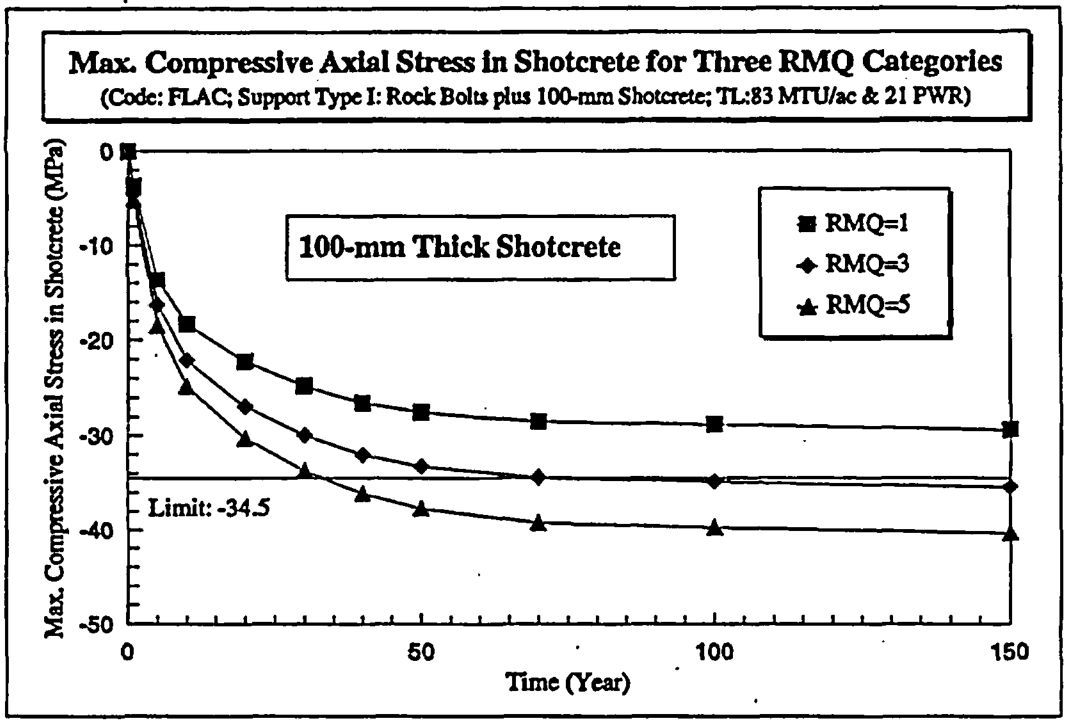
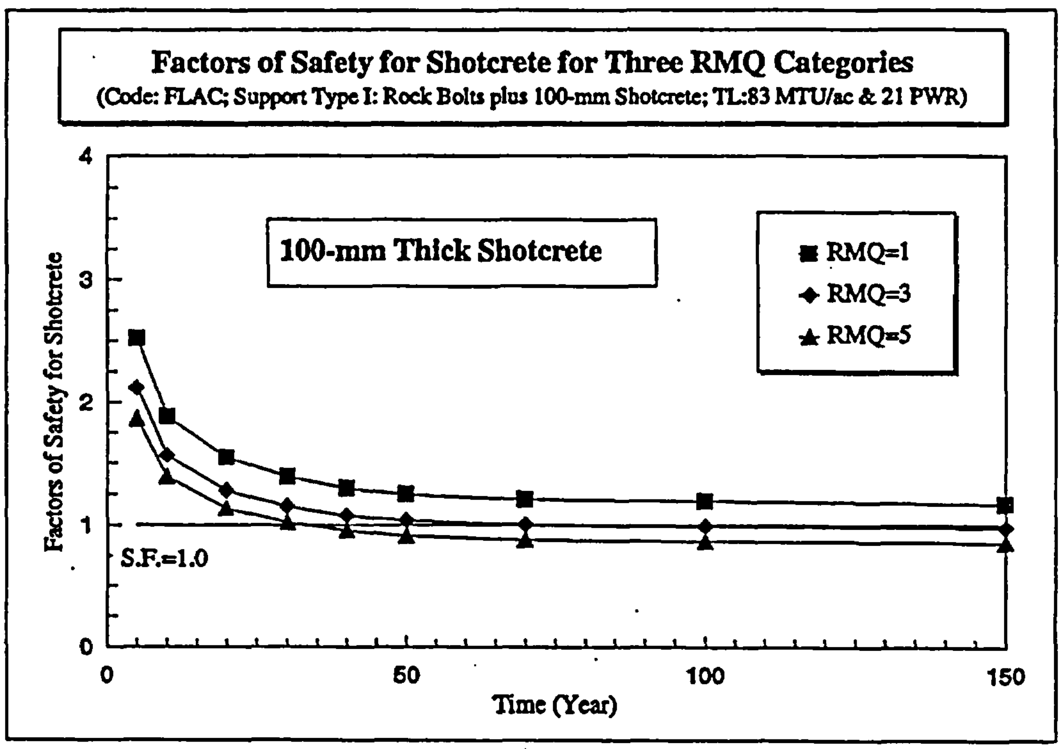


Figure B-11. Axial Forces in Rock Bolts and Shotcrete for Ground Support Type I, RMQ=3 and 83 MTU/acre: (a) 10 Years after Emplacement; (b) 50 Years after Emplacement; (c) 150 Years after Emplacement

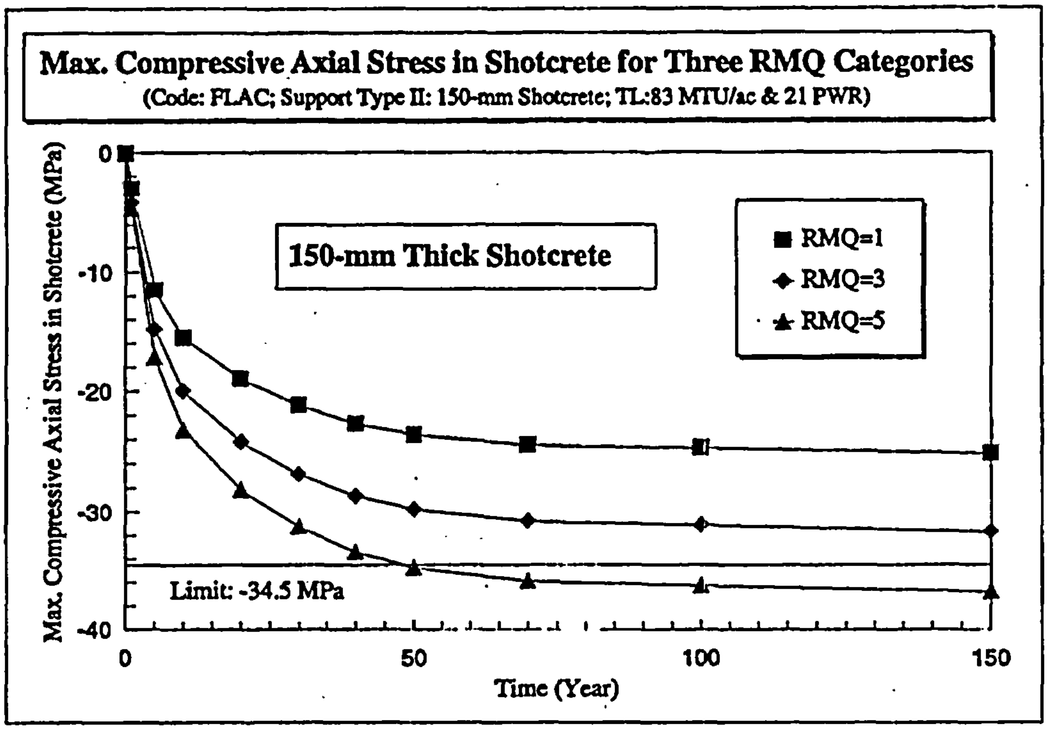


(a)

