OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
SPECIAL INSTRUCTION SHEET

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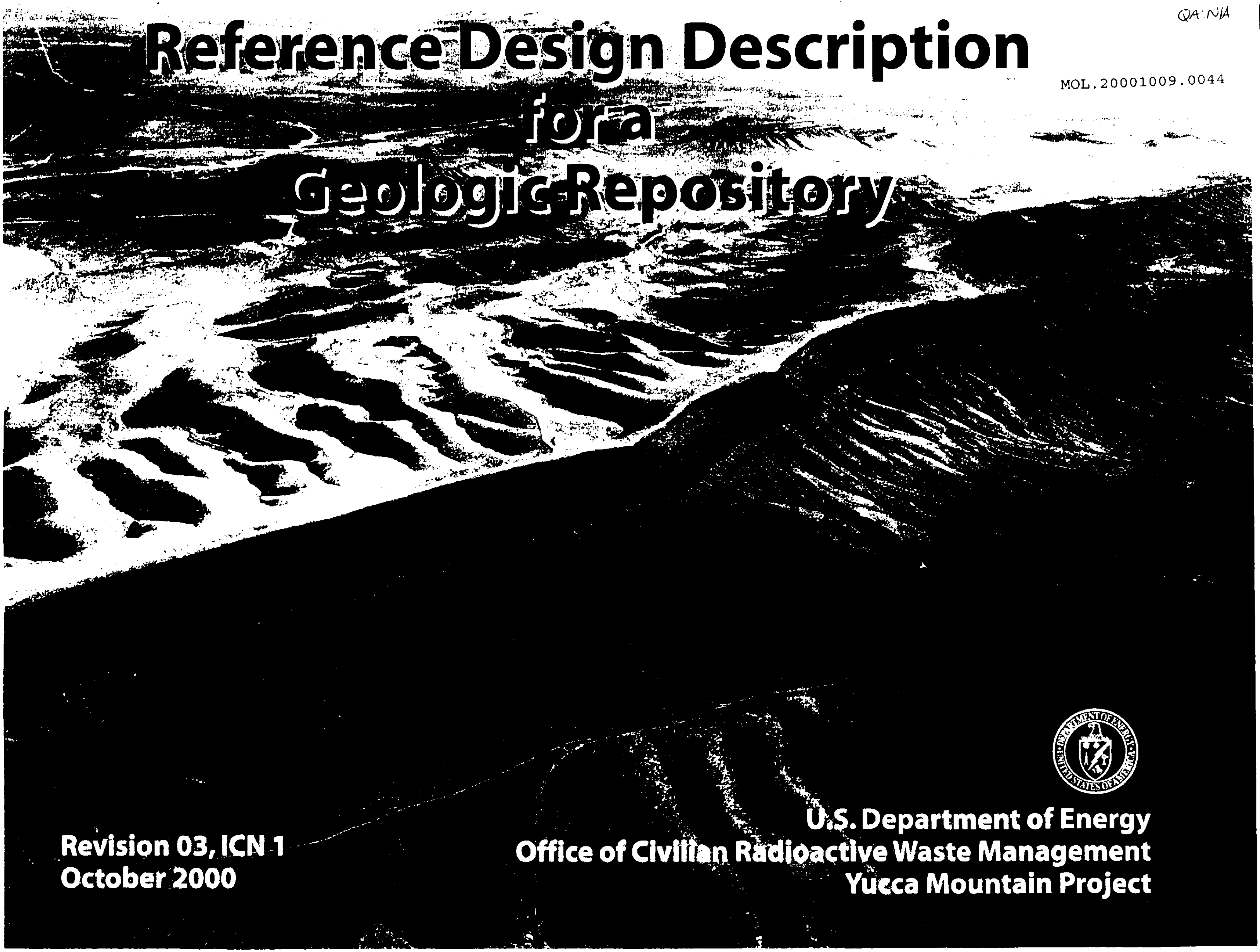

Revision 03, ICN 1
October 2000

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Project

SUMMARY OF CHANGES

Revision Number	Interim Change No.	Description of Change
00	--	Initial issue
01	--	Added Primary Repository Performance Parameters (pages 8 and 9), clarified use of co-disposal container and updated dimensions of the canistered fuel-waste package assembly (page 41), corrected the time period to maintain the option to retrieve in order to be consistent with the Mined Geologic Disposal System Requirements Document (page 43), Waste Emplacement System details expanded/clarified (page 45), updated the EBS Design Options (page 58 and 59) and editorial text/graphic changes.
02	--	Updated to reflect Viability Assessment design.
03	--	Updated to reflect the design presented in the Site Recommendation Consideration Report and to provide a description of the Natural Barrier System.
03	01	Provides updated information on the Subsurface Ventilation System and the Natural Barrier System, and includes minor editorial text/graphic changes.

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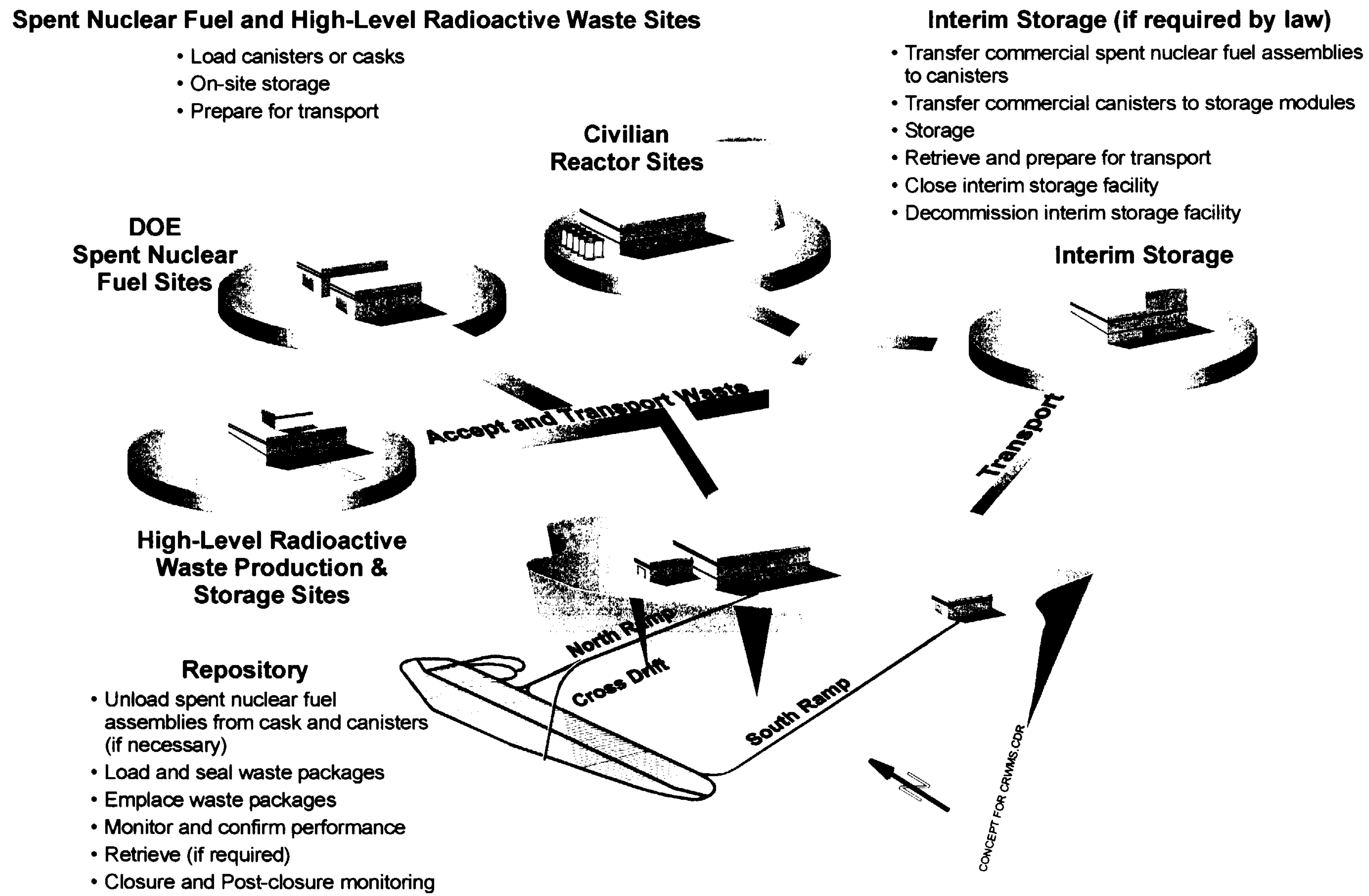
Concept for Civilian Radioactive Waste Management System and Repository



1. INTRODUCTION

One of the current major national environmental problems is the safe disposal of large quantities of spent nuclear fuel and high-level radioactive waste materials, which are rapidly accumulating throughout the country. These radioactive byproducts are generated as the result of national defense activities and from the generation of electricity by commercial nuclear power plants. At present, spent nuclear fuel is accumulating at over 70 power plant sites distributed throughout 33 states. The safe disposal of these high-level radioactive materials at a central disposal facility is a high national priority.

