RETRIEVABILITY AS PROPOSED IN THE U.S. HIGH-LEVEL RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL REPOSITORY CONCEPT

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ABSTRACT

The Nuclear Waste Policy Act as amended in 1987, states that any high-level radioactive waste (HLW) and Spent Nuclear Fuel (SNF) repository (hereafter referred to as the repository) shall be designed and constructed to permit retrieval. Reasons for retrieval include public health and safety, environmental concerns, and recovery of economically valuable contents SNF. The U.S. Nuclear Regulatory Commission (NRC) requires that HLW and SNF must be retrievable starting at any time up to 50 years after start of emplacement.

The U.S. Department of Energy (DOE) intends to maintain a retrieval capability throughout the preclosure period. Possible preclosure periods range from a minimum of 50 years to as much as 300 years. Closure of the repository consists of sealing all accessible portions of the repository, including ventilation shafts, access ramps, and boreholes. Access to the repository after closure is not intended.

Retrievability and monitoring are important concepts in the development of a viable approach to disposal of HLW and SNF in the U.S. The capability of retrieval provides flexibility to react to changes after emplacement. A period of monitoring after emplacement provides additional assurance that the original design basis of the repository has been met, and provides information upon which to base a decision to close a repository. The extended monitoring capability proposed for the repository does not degrade its safety. Retrieval activities could be initiated at any time prior to repository closure.

INTRODUCTION

Retrieval of HLW and SNF from the proposed U.S. repository at Yucca Mountain has received careful consideration. The ability to retrieve HLW and SNF provides operational flexibility to address any changes that may occur after emplacement. This provides an added margin of safety to the repository design and also provides the option to retrieve a potentially valuable resource prior to repository closure.

BASIS FOR U.S. CONSIDERATION OF RETRIEVABILITY

Legislative Requirements

The Nuclear Waste Policy Act, as amended in 1987 (1), defines the requirement for HLW and SNF retrievability and provides the reasons for which retrieval may be required. Section 122 of the Act states that any repository to be approved as a result of the Act shall be designed and constructed to permit the retrieval of any HLW and SNF placed in such repository. It also states that such retrieval should take place during an appropriate period of operation of the facility. This latter requirement defines retrievability as a preclosure activity. Reasons for which retrievability is justified under the Act include public health and safety, environmental concerns, and recovery of economically valuable contents of spent fuel. The period of retrievability will be as specified by the Secretary of Energy at the time of design, and it will be subject to approval or disapproval by the NRC.

Regulatory Requirements

The NRC requirements for HLW and SNF retrievability are given in Title 10 of the Code of Federal Regulations (CFR), Part 60 and proposed Part 63 (2, 3). These regulations establish a minimum period during which retrieval must be possible. Emplaced HLW and SNF must be retrievable on a reasonable schedule, starting at any time up to 50 years after start of emplacement, unless the NRC approves a different time period. A reasonable period is defined as the period that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of HLW and SNF.

DURATION OF CAPABILITY FOR RETRIEVAL

Preclosure Period

The U.S. approach to retrievability envisions that HLW and SNF would be retrievable at any time during the preclosure period. The regulatory minimum for retrievability is 50 years from start of emplacement, but the DOE intends to maintain a retrieval capability throughout the preclosure period. The actual duration of the preclosure period for a repository has not been determined, as it is subject to several inputs.

Recent project activity has addressed the issue of uncertainties in both natural and engineered system performance. It has been proposed that cooler temperatures during both the preclosure and postclosure periods may reduce uncertainties in modeling the system behaviors and may also be beneficial to repository operations. A design change has recently been approved which incorporates a cooler design (4). The previous design resulted in emplacement drift rock wall temperatures well above the boiling temperature of water (96 degrees C at the elevation of Yucca Mountain) both before and after closure. The revised design maintains the rock below 96 degrees C during the preclosure period, although closure at 50 years may result in rock temperatures above 96 degrees C. The revised design is also capable of maintaining rock temperatures below 96 degrees C throughout the postclosure period through one or more of several operational modes. Those modes include extending the preclosure period (and ventilation duration), increasing the waste package spacing, and aging the waste before emplacement to reduce the thermal output of the waste.