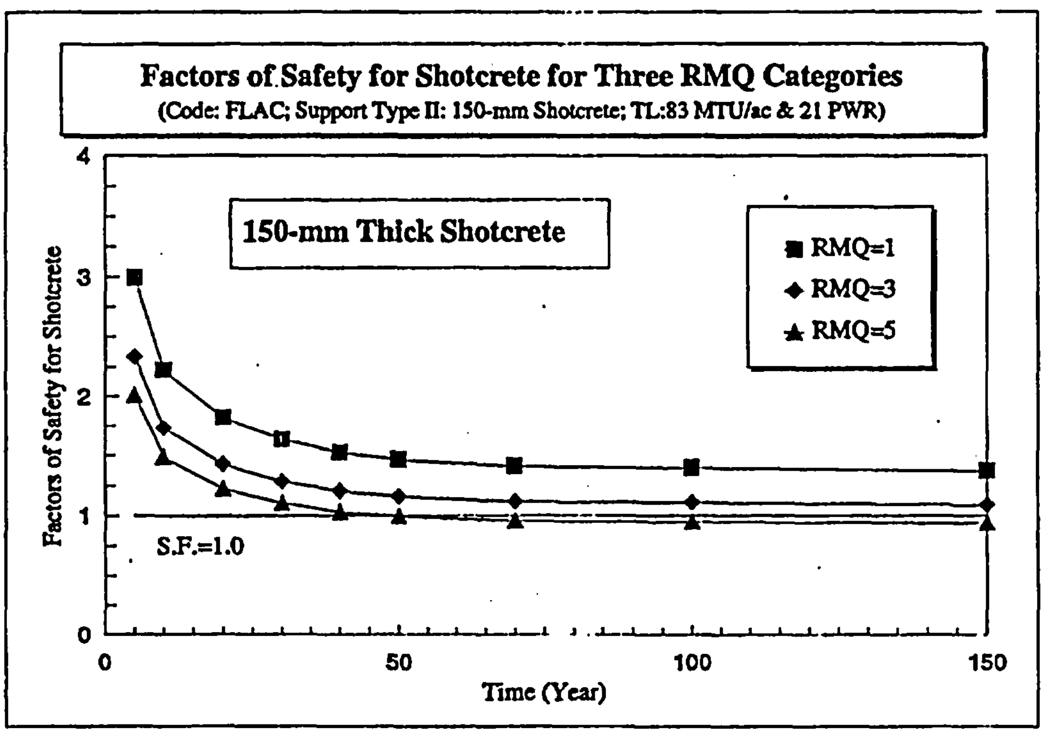


(b)

Figure B-12. Time Histories of Max. Compressive Axial Stress in Shotcrete and its Factors of Safety for Ground Support Type I, Different RMQ Categories and 83 MTU/acre (a) Max. Compressive Axial Stress; (b) Factors of Safety

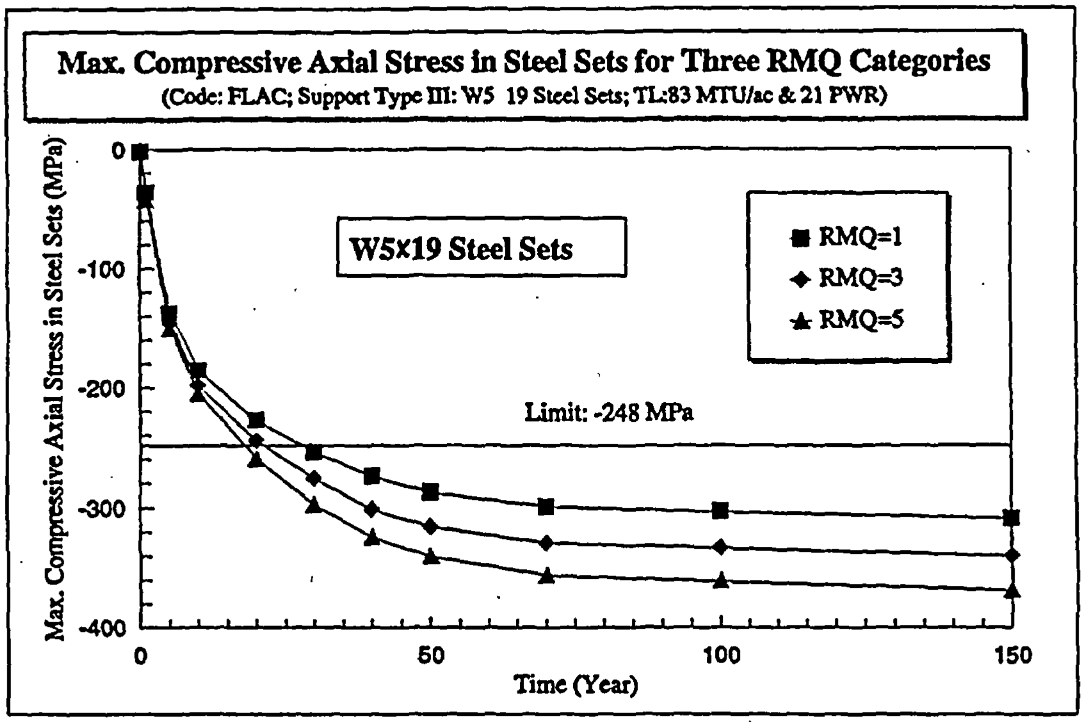


(a)