This Reference Design Description explains the current design for a potential geologic repository that may be located at Yucca Mountain in Nevada for the disposal of spent nuclear fuel and high-level radioactive waste materials. This document describes a possible design for the three fundamental parts of a repository: a surface facility, subsurface repository, and waste packaging. It also presents the current conceptual design of the key engineering systems for the final four phases of repository processes: operations, monitoring, closure, and postclosure. In accordance with current law, this design does not include an interim storage option. In addition, this Reference Design Description reviews the expected long-term performance of the potential repository. It describes the natural barrier system which, together with the engineered systems, achieves the repository objectives.

This design will protect the public and the environment by allowing the safe disposal of radioactive waste received from government-owned custodial spent fuel sites, high-level radioactive waste sites, and commercial power reactor sites. All design elements meet or exceed applicable regulations governing the disposal of high-level radioactive waste. The design will provide safe disposal of waste materials for at least a 10,000 year period. During this time interval, natural radioactive decay of the waste materials will result in fission products that pose a minimal radiological hazard to the public afterward. For example, after 100 years, the relative hazard from the waste fission products will have diminished approximately 90 percent. After 1,000 years, the hazard will have diminished 99 percent, and after 10,000 years it will have diminished 99.9 percent. The resulting radiological hazard after 10,000 years is minimal, being of the same order of magnitude as that posed by 0.2 percent uranium ore, which is equivalent to that which was used to originally produce the nuclear fuel.

Because developing such a repository is extremely complex, the design will move forward in three stages: Site Recommendation, License Application, and Construction. This document presents the design as it will be submitted in the Site Recommendation Consideration Report; the design will be updated as the design process moves forward. As more cost-effective solutions, technical advancements, or changes to requirements occur, the design may evolve.

The U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management is developing a system that includes this potential repository. This waste management system integrates acceptance, transportation, storage, and disposal of spent nuclear fuel and high-level radioactive waste. Acceptance and transportation will be handled by regional servicing contractors under contract to the DOE. The U.S. Nuclear Regulatory Commission will conduct an in-depth and thorough licensing review to determine the acceptability of the proposed waste management system.

Eight sections of this document follow. Section 2 discusses the design requirements for the proposed repository. Section 3 describes the physical layout of the proposed repository. Section 4 describes the evolutionary phases of the development of the proposed repository. Section 5 describes the receipt of waste. Section 6 details the various systems that will package the waste and move it below ground, as well as safety monitoring and closure. Section 7 describes the systems (natural and engineered) that ensure continued safety after closure. Section 8 offers design options that may be adopted in the future, and Section 9 provides a summary statement on the repository.

1. INTRODUCTION (CONTINUED)

The design work for the engineering systems described in this document was accomplished using established engineering practices and state-of-the-art technology. Technical design work and scientific activities described in this document were conducted in accordance with quality assurance/quality control requirements outlined in the DOE *Quality Assurance Requirements and Description* document and its associated implementing procedures.

Table 1. Spent Nuclear Fuel and High-Level Waste to be Accepted at the Repository

Type	Amount (MTHM*)
Commercial Spent Nuclear Fuel	63,000
Commercial High-Level Waste	640
Defense High-Level Waste	4,027
DOE Spent Nuclear Fuel	2,333
Total	70,000

*MTHM = metric tons heavy metal

Table 2. Annual Repository Receipt Rates

Year	Commercial Spent Nuclear Fuel (MTHM)	Commercial High-Level Waste, Defense High-Level Waste, and DOE Spent Nuclear Fuel (MTHM)
2010	400	TBD**
2011	600	TBD
2012	1,200	TBD
2013	2,000	TBD
2014	3,000	TBD
2015 to 2031	3,000	TBD
2032	3,000	TBD
2033	1,900	0

** TBD = To Be Determined

2. KEY REQUIREMENTS FOR REPOSITORY DESIGN

The Nuclear Waste Policy Act of 1982, as amended (42 USC 10101 et seq.), and the following federal regulations established the primary requirements governing the design of the potential repository:

- 10 CFR 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories. **NOTE**: The U.S. Nuclear Regulatory Commission has published proposed rule 10 CFR 63, Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada, to replace 10 CFR 60 for the Yucca Mountain repository. The current design is based upon this proposed rule.
- 10 CFR 20, Standards for Protection Against Radiation.
- 29 CFR 1910, Occupational Safety and Health Standards.
- 10 CFR 960, General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories. **NOTE**: The U.S. Department of Energy has published proposed rule 10 CFR 963, Yucca Mountain Site Suitability Guidelines, to replace 10 CFR 960. The current design is based upon this proposed rule.
- 40 CFR 191, Environmental Radiation Protection for Management and Disposal of High-Level Waste. **NOTE**: The United States Environmental Protection Agency has published proposed rule 40 CFR 197, Environmental Radiation Protection Standards for Yucca Mountain, Nevada, to replace 40 CFR 191 for the Yucca Mountain Repository. The current design is based upon this proposed rule.

The potential repository will be designed with sufficient flexibility to accommodate possible future modifications that might result from changing requirements. The current design is intended for an open operational period of approximately 50 to 100 years for waste emplacement and monitoring, but will include provisions that could allow deferral of repository closure and possible waste retrieval for up to 300 years from the initiation of waste emplacement.

All site-generated hazardous, low-level radioactive, and mixed waste will be collected and packaged for transport to other government approved facilities for disposal.

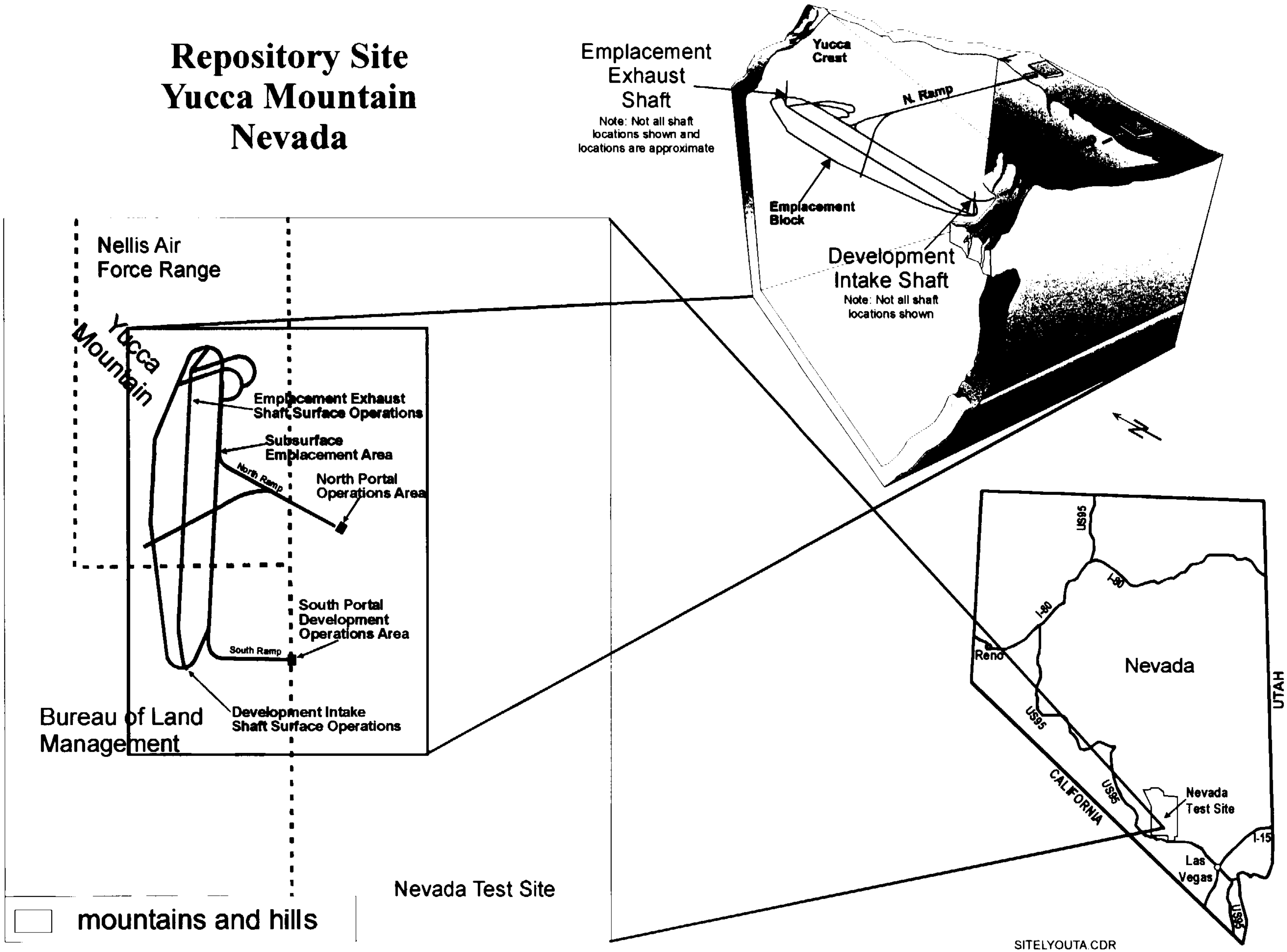
The Yucca Mountain repository will be capable of accepting 70,000 MTHM or equivalent of spent nuclear fuel or high-level waste as shown in Table 1. In Table 2, the annual receipt rates for the repository are specified. The design information presented in this document reflects this 70,000 MTHM disposal capacity, which is the amount presently limited by law (Nuclear Waste Policy Act of 1982). However, the repository design will be capable of expanding the capacity to 118,000 MTHM, should repository requirements and legal constraints change in the future.