There are therefore multiple conceptual preclosure periods. The minimum preclosure period is that necessary for compliance with the NRC regulations, and is 50 years from the beginning of emplacement.

Another potential preclosure period results from a repository concept that defers the closure decision to future generations. The U.S. concept does not preclude extending the preclosure period to allow future generations to make the decision when to close and to continue to monitor and acquire performance data to support such a closure determination. The repository is being designed to permit a preclosure period of 300 years, with reasonable maintenance. This approach is directly responsive to public input. Public concerns have been expressed that closure in relatively short periods does not provide adequate assurance of safety.

Accessibility After Closure

The U.S. concept of HLW and SNF repository closure includes sealing all accessible portions of the repository, including ventilation shafts, access ramps, and boreholes. Drip shields will be installed over the waste packages prior to the sealing operations. Although earlier concepts included backfilling of the emplacement drifts, such backfilling is not included in the current design, but is not precluded from future consideration. Access to the repository after closure is not intended.

DESCRIPTION OF THE REPOSITORY LAYOUT

The regulatory requirements for retrieval help define three basic criteria for the design of the subsurface facilities.

Robust Infrastructure

The preclosure period for the repository will vary, depending on decisions and licensing issues that will evolve with time. Current estimates for closure include scenarios for no retrieval action, exercise of the retrieval option, and an extended preclosure monitoring period.

- If no retrieval is deemed necessary, the repository could be closed in 65 years. This period of time includes approximately 5 years for initial construction, 50 years for waste emplacement and monitoring, and 10 years for decommissioning, sealing, and closure.

- The requirements documents reflect criteria for an extended monitoring of the repository that would extend the preclosure period to as much as 300 years. The rationale for this requirement is that the decision to close the repository may best be made by future generations, based on considerations that cannot be anticipated at this time, such as the availability of future treatment technology, the reuse of the nuclear fuel, or the realization of a better disposal alternative.

- Because the repository may remain open for over 100 years, and possibly as long as 300 years, its structures must last that long with manageable maintenance in an environment with high radiation and high temperature. This requirement applies to excavations, ground support, permanent mechanical components, transportation, ventilation, and other utilities.

Selective Retrieval

Maintaining the ability to selectively retrieve HLW and SNF packages affects the basic repository layout, mechanical equipment, and infrastructure (to allow performance of emplacement functions in reverse order), as well as the flexibility of access to individual waste packages. The current design does not incorporate the ability to "carry over," or remove, a waste package from a drift without first removing all waste packages from the entrance up to the package of interest.

Alternate Ingress and Egress Routes

Emplacement drift ground control deterioration and rockfall, progressive or sudden, could block access and reduce ventilation to a particular location of the repository. To maintain the capability to retrieve any HLW or SNF from the repository, dual or redundant drift access is important. The current layout has the ventilation raise coming up (from a ventilation level below) in the center of each drift (Figure 1). The rails for the emplacement gantry end at the collar of this raise, so the emplacement rails are not continuous through the entire length of the drift. This does not allow full access to all parts of the drift from either end without temporary modifications that would include placing a prefabricated section of rail over the raise opening. Design improvements are being considered to maintain rail access across the raise, such as a lower-profile raise collar. Temporary capping or other means to span the raise if access is needed across it are also being considered.