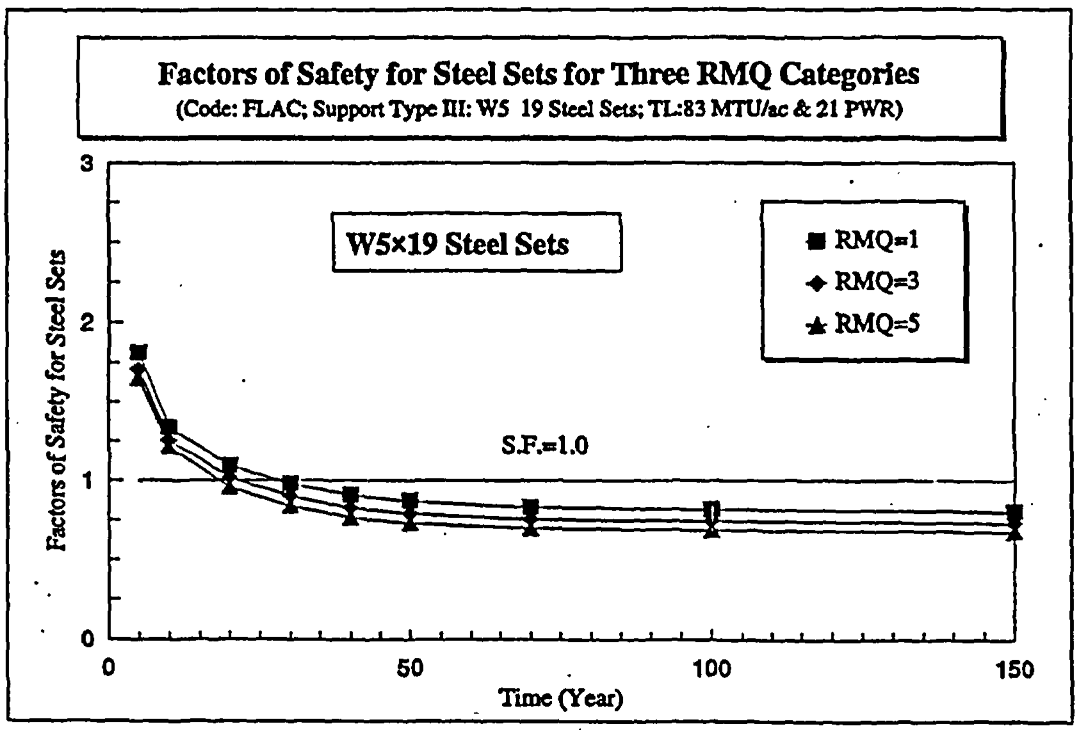


(b)

Figure B-13. Time Histories of Max. Compressive Axial Stress in Shotcrete and its Factors of Safety for Ground Support Type II, Different RMQ Categories and 83 MTU/acre (a) Max. Compressive Axial Stress; (b) Factors of Safety



(a)



(b)

Figure B-14. Time Histories of Max. Compressive Axial Stress in Steel Sets and Their Factors of Safety for Ground Support Type III, Different RMQ Categories and 83 MTU/acre (a) Max. Compressive Axial Stress; (b) Factors of Safety

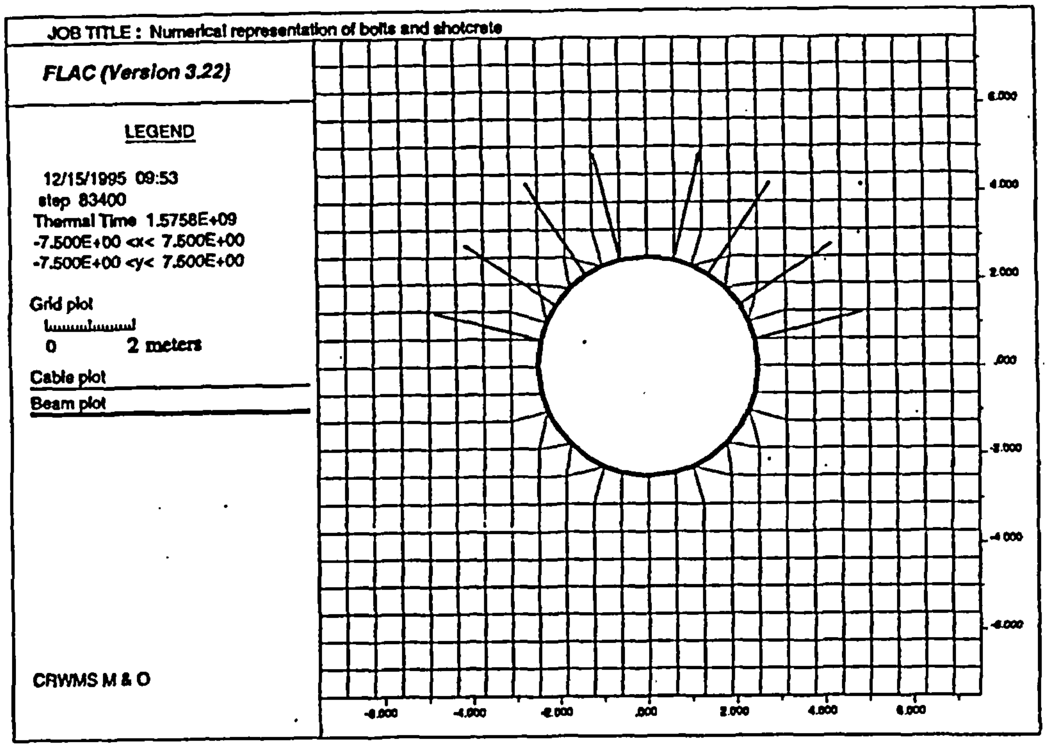


Figure B-15. Numerical Representation of Bolts and Shotcrete in the Center Drift

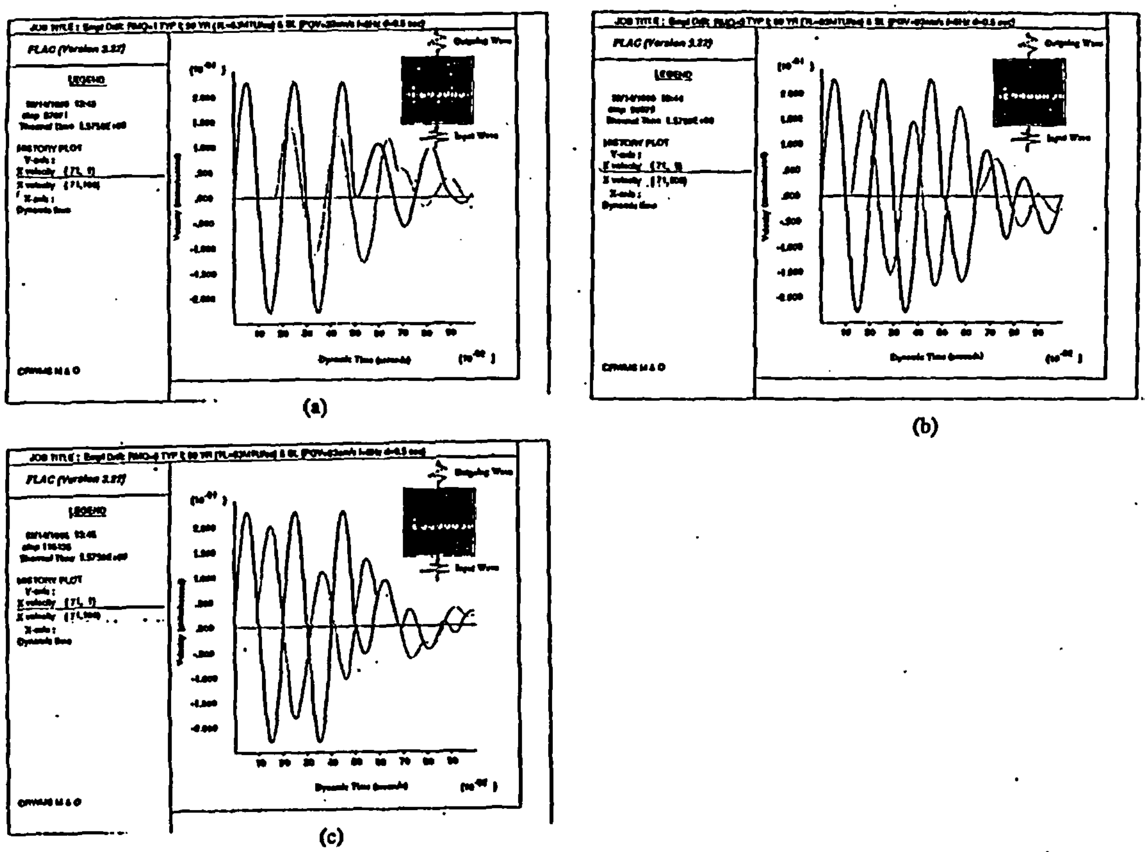


Figure B-16. Input Seismic Wave (PGV=23 cm/s, freq.=5 Hz) at the Base of FLAC Model and Outgoing Seismic Wave Monitored at the Top of FLAC Model When the Center Drift Is Reinforced with Bolts on 1.0 m Spacing and 100 mm Thick Shotcrete (Ground Support Type I): (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