The repository will be capable of receiving (by road and/or rail) and packaging (including opening non-disposable canisters) the following types of waste:

- Individual commercial spent nuclear fuel assemblies
- Commercial spent nuclear fuel in disposable canisters (multi-purpose canisters/large canisters)
- Commercial spent nuclear fuel in non-disposable canisters
- DOE and Naval spent nuclear fuel in disposable canisters (large or small canisters)
- Commercial and defense high-level waste, including immobilized plutonium, in small disposable canisters.

The emplacement area will be located below ground. The temperature of the emplacement area will be controlled to preserve the nuclear fuel cladding (the protective metal tubing that encases the fuel-pellet waste form). The temperature will also be controlled to allow free drainage between the emplacement drifts of any possible moisture that may seep into the emplacement area.

Repository Site
Yucca Mountain
Nevada



3. PHYSICAL LAYOUT OF SITE

3.1 REPOSITORY SITE

Yucca Mountain is a potential site for a geologic repository. It is located in an area of uninhabited desert on federal land in Nye County in southern Nevada, about 160 kilometers (100 miles) northwest of Las Vegas. The potential repository will include surface and subsurface facilities.

Engineering concepts will determine the arrangement of surface repository facilities for safe and efficient operations. The following factors are being addressed:

- Subsurface accesses
- Radiological exposure boundaries
- Flood areas, fault zones, and meteorological patterns
- Support for surface and subsurface operations
- Preclosure radiological safety
- Minimization of environmental impact

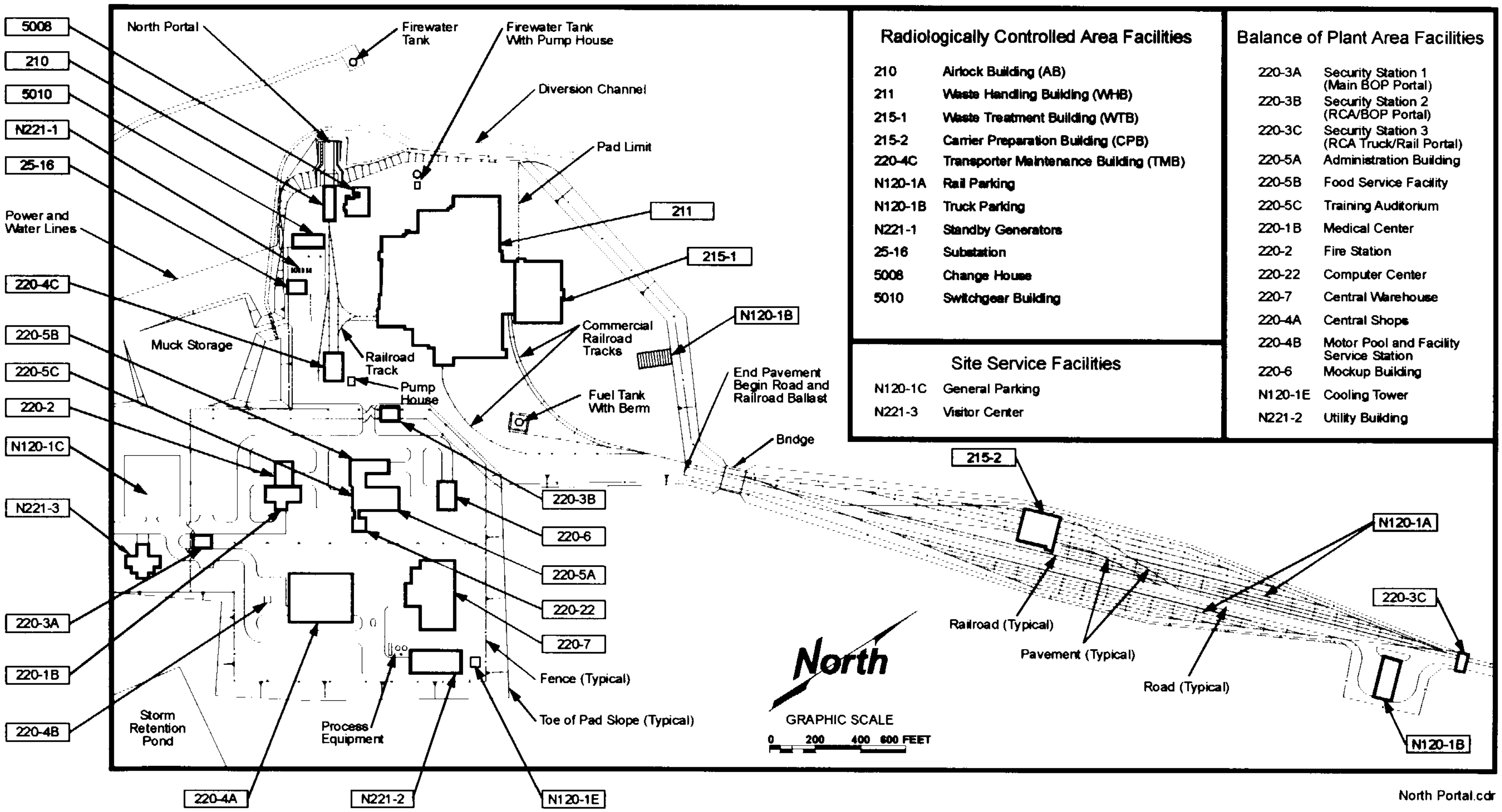
The surface facility location will consist of the following major areas:

- North Portal area: This 150-acre area will contain the radiologically controlled (protected) area (including the nuclear waste handling facilities) and the support facilities detailed in Section 3.2. The waste will be received and packaged in this area.
- South Portal area: This 37-acre area at the southern entrance to the potential repository will support the excavation of the underground area. Facilities for maintenance, warehousing, material staging, security, and transportation will be located here.
- Emplacement exhaust shaft areas: These three-acre sites are located on the surface at the opening of the exhaust shafts. Facilities in these areas will contain the ventilation exhaust fans for waste emplacement operations and support fan maintenance.
- Intake shaft areas: These three-acre sites are located on the surface at the opening to the intake shafts and will have a facility to house the development intake fans and auxiliary hoisting system for excavation operations.

The subsurface facility location will include the North and South Ramps, which will allow access to the emplacement block located in a welded tuff rock formation (a strong consolidated volcanic rock). The emplacement area will be located in the unsaturated region (above the water table) of the site. The potential site for the emplacement area location is bounded by geologic faults, but it was chosen, in part, because investigations indicated that the emplacement area itself is free of significant faults.

The waste will be placed in underground drifts (horizontal excavations) located in the emplacement block area. High-level radioactive waste packages will be placed in the drifts between the commercial spent nuclear fuel packages. The distance between the drifts and the spacing of the waste packages within the drifts will be established to meet thermal objectives. These objectives include keeping nuclear fuel cladding below 350°C (662°F), providing the flexibility of operating the repository at a temperature that can be either above or below the boiling point of water, and allowing drainage of any potential water between the emplacement drifts.