The concept for the proposed repository at Yucca Mountain includes horizontal emplacement drifts located in the unsaturated zone, approximately 300 meters below the mountain surface and approximately 300 meters above the saturated zone. The recent design change has focused on reducing performance assessment uncertainties through achieving a cooler design than that proposed in the Viability Assessment. The SNF loading has been reduced from 85 to approximately 56 metric tons of heavy metal equivalent per acre. The emplacement drift centerline spacing has been increased from 28 to 81 meters to provide a region below 96 degrees C between the drifts to facilitate water drainage. The maximum power per waste package has been reduced from approximately 18 kilowatts (kW) to less than 12 kW. The preclosure ventilation rate has been increased from 0.1 cubic meters per second (CMS) per drift to 15 CMS per drift. Other features, such as a drip shield over the waste packages, have been added to provide defense-in-depth by reducing the amount of water contacting the waste packages during the postclosure period.

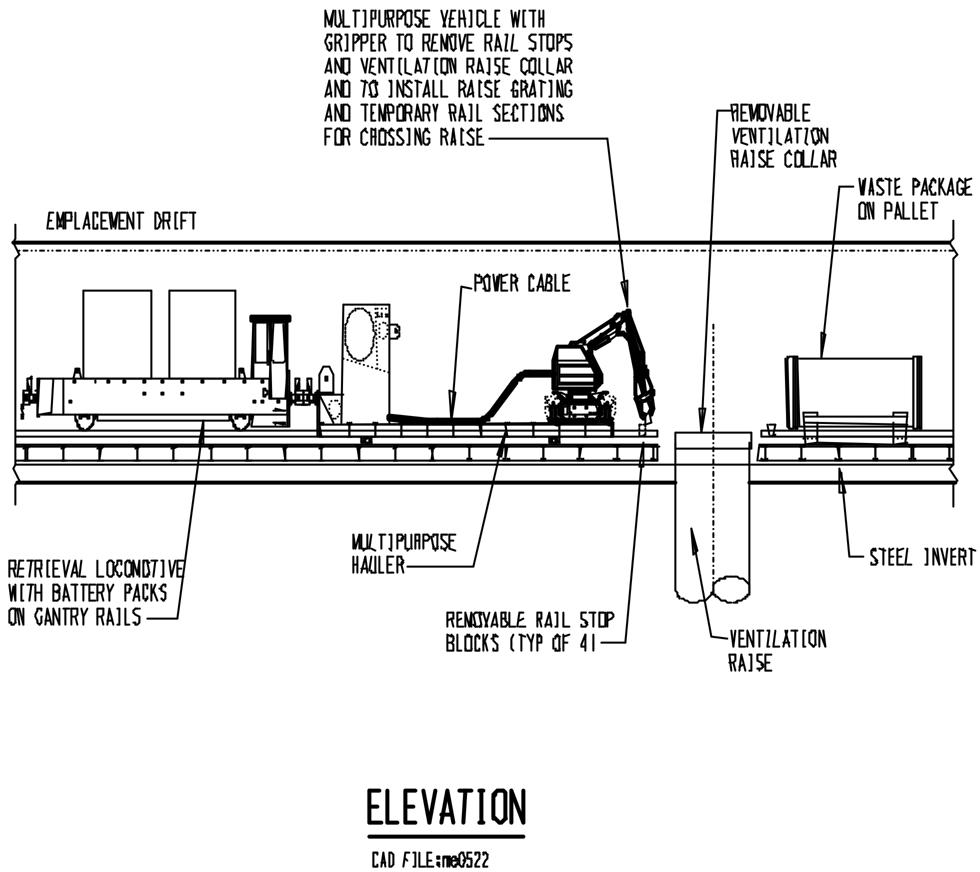

Fig. 1. Ventilation Raise in Emplacement Drift

The emplacement drifts are to remain open until closure of the repository. This provides numerous performance benefits in this emplacement concept, primarily removing heat and moisture during the preclosure period, lowering the eventual peak postclosure temperatures, and slowing the increase in relative humidity upon closure. Other benefits include facilitating the measurements taken during the performance confirmation period, after loading the waste packages into the drifts. With respect to retrieval, this provides the benefit of not impeding retrieval, permitting a reversal of the emplacement process to accomplish retrieval under normal conditions. The preclosure period is therefore to improve performance, and the resultant extension of the retrievability capability is a secondary effect.