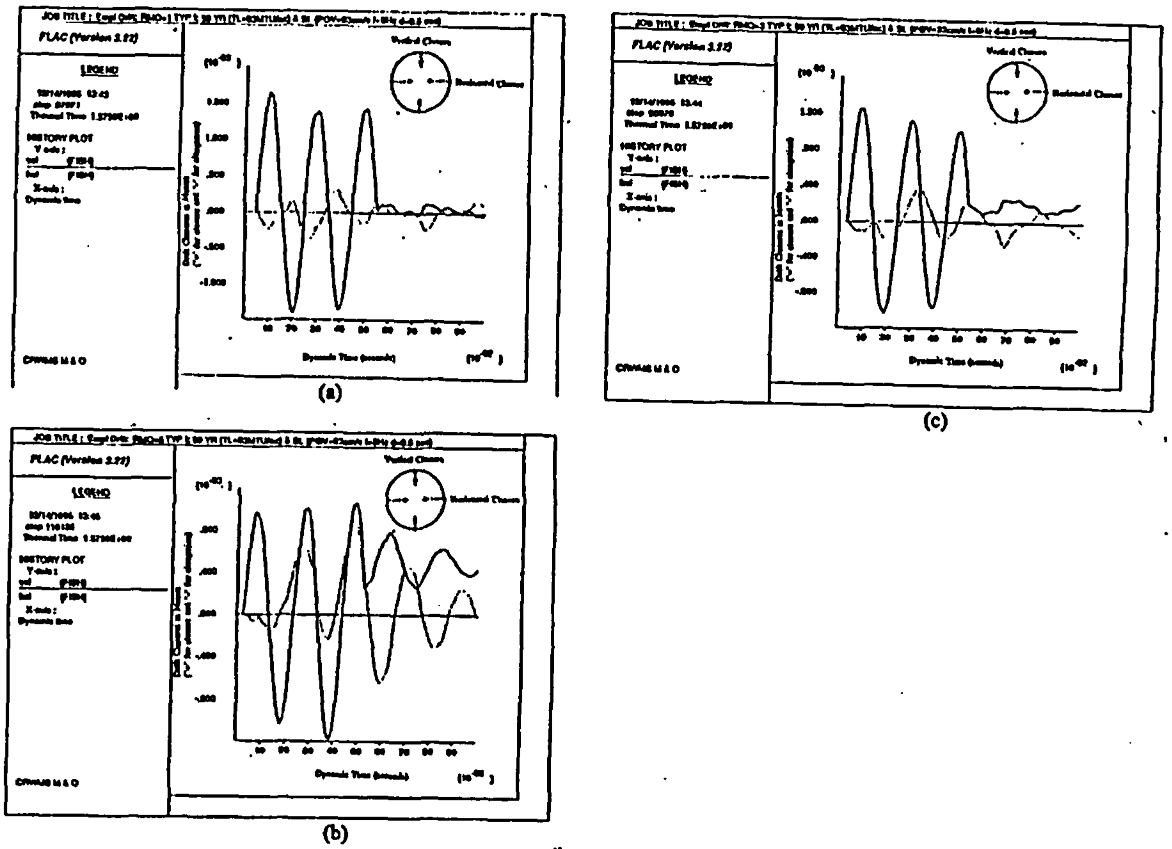


Figure B-17. Vertical and Horizontal Closures Caused during the Seismic Loading (PGV=23 cm/s, freq.=5 Hz) for the Center Drift with Ground Support Type I: Horizontal Axis Shows the Dynamic Time in Seconds and Vertical Axis Shows the Closure in Meters. (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

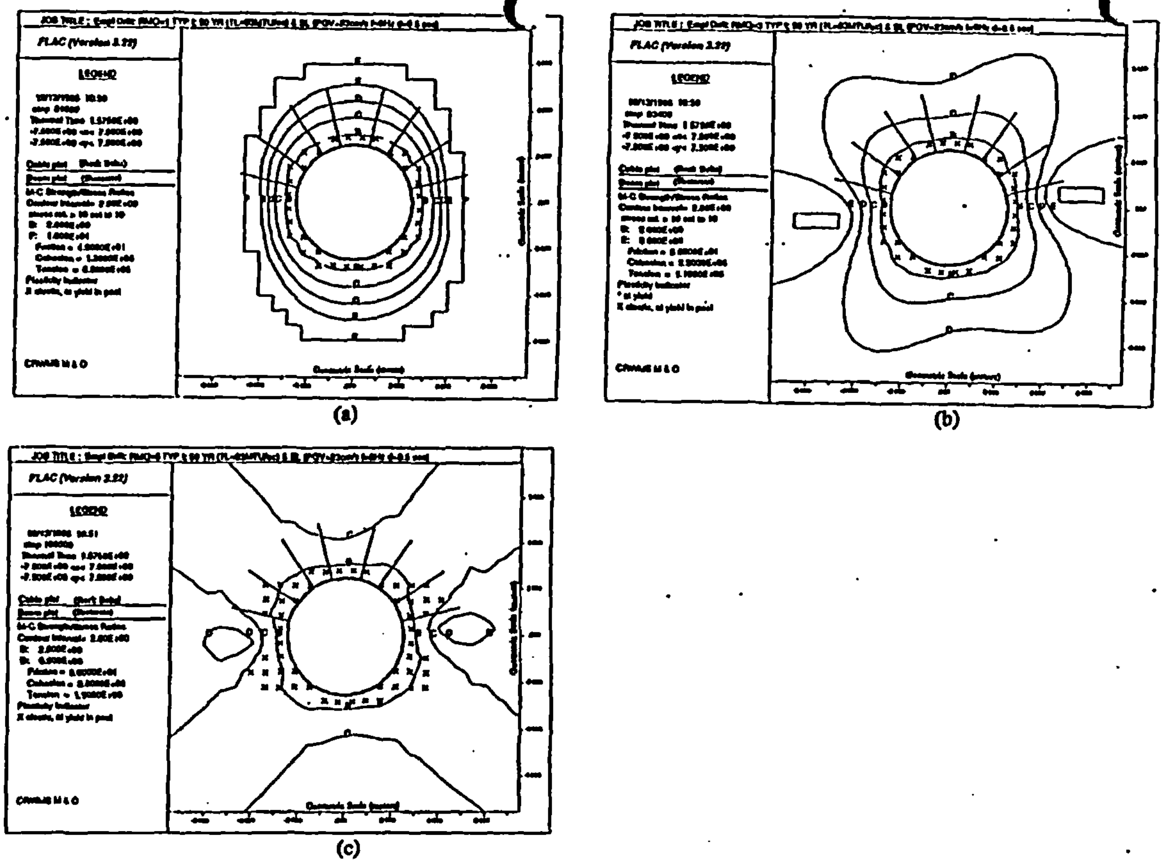


Figure B-18. Safety Factor Contour Plots and Rock Mass Plasticity Location Indicators about the Center Drift under the Seismic Loading (PGV=23 cm/s, freq.=5 Hz) and with Ground Support Type I: (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