North Portal Repository Area Site Plan Above Ground



3.2 NORTH PORTAL AREA

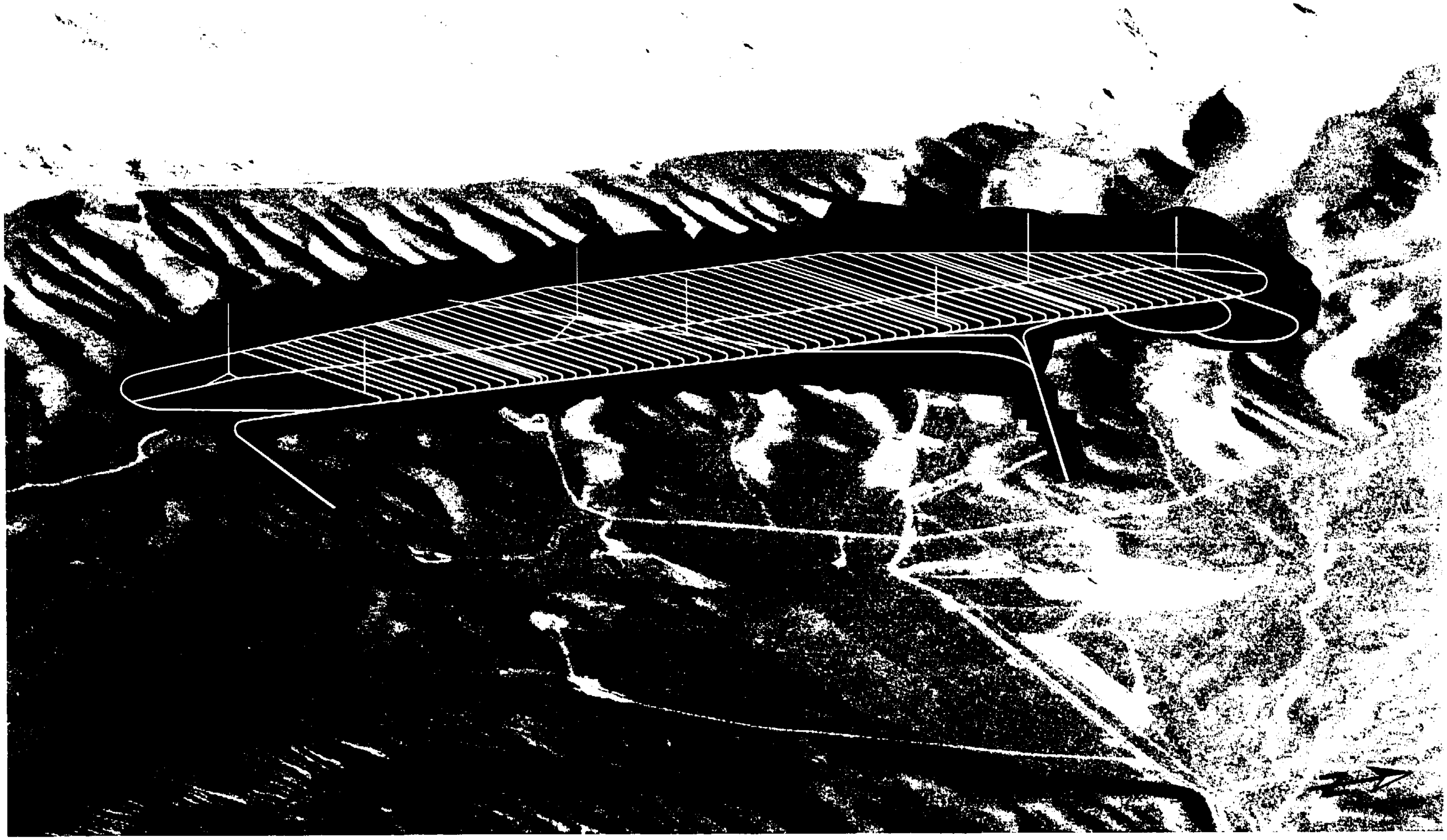
In a 150-acre area located at the northern entrance (North Portal) of the potential repository, waste materials will be received and packaged for emplacement. Radioactive materials will be processed in the radiologically controlled area, and support activities will be carried out in the remaining areas.

A radiologically controlled area will include the following facilities:

- Waste Handling Building, where spent nuclear fuel assemblies and disposable waste canisters will be put into disposal containers
- Waste Treatment Building, where low-level waste will be treated for off-site disposal
- Transporter Maintenance Building, where vehicles used to transport and emplace waste will be serviced
- Airlock Building for ventilation during construction and operations
- Carrier Preparation Building, where shipping casks will be prepared for removal from rail or truck carriers
- Carrier Washdown Building, where carriers are cleaned
- Parking areas for rail cars and truck/trailers
- Facilities for housing and supporting standby generators
- Existing electrical substation
- Standby Generators
- Existing Switchgear Building
- Existing Change House

The balance of the area includes the following facilities: security stations, administration building, food service facility, training auditorium, fire station, medical and computer centers, central warehouse, central shops, water tanks, motor pool and facility service station, mock-up building, cooling tower, utility building, visitor center, and general parking area.

Subsurface Facility



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3.3 SUBSURFACE FACILITY

The subsurface facility will include main tunnels, accesses, alcoves, and widely-spaced emplacement drifts. The facility's physical location, general arrangement, and the mountain's natural geologic barrier support long-term waste isolation. The subsurface facility provides for initial isolation of the waste by locating the emplacement drifts away from major faults and above the water table.

The subsurface facility includes:

- Two inclined access ramps
- Six or more vertical ventilation shafts
- Waste emplacement block with:
  - Service main drifts
  - Exhaust main drift
  - Waste emplacement drifts
  - Performance confirmation drifts

The ramps, shafts, and service and exhaust drifts will be backfilled and sealed during the closure phase.

The waste emplacement drifts will be located at a depth greater than 200 meters (660 feet) below the surface, and from about 200 meters (660 feet) to 400 meters (1,320 feet) above the water table. The drifts will accommodate about 11,000 waste packages in a line load thermal configuration (straight line of nearly adjacent waste packages). The waste emplacement drifts will run in an approximate east-west direction. A total of about 60 kilometers (37 miles) of drifts will be mined in an area of approximately 1,100 acres.

The facility will have two types of main drifts that will be mechanically excavated by a tunnel boring machine:

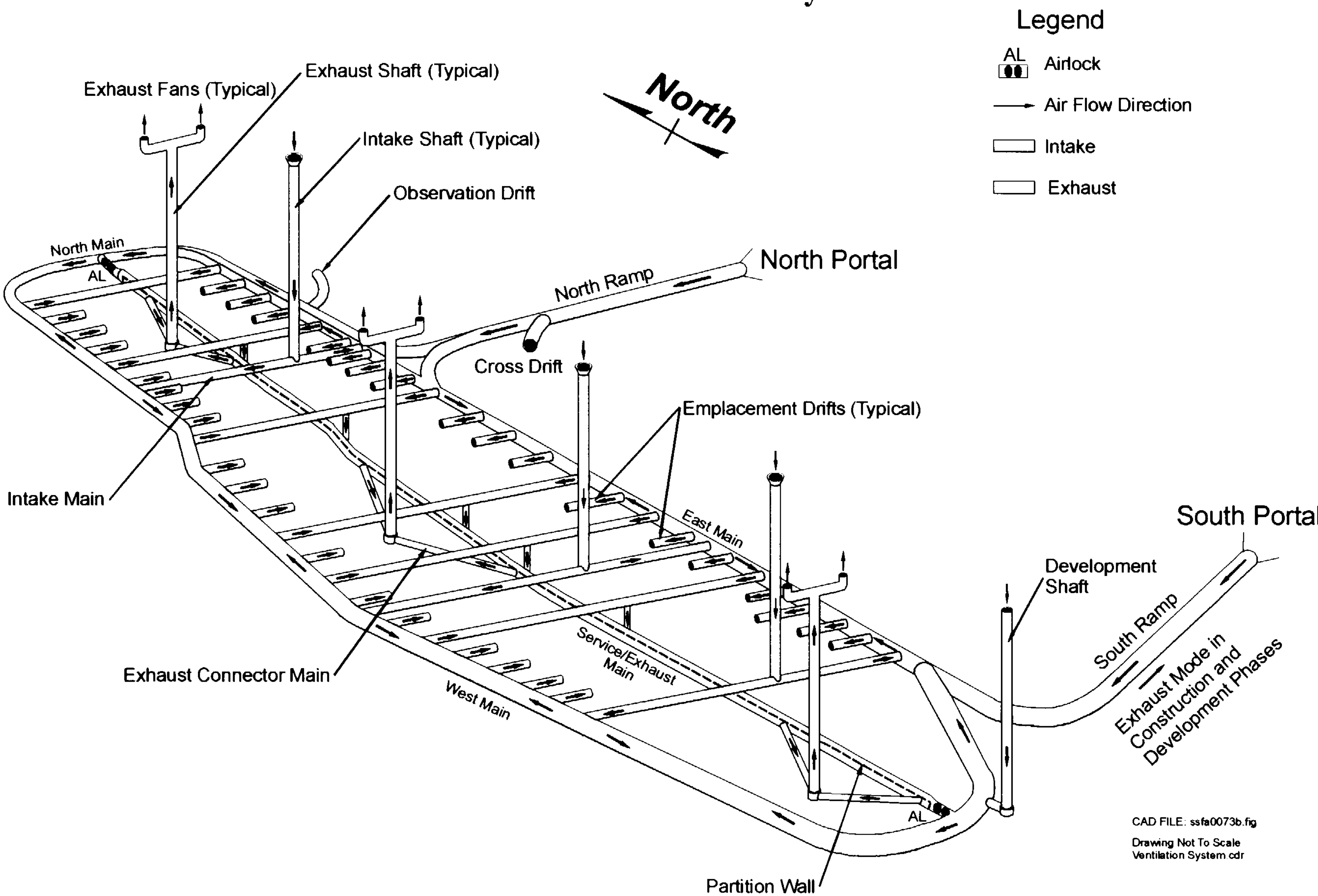
- The service main drifts (including ramps) for access will have the following features:
  - 7.6 meters (25 feet) in diameter
  - Maximum grade of 2.6 percent on the South Ramp to accommodate rail transport during construction, and 2.2 percent on the North Ramp for emplacement transportation -- the North and South Ramps have already been constructed
- The exhaust main drift for ventilation will have the following features:
  - 7.6 meters (25 feet) in diameter
  - Location 10 meters (33 feet) below the emplacement drifts
  - Connection to emplacement drifts by a series of ventilation raises (small shafts)