METHODS OF RETRIEVAL

Drift Conditions During Retrieval

After the emplacement drifts have been loaded with waste packages, ventilation will continue throughout the preclosure period. With a sustained ventilation flow rate of 15 CMS, air temperatures inside the drift will remain at or below a peak temperature of approximately 60 degrees C during the first 100 years (5). An increase in the ventilation rate would lower the drift air temperatures below 50 degrees C, low enough for the retrieval gantry to operate reliably in the drift environment. Radiation levels would be too high for unprotected personnel access into the emplacement drifts (6). In cases where human incursion may be necessary, some or all of the waste packages would have to be removed, and extensive preparations would have to be made for radiation control.

Other potential drift conditions would affect retrieval, including:

- The structural integrity of the waste package support pallets
- The conditions of the invert structure and rails
- A large block rockfall
- Conditions related to the containment integrity of the waste packages
- Any major deterioration and collapse of the ground support and drift walls.

The waste packages are designed to not fail under any credible rockfall or incident. Therefore, the unlikely presence of a potentially breached waste package would require case-specific information and planning before any retrieval attempt, as would any detected adverse condition in the emplacement drift that would force a deviation from normal operating conditions.

Generally, preparation for retrieval under abnormal conditions would be the same as stated for the normal operation, with the exception that a unique retrieval plan would be developed as required for each case. Due to the double-ended nature of the emplacement drifts, retrieval may be accomplished from either end.

Normal Retrieval Procedure and Equipment

The emplacement drifts will be monitored periodically, with an expected inspection frequency of 10 years. A remotely operated inspection gantry would be used during those inspections. Such monitoring will provide data for a database on drift conditions that would be used to plan maintenance activities. If it were decided that spent nuclear fuel would be retrieved from the repository, this database and additional case-specific monitoring would be available for planning of retrieval activities. If drift conditions were normal, retrieval operations would be executed using the same waste package emplacement equipment in reverse sequence as that used for emplacement. To maintain air temperatures below 50 degrees C during retrieval, the ventilation flow rates may have to be adjusted several weeks before the drift incursion.

The normal retrieval sequence of operations is essentially the reverse sequence of emplacement operations (7). This sequence has been simplified to identify key steps in the process and is listed below:

1. The locomotive and gantry carrier travels to the emplacement drift.

2. The locomotive and gantry carrier proceed through the airlock, and the gantry carrier engages the emplacement drift dock.

3. The gantry moves off the gantry carrier, and the carrier is removed from the drift turnout.

4. The airlock doors are closed, and the gantry moves to the location of the first waste package.

5. The gantry picks up the pallet and waste package and moves back to the emplacement drift dock.

6. The transport locomotives and empty waste package transporter move to the main drift adjacent to the emplacement drift. The controls are turned over to remote operation, and the operators leave the locomotives.

7. A secondary locomotive decouples ahead of the drift entrance. The primary locomotive and waste package transporter move from the main drift into the drift turnout.

8. The primary locomotive and waste package transporter move into the airlock, the waste package transporter doors open, the waste package transporter docks, and the bed plate is extended onto the open deck.

9. The loaded gantry moves over the open deck of the transporter, deposits the pallet and waste package on the transporter bed plate, and moves back into the drift.

10. The pallet and waste package are pulled into the shielded compartment of the transporter via the bed plate, which is supported on rollers.

11. The primary locomotive moves the waste package transporter away from the edge of the emplacement drift, and the transporter doors and emplacement drift side airlock doors close.

12. The primary locomotive and waste package transporter move from the turnout into the main drift.

13. The secondary locomotive couples to the rear of the waste package transporter, the operators board the locomotives, and the train moves to the surface. (Steps 1 through 13 are repeated for each waste package to be retrieved from the drift.)