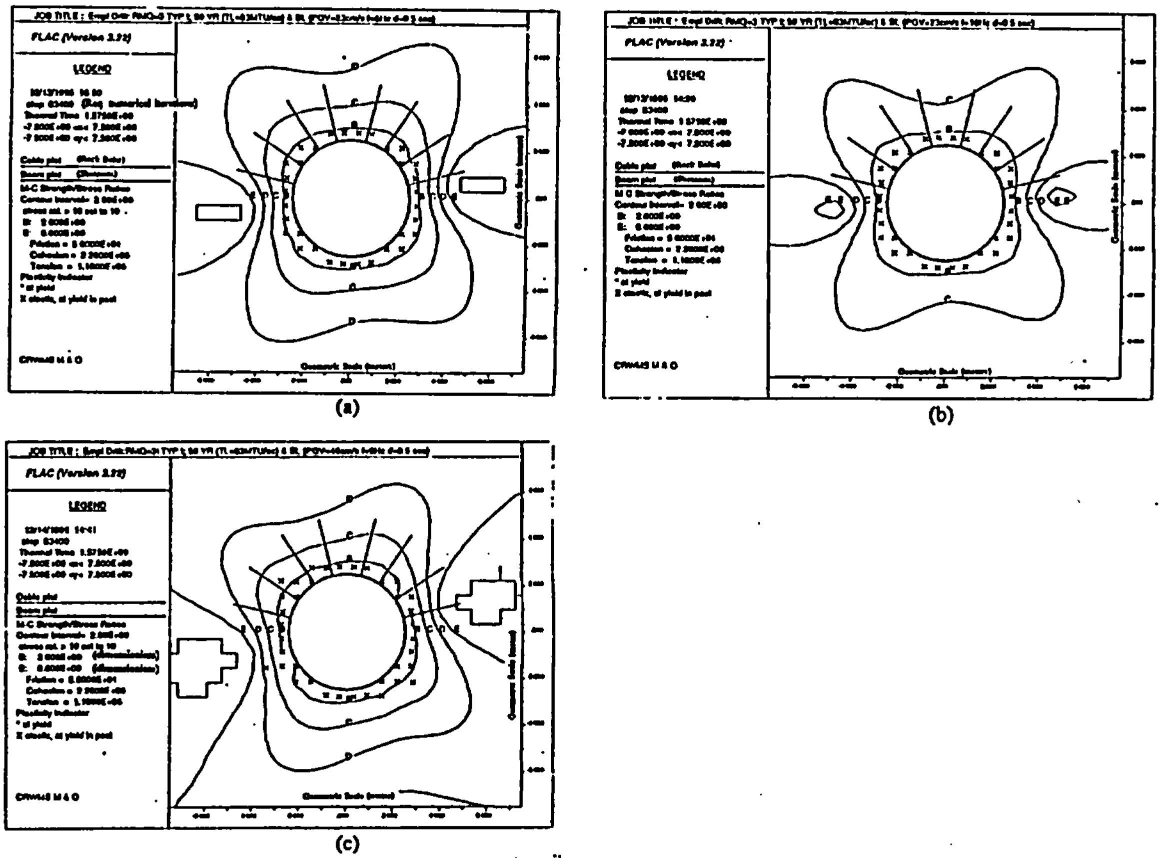


Figure B-19. Safety Factor Contour Plots and Rock Mass Plasticity Location Indicators about the Center Drift under the Different Seismic Loadings, for RMQ=3, and with Ground Support Type I: (a) Under Seismic Loading with PGV=23 cm/s, freq.=5 Hz; (b) Under Seismic Loading with PGV=23 cm/s, freq.=10 Hz; (c) Under Seismic Loading with PGV=46 cm/s, freq.=5 Hz.

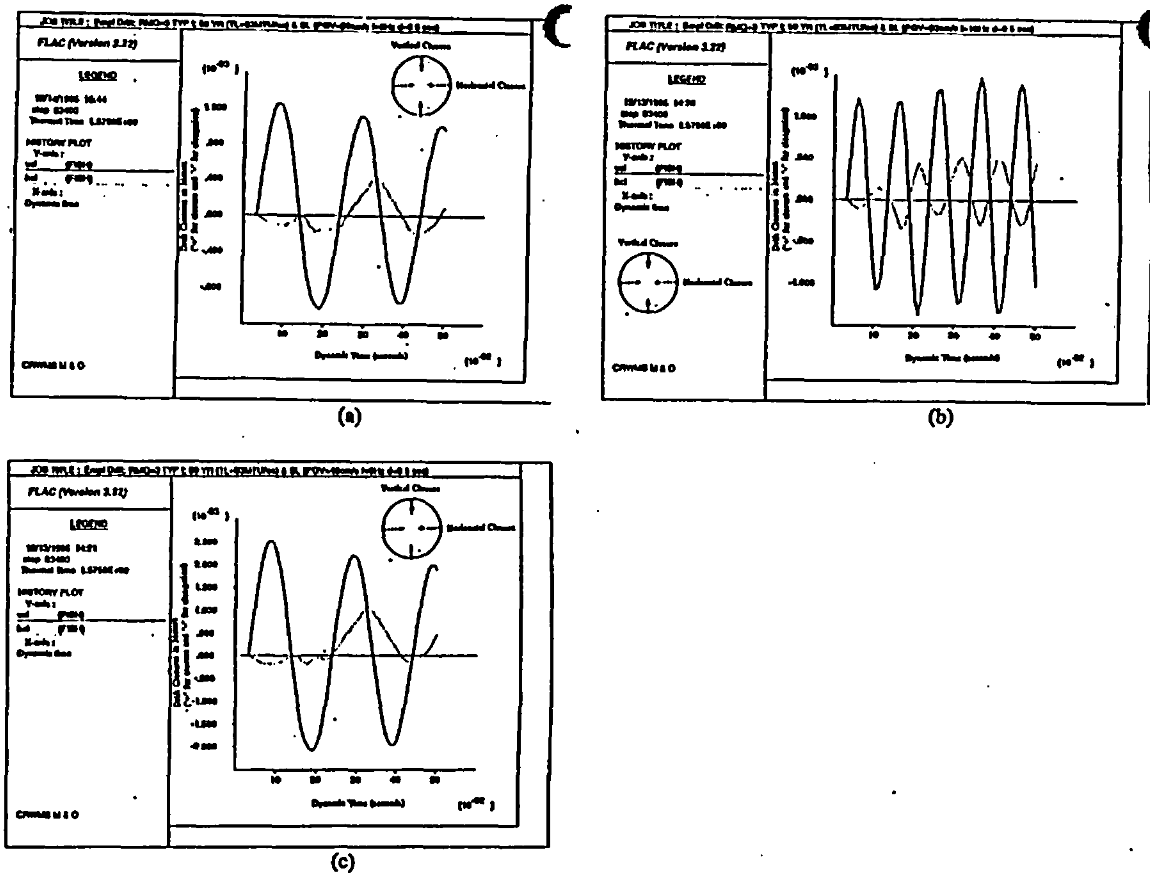


Figure B-20. Vertical and Horizontal Closures Caused about the Center Drift under three Different Seismic Loadings for RMQ=3, and with Ground Support Type I: Horizontal Axis Shows the Dynamic Time in Seconds and Vertical Axis Shows the Closure in Meters: (a) Under Seismic Loading with PGV=23 cm/s, freq.=5 Hz; (b) Under Seismic Loading with PGV=23 cm/s, freq.=10 Hz; (c) Under Seismic Loading with PGV=46 cm/s, freq.=5 Hz.