Individual waste emplacement drifts also will be excavated mechanically and will have the following features:

- 5.5 meters (18 feet) in diameter
- 81 meters (266 feet) spacing between centers of emplacement drifts (can be changed for thermal reasons)
- 800 meters (2625 feet) to about 1300 meters (4265 feet) in overall length with a raise from the exhaust main drift near the center of the emplacement drift
- Remotely controlled doors at the entrances to control access
- Raised floor above the main drift to allow a waste package to be off-loaded directly out of the transporter in preparation for emplacement

Approximately 10 percent of the emplacement drifts will be completed before beginning waste emplacement operations. The remaining 90 percent will be completed in phases contemporaneous with waste emplacement operations.

Subsurface Ventilation System



3.4 SUBSURFACE VENTILATION SYSTEM

The Subsurface Ventilation System will support operation of the subsurface repository by providing:

- Air to personnel during the emplacement period
- Limited temperature control of the underground facility operations areas based on airflow volume and outside air temperature
- Cooling of the emplacement drifts to meet thermal goals

The development (drift excavation) and waste emplacement operations will be physically separated from each other; each area will have its own ventilation system and ramp access. The system will consist of ducting, fans, seals, and electronic controls. It will interact with the surface for air intake and exhaust, electric power, and monitoring. Most major equipment will be located above ground.

During emplacement operations, drifts will continue to be excavated without interfering with waste emplacement. Two separate, independent ventilation systems will operate simultaneously during this period. One system will provide ventilation for the excavation operations required to develop the emplacement drifts, while the other will supply air to the waste emplacement operations. Temporary walls (isolation air locks) in the main drifts at the points that divide the two sides will separate ventilation of the two systems. These temporary walls will be moved to new points in the main drifts to provide access to newly excavated drifts for waste emplacement.

The ventilation system on the subsurface development (excavation) side will:

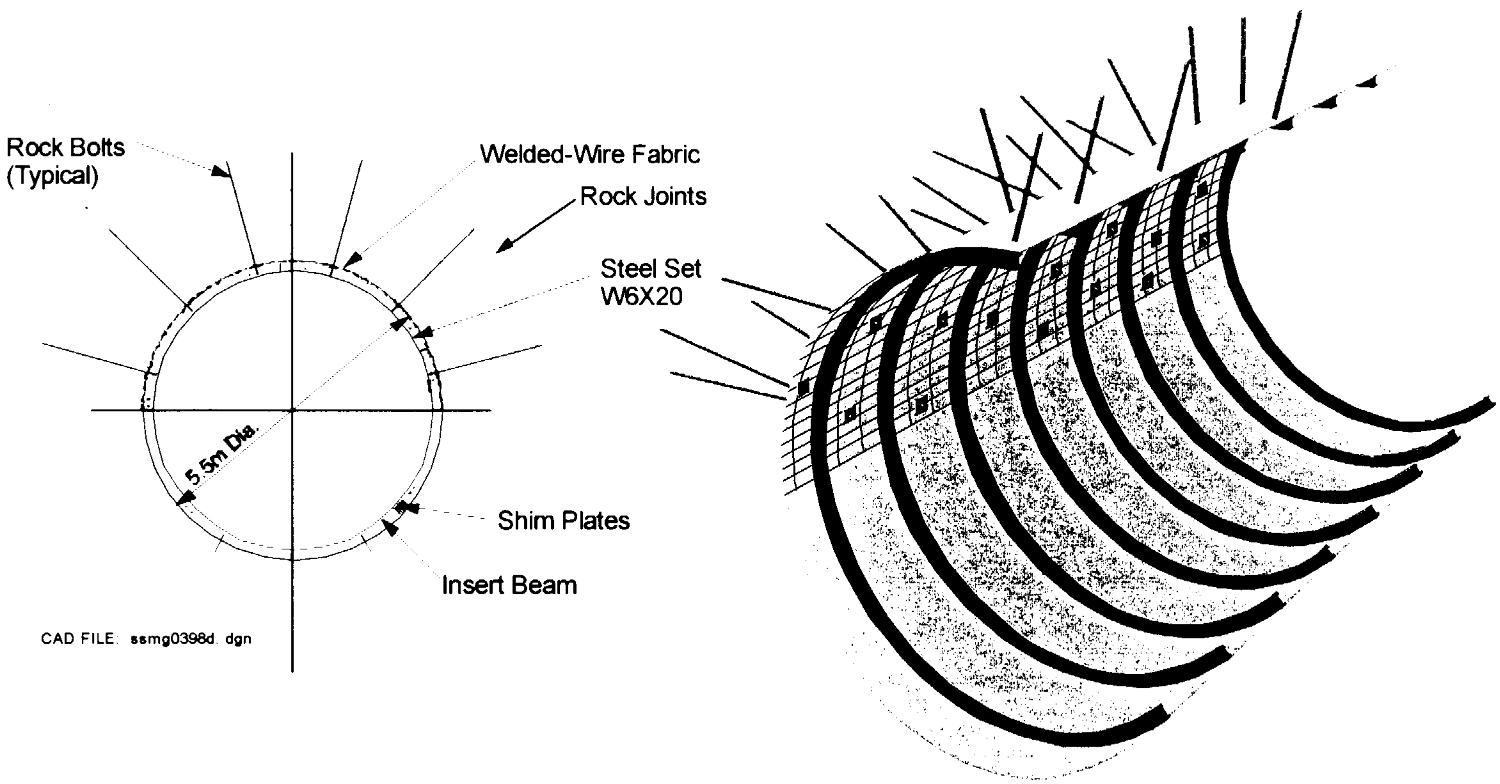
- Force air into the subsurface excavation drifts by way of fans at the intake shafts
- Exhaust air through the South Ramp and exhaust shafts
- Maintain air pressure on the excavation side above the air pressure on the emplacement side

The ventilation system on the emplacement side will:

- Pull air into the North Ramp and intake shafts for emplacement areas using fans in the exhaust shafts
- Exhaust the air through the exhaust shafts
- Maintain a lower air pressure than on the excavation side of the subsurface layout

This ventilation arrangement will ensure that in the event of a failure on either side, the pressure differential between development and emplacement areas will be maintained. Thus, any possible radioactive releases will be restricted to the emplacement side.

Ground Control System



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3.5 GROUND CONTROL SYSTEM

The Ground Control System will provide for the safe construction and operation of the subsurface facility (main and waste emplacement drifts). It consists of a concrete lining in the main drifts, and steel sets and rock bolts for structural support in the emplacement drifts.

For the open operational lifetime of the repository (50 to 100 years), the maintenance philosophy for underground openings is to have robust ground support so that routine maintenance of the drifts will not be necessary once the waste packages are emplaced. For those shafts, ramps, main drifts, and observation drifts (Performance Confirmation drifts) that do not have high temperatures or radiation levels during normal operations, periodic, planned maintenance will be performed. With appropriate maintenance and monitoring, the operational lifetime of the repository could remain open for up to 300 years for possible waste retrieval.

The Ground Control System will consist of the structures installed within the excavated openings or reinforcement made to the rock surrounding the openings. Two ground control systems are used for the emplacement drifts. The current design uses full circle steel sets (with wire fabric) in approximately 70 percent of the total length of the emplacement drifts, ventilation drifts, and other drifts. Where required (in approximately 30 percent of the drifts), the ground support will include fully grouted rock bolts in addition to the steel sets and fabric. The type of ground control support used in any given section of a drift or ramp will depend upon the specific rock properties of that particular section.