14. The locomotive moves the gantry carrier from the main drift to the emplacement drift turnout.

15. The locomotive and gantry carrier move into the airlock and the gantry carrier engages the emplacement drift dock.

16. The gantry is moved onto the gantry carrier, and the locomotive pulls the carrier away from the emplacement drift dock and out of the airlock.

17. The locomotive and the gantry carrier move from the turnout to the main drift and return to a standby location.

If the waste package to be retrieved were not the waste package nearest the drift entrance, all waste packages in front of it would have to be temporarily relocated to another emplacement drift, following a sequence of events similar to that described above. In the unlikely event that a damaged waste package or a drift condition preventing normal retrieval is encountered, then the sequence is interrupted, and a contingency plan is initiated to mitigate the problem. Retrieved waste packages that are in good condition will be taken to the surface and staged in a dedicated area within the surface facilities complex. Damaged waste packages, or waste packages suspected of being damaged, will be taken to the surface facilities for detailed inspection, repairs, or repackaging as needed. The locomotives, gantry, gantry carrier, and waste package transporter used for normal retrieval are the same as those used for emplacement.

Off-Normal Retrieval Procedures and Equipment

When the equipment and operating sequence described above cannot be used, retrieval conditions are considered off-normal. Off-normal retrieval conditions, most likely due to drift wall deterioration and the resulting blockage of the rail system, prevent the use of the waste package gantry. Under off-normal retrieval conditions, several additional operations would be added to the retrieval sequence. These additional steps would most likely include the following:

- Monitoring and detailed characterization of damage
- Development of a case-specific contingency plan
- Cleanup and removal of debris
- Stabilization of the drift (including ground support repairs or replacement)
- Restoration of the rails and other damaged structures and utilities
- Repositioning of the pallet and waste package, if necessary
- Establishment of radiation controls and other administrative controls for the retrieval of a damaged or breached waste package.

In cases of significant rockfall and deterioration of drift structures, restoring the drift to original conditions may not be practical. In such cases, off-normal retrieval procedures and equipment will be used commensurate with the situation. A series of design basis events that could affect normal retrieval conditions were analyzed (7) to determine the operational procedure and type of equipment that could be used to retrieve waste packages. The two design basis events analyzed and of particular relevance to off-normal retrieval conditions in the emplacement drifts were: 1) rockfall or ground support collapse onto a waste package from causes other than seismic events, and 2) rockfall or ground support collapse onto a waste package caused by a seismic event. For the rockfall or ground support collapse to occur would take a beyond design basis seismic event. Other design basis events analyzed with respect to off-normal retrieval pertained to the mechanical failure of the gantry and the derailment of the gantry at normal speed.

The two pieces of equipment designed for removal of the gantry, the emplacement drift gantry carrier and the multipurpose hauler (Figure 2), operate on rollers. A steel plate would have to be installed over the drift invert to deploy this equipment. A multipurpose vehicle (Figure 3) can be operated from the multipurpose hauler to clear debris, emplace steel plates, and cut and remove damaged structures. This equipment would be remotely operated.