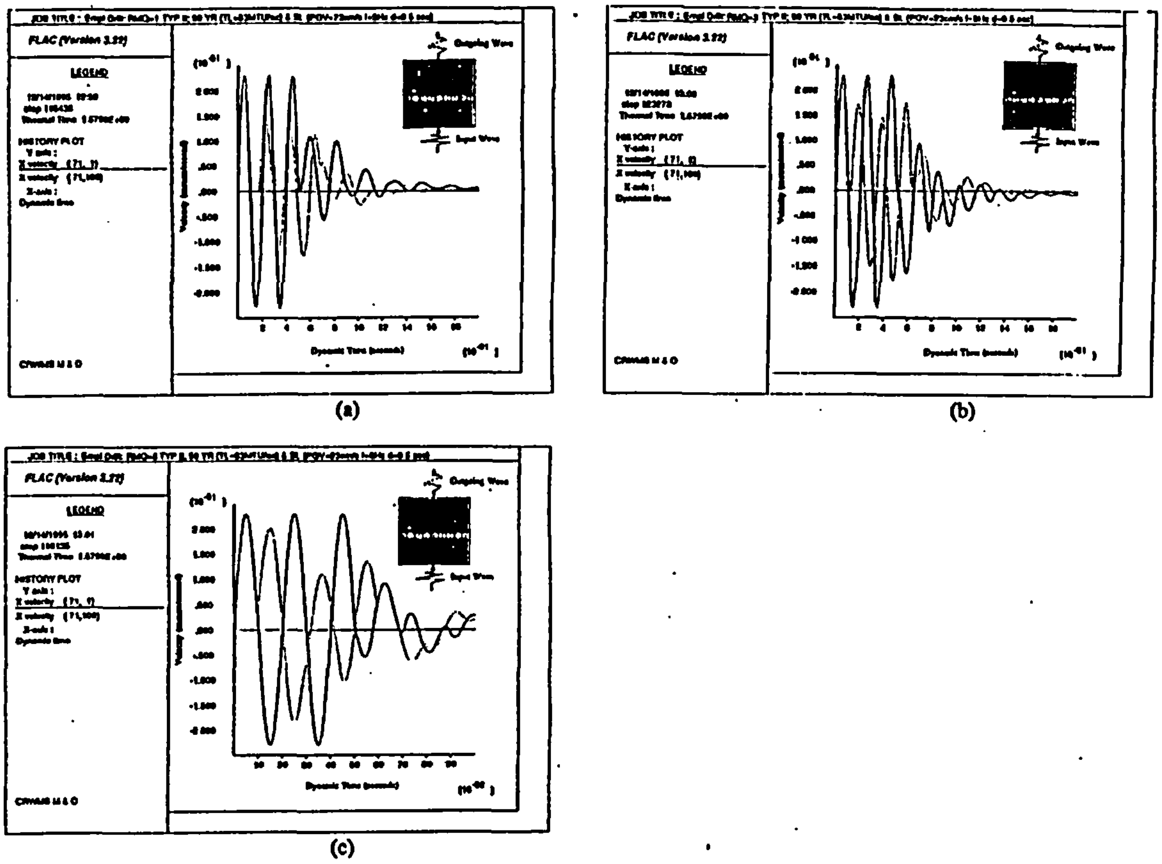


Figure B-21. Input Seismic Wave (PGV=23 cm/s, freq.=5 Hz) at the Base of FLAC Model and Outgoing Seismic Wave Monitored at the Top of FLAC Model When the Center Drift Is Reinforced with 150 mm Thick Concrete or Shotcrete Liner (Ground Support Type II): (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

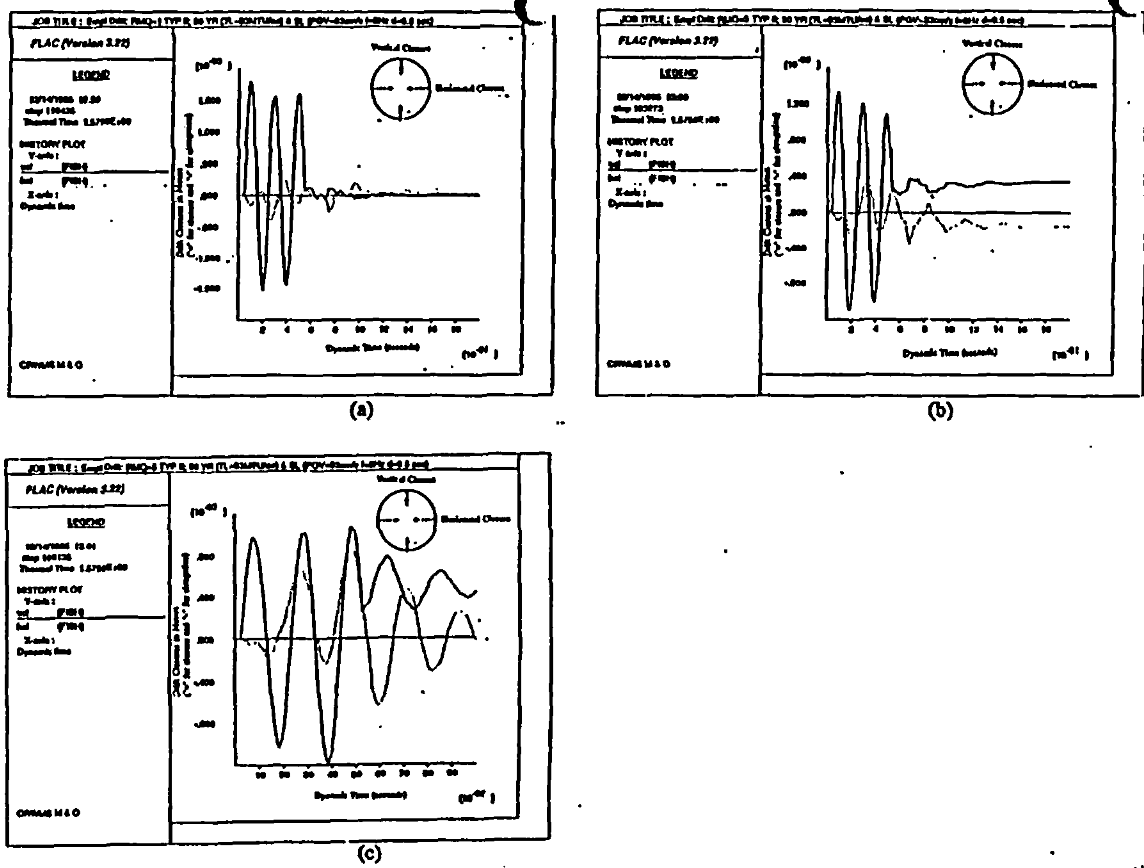


Figure B-22. Vertical and Horizontal Closures Caused during the Seismic Loading (PGV=23 cm/s, freq.=10 Hz) for the Center Drift with Ground Support Type II: Horizontal Axis Shows the Dynamic Time in Seconds and Vertical Axis Shows the Closure in Meters. (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