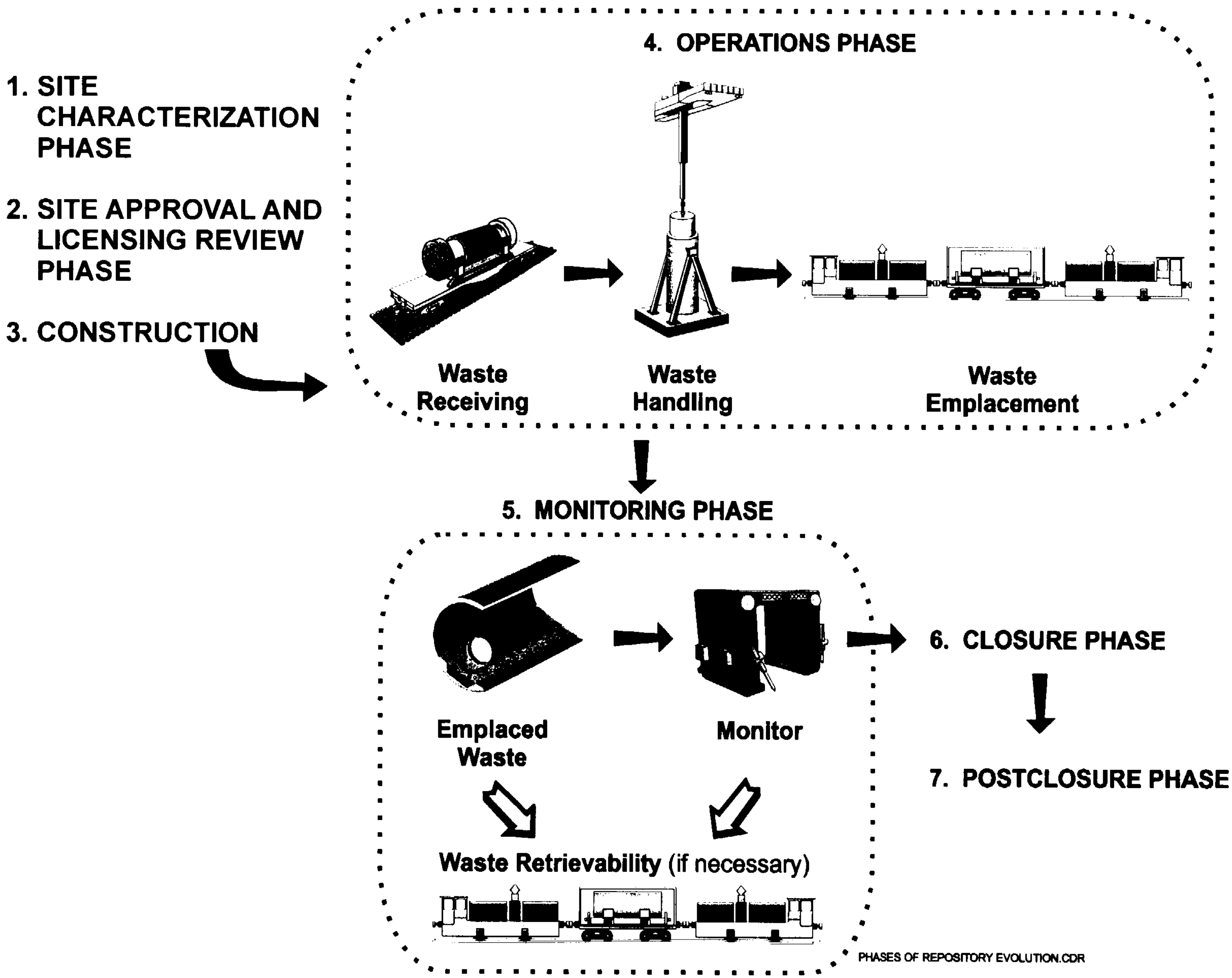
Cast-in-place concrete linings are currently planned only for the access ramps and main drifts.

The details of the Ground Control System will be determined for each specific application. The Ground Control System will be designed to:

- Provide a robust support system with minimal maintenance requirements
- Maintain stable underground openings under the range of anticipated conditions, during the operations and monitoring phases, and during closure
- Facilitate mapping of the rock mass in selected areas

Regarding the concrete lining in the main drifts, special types of concrete are being evaluated to minimize any chemical reaction between the concrete and any possible moisture within the repository environment.

Phases of Repository Evolution



4. PHASES OF REPOSITORY EVOLUTION

Of the seven phases that comprise the evolution of the potential repository, six are explained below: site characterization, site approval and licensing review, construction, operations, monitoring, and closure; the seventh phase, postclosure, is explained in Section 7.

4.1 SITE CHARACTERIZATION PHASE

The Yucca Mountain project is currently in the site characterization phase. This phase includes gathering and evaluating data to provide a basis for a site recommendation decision and, if warranted, prepare a License Application. The Exploratory Studies Facility was constructed during this phase to help evaluate the suitability of Yucca Mountain as the location of a geologic repository.

4.2 SITE APPROVAL AND LICENSING REVIEW PHASE

This phase follows site characterization. It begins after the Secretary of Energy reviews the Site Recommendation Report and recommends the site for the development of a repository to the President. If recommended, and Congress approves the site, the DOE will submit a license application to the U.S. Nuclear Regulatory Commission for construction of the repository. The U.S. Nuclear Regulatory Commission will then review the license application and, if satisfactory, may authorize construction of a geologic repository at the Yucca Mountain Site.

4.3 CONSTRUCTION PHASE

The construction phase will begin after receiving a construction authorization from the U.S. Nuclear Regulatory Commission. It includes building and equipping the surface facilities, modifying the Exploratory Studies Facility to become one of the main service drifts, continuing excavation and equipping of subsurface facilities, manufacturing of disposal containers, demonstrating repository operations, and gathering data to verify repository performance predictions.

4.4 OPERATIONS PHASE

The operations phase consists of three major activities: waste receiving, waste handling, and waste emplacement. During repository operations, additional activities will include developing the emplacement drifts and manufacturing disposal containers for the waste materials.

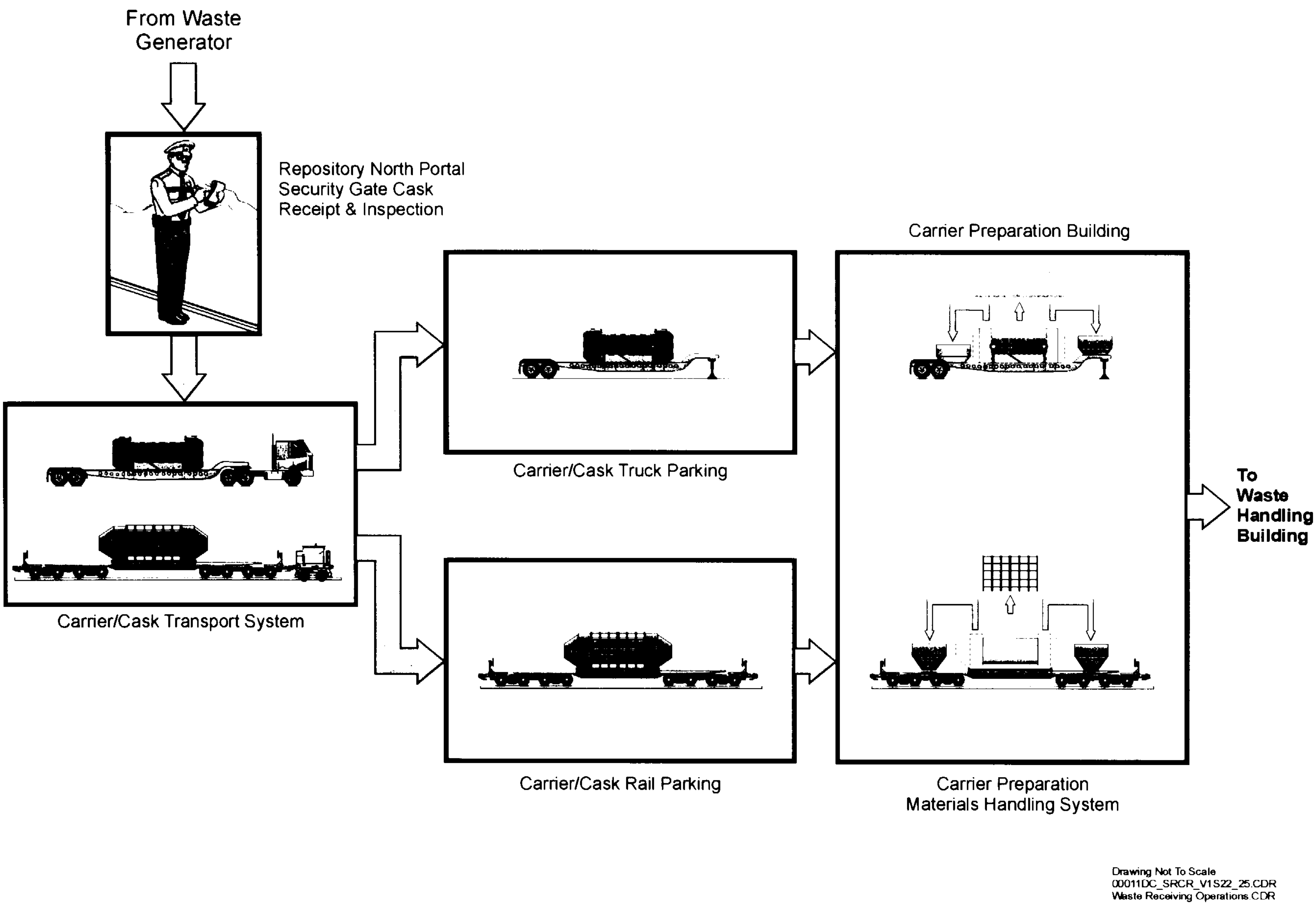
4.5 MONITORING PHASE

Monitoring will continue after all waste packages have been emplaced. This will include continuing to collect and analyze data to confirm predicted repository performance, as well as to maintain the subsurface facility. The capability to retrieve the waste packages will also be maintained.