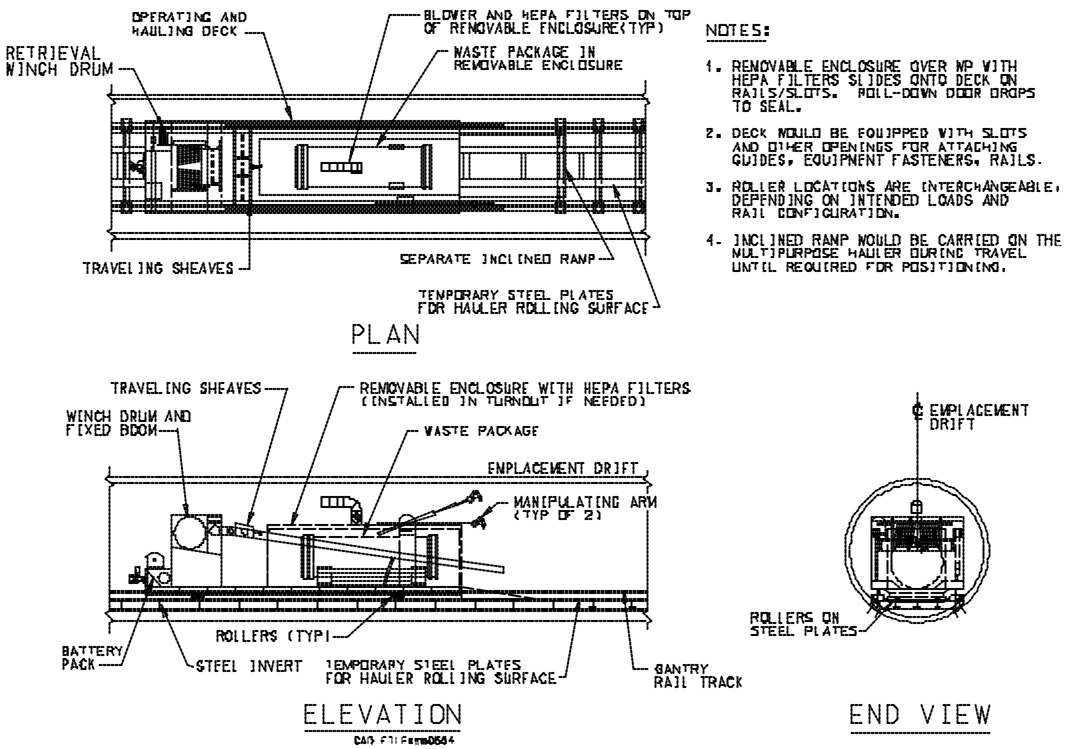

Fig. 2. Multipurpose Hauler

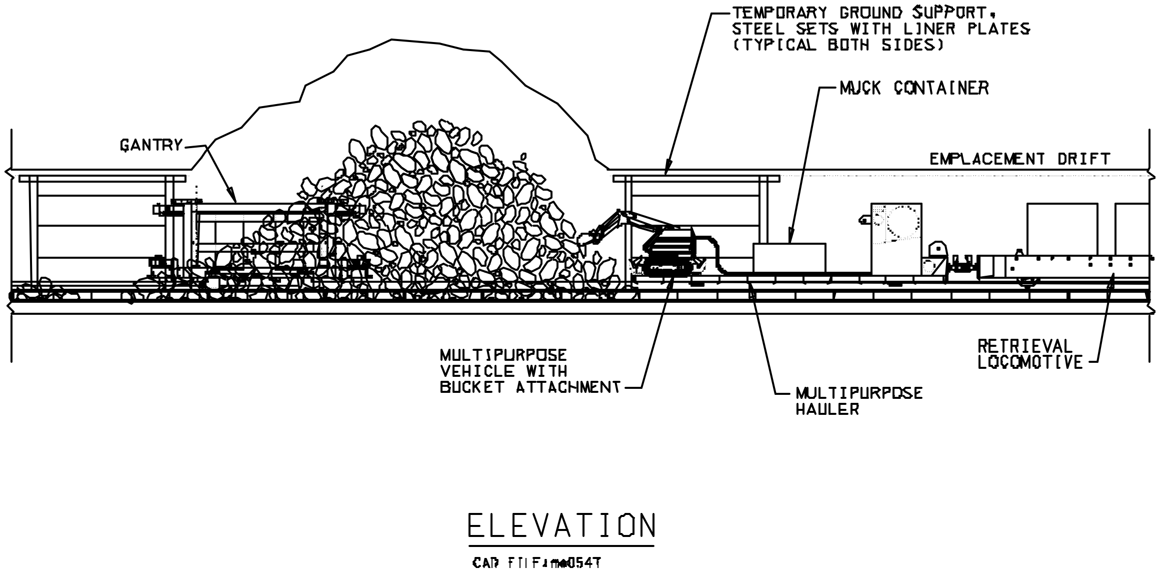

Fig. 3. Multipurpose Vehicle

When a derailed or damaged gantry has to be removed from the drift, the emplacement drift gantry carrier can load and carry the gantry away from the emplacement drift. The multipurpose hauler can be used to pull and load the pallet and waste package onto the deck of the hauler to proceed with retrieval operations (Figure 4). As shown in Figure 4, the emergency drift between adjacent emplacement drifts would only be driven if additional ventilation flow capacity for cooling was required.