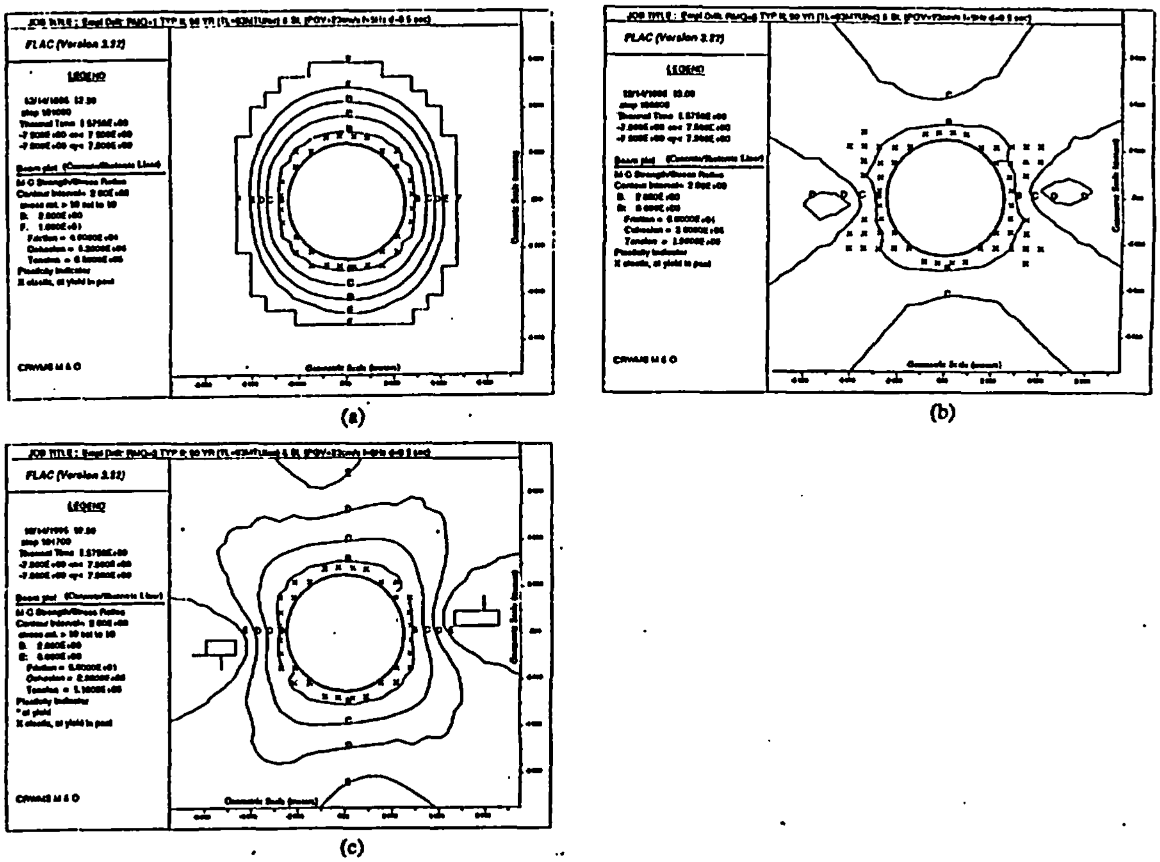


Figure B-23. Safety Factor Contour Plots and Rock Mass Plasticity Location Indicators about the Center Drift under the Seismic Loading (PGV=23 cm/s, freq.=5 Hz) and with Ground Support Type II: (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

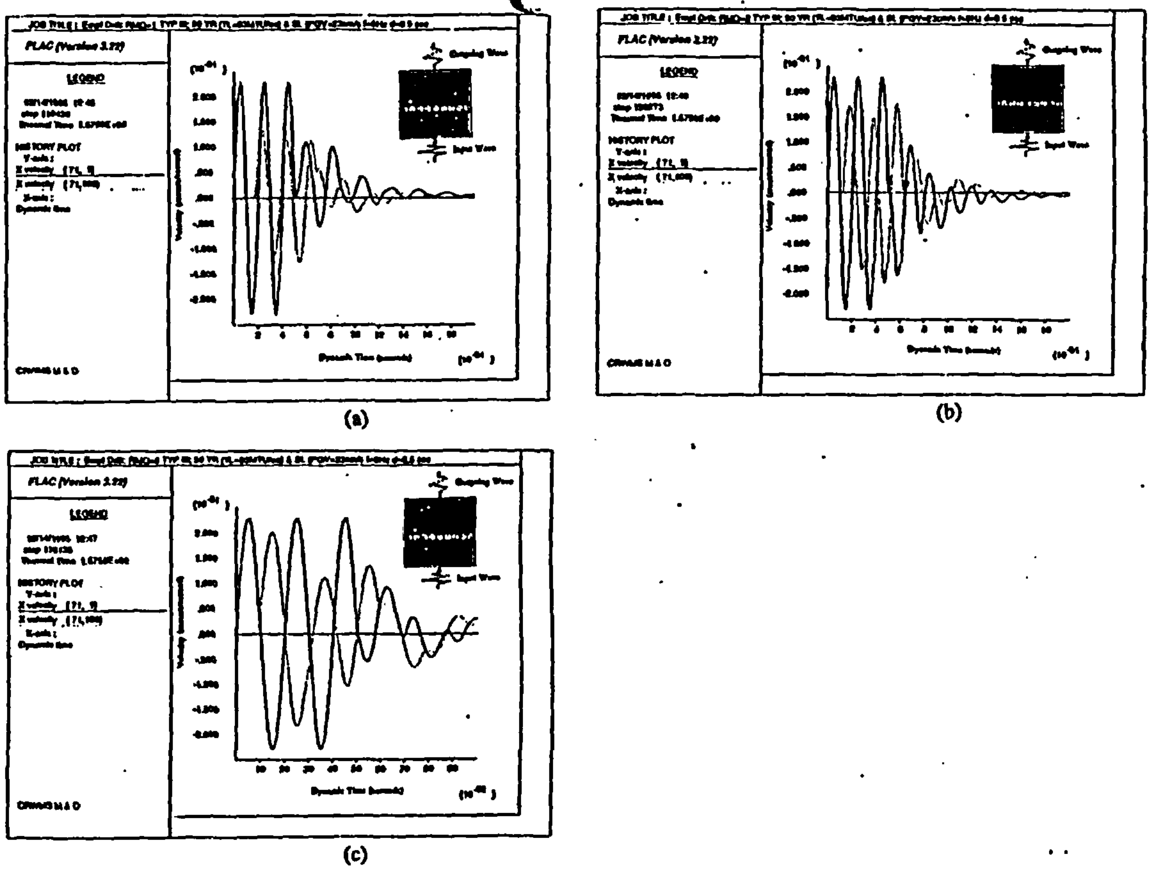


Figure B-24. Input Seismic Wave (PGV=23 cm/s, freq.=5 Hz) at the Base of FLAC Model and Outgoing Seismic Wave Monitored at the Top of FLAC Model When the Center Drift Is Reinforced with W5X19 Steel Sets on 1.2 m Spacing (Ground Support Type III): (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