4.6 CLOSURE PHASE

The closure phase will begin after the license amendment to close the repository has been received from the U.S. Nuclear Regulatory Commission. Closure will include placing drip shields over the waste packages and backfilling and sealing access openings. The surface facilities will be decontaminated and dismantled. The surface area will be restored in accordance with U.S. Nuclear Regulatory Commission requirements, and the repository will be protected from future unauthorized intrusions.

Waste Receiving Operations



5. WASTE RECEIVING OPERATIONS

The potential repository will receive high-level radioactive waste and spent nuclear fuel in shielded shipping casks, which will be licensed for nuclear waste transport by the U.S. Nuclear Regulatory Commission, and transported on rail or highway carriers. The shipments will pass through a security station and receive a receipt and security inspection before entering the radiologically controlled area near the North Portal. After the inspection, an on-site vehicle (prime mover) will move the shipment to carrier/cask parking for either truck or rail carriers in the controlled area.

Once on site, the Carrier/Cask Transport System will handle the shipment. The shipment will be moved to the Carrier Preparation Building, which will support the preparation and inspection of waste transportation casks before they enter the Waste Handling Building. The building, a single-level metal structure with about 1,900 square meters (20,000 square feet) of floor space, will contain the Carrier Preparation Materials Handling System. The building will house:

- Two staging bays for truck or rail carriers
- Work platforms
- Two 15-ton bridge cranes
- Two bridge-mounted manipulators
- An office area

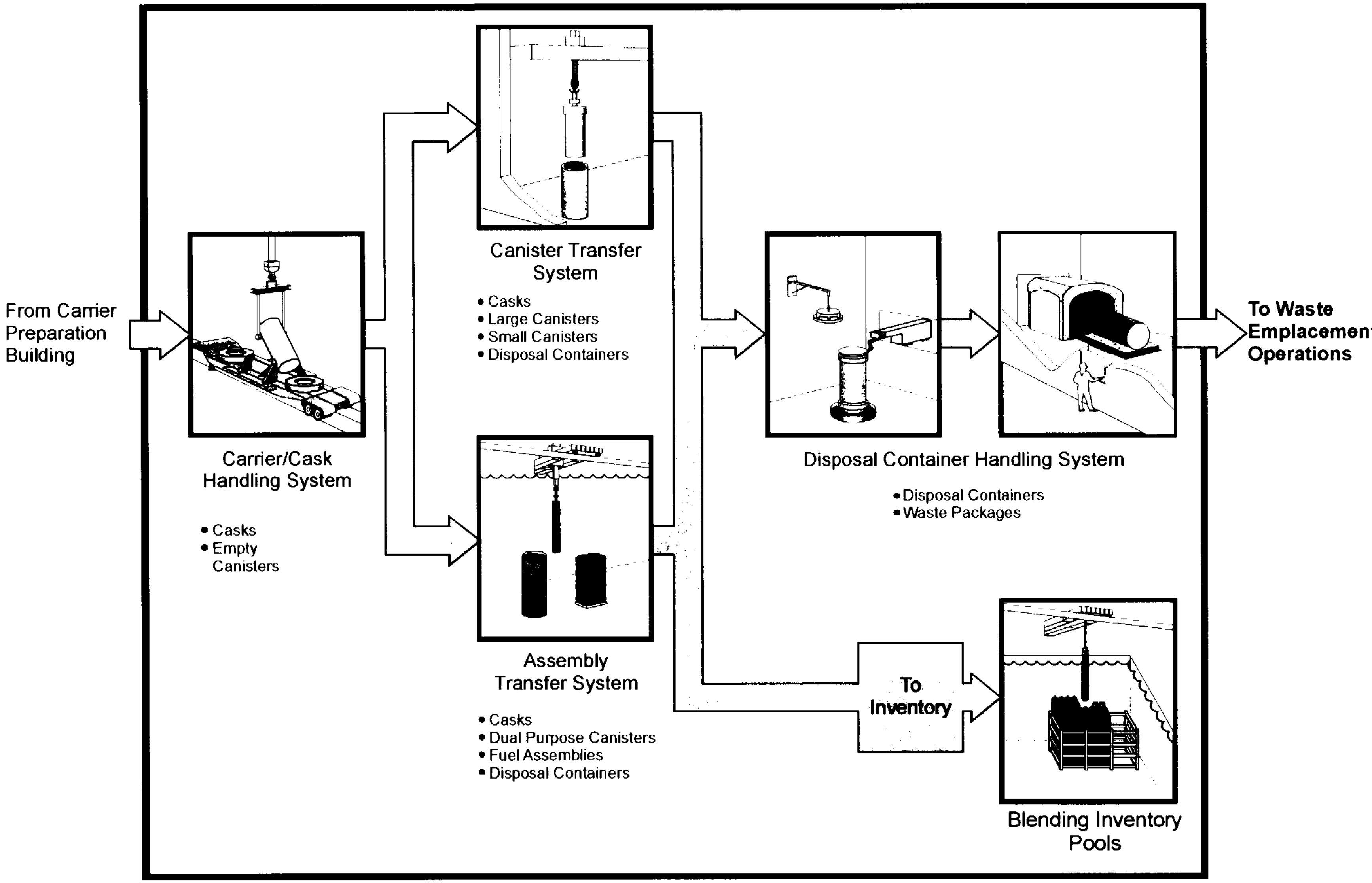
The Materials Handling System will receive and inspect shipping casks, then prepare the casks for unloading in the Waste Handling Building; the system will:

- Remove or retract the shipping personnel barriers from the cask
- Perform a radiological survey
- Remove the shipping cask impact limiters

When the carrier and cask have been prepared for cask removal, and the Waste Handling Building is ready to receive a waste shipment, the Carrier/Cask Transport System will move the carrier and cask to the Waste Handling Building.

After waste removal, the carrier with the empty cask will be prepared for shipping–including decontamination to meet applicable radiation protection standards–and will be moved from the Waste Handling Building back to the Carrier Preparation Building. The impact limiters and personnel barriers will be reinstalled. The carrier and empty cask will be returned to the carrier/cask parking area for removal from the repository.

Waste Handling Operations



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6. WASTE HANDLING OPERATIONS