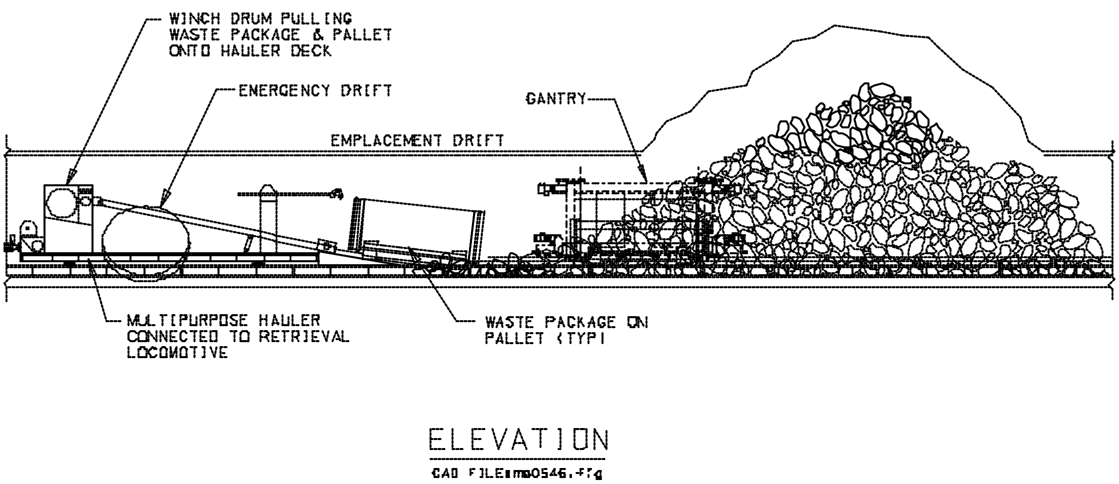

Fig. 4. Multipurpose Hauler

CLOSURE OF A REPOSITORY

Closure Authority

The decision to recommend closure will be based upon completion of an appropriate preclosure performance confirmation monitoring program. To receive approval to close a repository, the DOE must submit a license amendment to the NRC. Information must be provided from the performance confirmation program to support a regulatory decision to close. The intent is to ensure that an adequate basis exists for understanding the postclosure performance of a repository prior to relinquishing the retrieval option and performing closure activities.

Closure Activities

When approval is granted, closure would commence and require a number of years to accomplish. The drip shields would be emplaced over the waste packages, backfill emplaced in access ramps and in perimeter and ventilation drifts, and seals installed in all penetrations to the surface of the mountain. These would include all access shafts and ramps, ventilation shafts, and boreholes. The intent of the closure activity is to isolate the repository from the accessible environment, preclude preferential flowpaths for water into the mountain, and minimize the possibility of purposeful or inadvertent intrusion.

SUMMARY

Maintenance of the retrieval option for radioactive waste from the repository is a regulatory requirement in the U.S. A design is being developed for a proposed repository that provides the capability to retrieve any or all emplaced radioactive waste. Reduction of uncertainties associated with the thermal regime may affect the duration of the preclosure period. Retrieval under normal conditions would be accomplished through the reversal of the emplacement process, but abnormal retrieval is also possible. The extended monitoring capability proposed for a repository does not degrade repository safety and, in fact, extends the potential period of retrievability. Retrieval activities could be initiated at any time prior to repository closure.

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