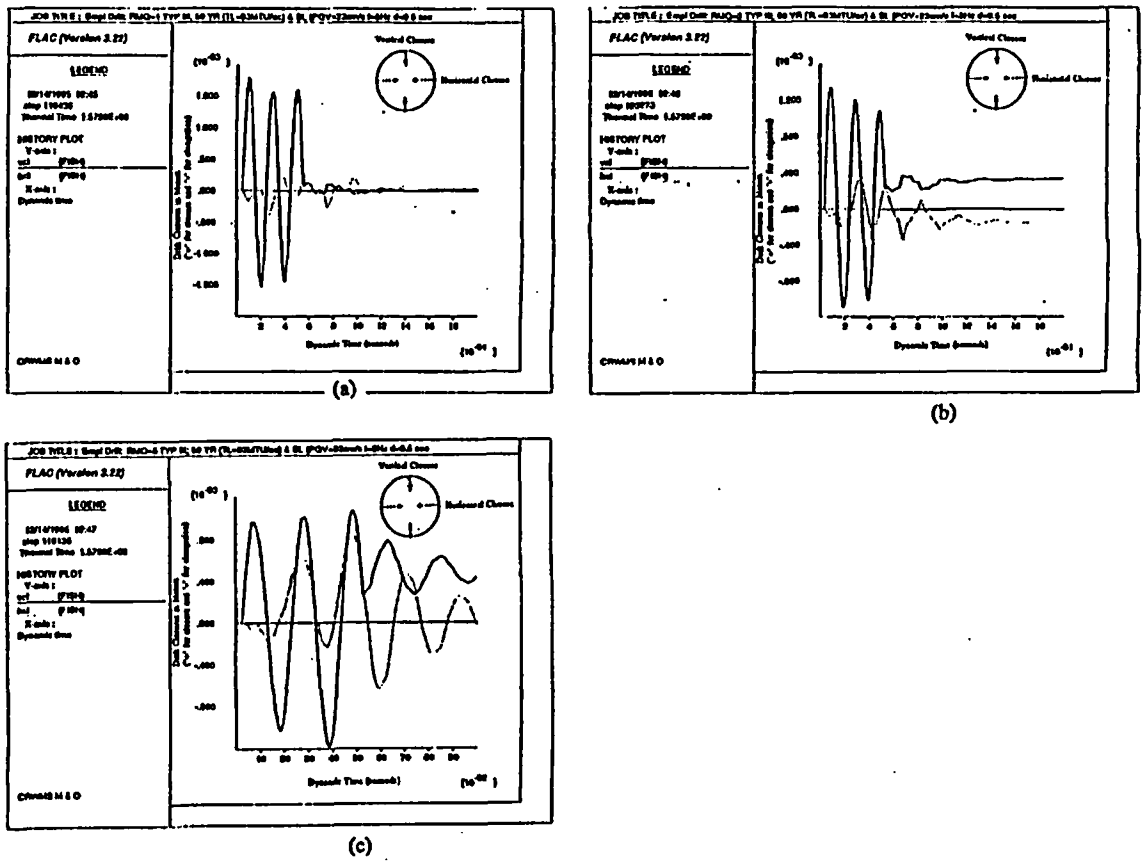


Figure B-25. Vertical and Horizontal Closures Caused during the Seismic Loading (PGV=23 cm/s, freq.=10 Hz) for the Center Drift with Ground Support Type III: Horizontal Axis Shows the Dynamic Time in Seconds and Vertical Axis Shows the Closure in Meters. (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.

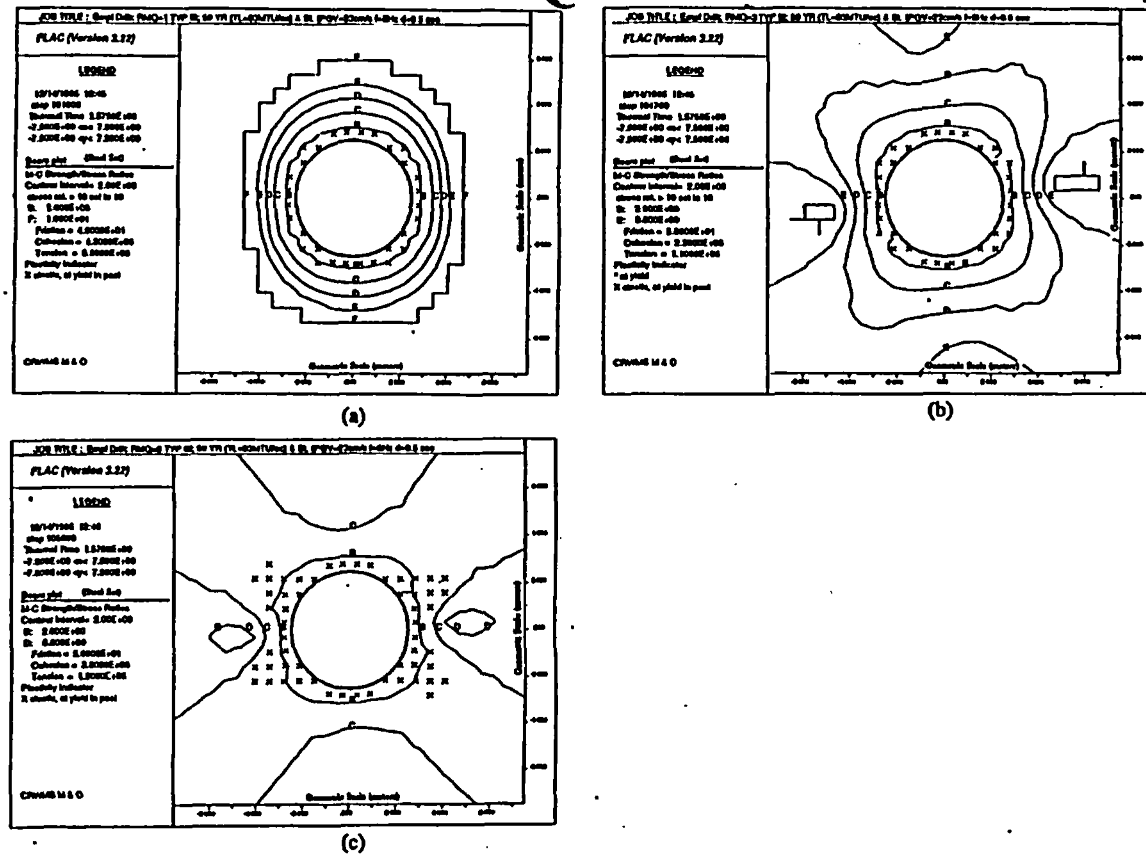


Figure B-26. Safety Factor Contour Plots and Rock Mass Plasticity Location Indicators about the Center Drift under the Seismic Loading (PGV=23 cm/s, freq.=5 Hz) and with Ground Support Type III: (a) Under RMQ = 1; (b) Under RMQ = 3; (c) Under RMQ = 5.