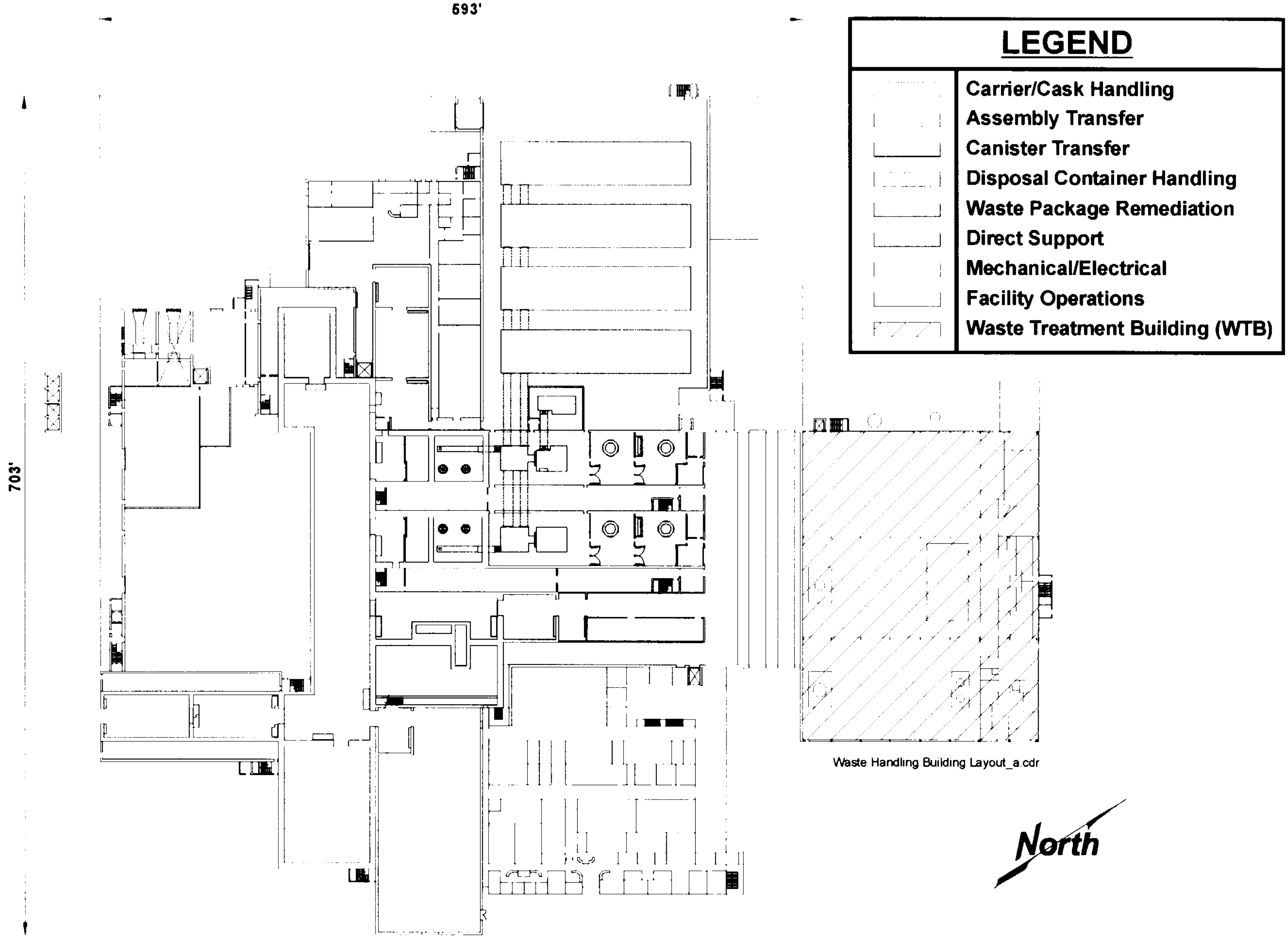
Once the cask has been prepared for removal from the carrier, the loaded shipping casks will be transported to the Waste Handling Building near the North Portal. The waste will then be transferred to disposal containers, welded closed, inspected, and loaded into an underground transporter. The Waste Handling Building will house a variety of support systems to provide a secure, controlled environment that protects the workers and confines potential contamination. Most waste handling operations will be remotely controlled to protect workers. Operations will be performed in the Waste Handling Building by the four systems listed below.

- The **Carrier/Cask Handling System** will remove loaded casks from the truck and rail carriers and place empty casks and empty dual-purpose canister overpacks on carriers. Depending upon the cask's contents, the handling system will move it to one of two transfer systems.
- The **Assembly Transfer System** will receive spent nuclear fuel assemblies in casks and dual-purpose canisters and transfer the assemblies to disposal containers or to a blending inventory pool for later loading into a disposal container.
- The **Canister Transfer System** will receive casks containing waste in disposable canisters and transfer the canisters to disposal containers.
- The **Disposal Container Handling System** will purge the disposal containers with an inert gas and then weld the lids onto disposal containers. It will then load the waste packages (loaded and sealed disposal containers) into a shielded transporter for transport to the subsurface for emplacement.

The **Waste Package Remediation System** will sample and inspect retrieved waste packages and repair or open waste packages that are off-normal or recovered for performance checking.

The locations of these systems within the Waste Handling Building are illustrated in Section 6.1 of this document.

Waste Handling Building Systems Layout (Ground Level)



6.1 WASTE HANDLING BUILDING

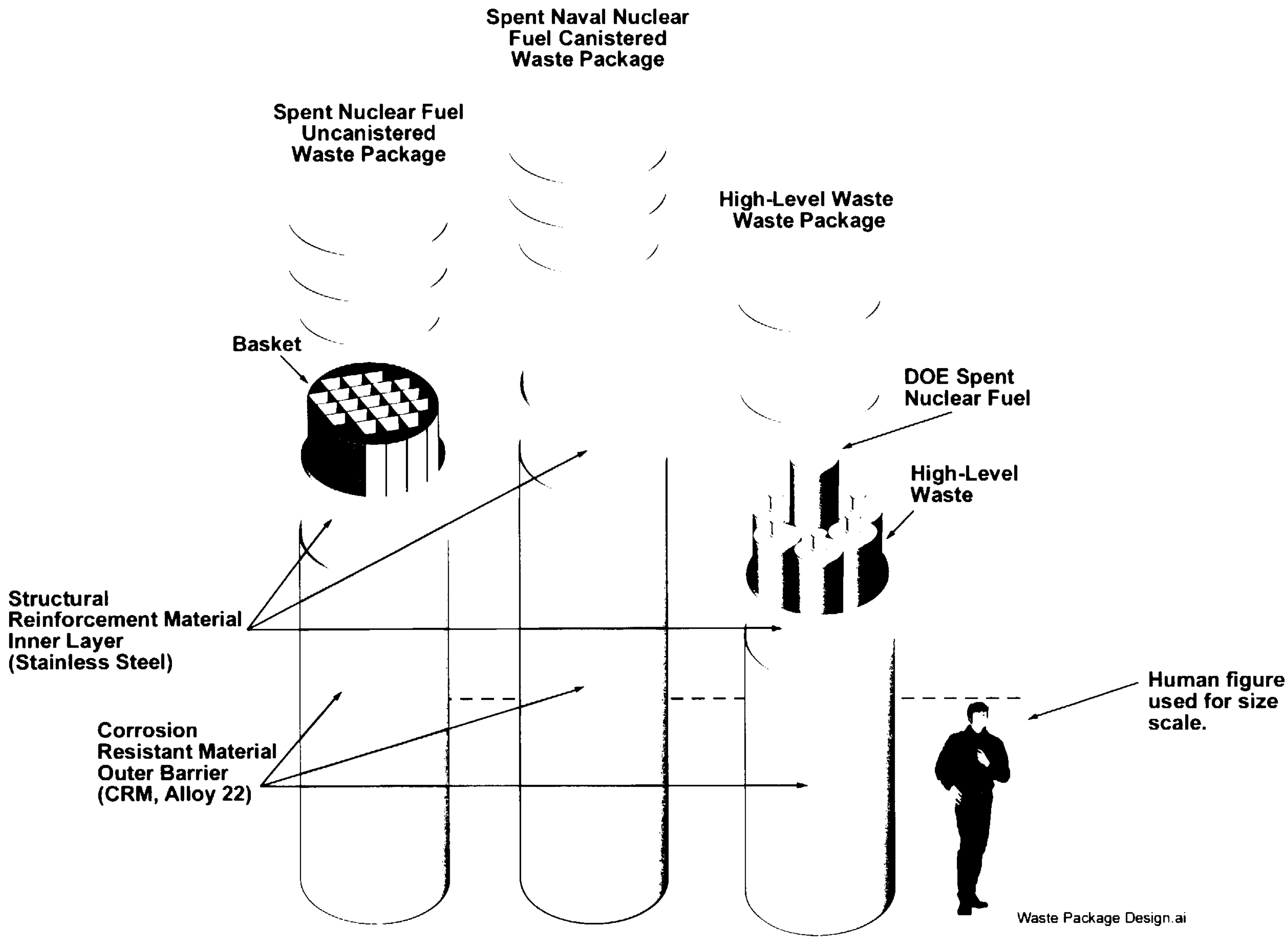
The Waste Handling Building will provide the facilities and equipment for preparing radioactive materials for emplacement in the repository. The building will house the Carrier/Cask Handling System, Assembly Transfer System, Canister Transfer System, Disposal Container Handling System, and the Waste Package Remediation System. It will also contain electric, security, fire protection, ventilation, communications, and radiological monitoring systems. The Waste Handling Building will provide a controlled environment for dry and wet handling operations. It will confine contamination and provide radiological protection for personnel and the public. To the greatest degree practicable, the design and operating concepts for the facility will incorporate equipment and procedures already approved by the U.S. Nuclear Regulatory Commission and in use at other licensed nuclear facilities.

The Waste Handling Building will include the waste handling areas, staging areas, support areas, and features described below:

- Multilevel concrete and steel structure
- About 60,000 square meters (650,000 square feet) of usable floor space
- One large bay for loading and unloading truck and rail carriers
- Two assembly transfer system lines, each with a cask preparation and decontamination area, a pool for unloading and staging assemblies, and a fuel assembly handling cell for loading individual assemblies into disposal containers
- Four fuel blending inventory pools for staging and aging fuel assemblies, and one pool for nonstandard fuel
- One canister transfer line with a cask preparation and decontamination area, and one canister transfer cell for transferring canisters into disposal containers
- One large cell for handling, staging, and welding disposal containers
- One small cell for loading a waste package onto an underground transporter
- One general purpose recovery cell for remediating off-normal waste packages
- Operating galleries to view and control transfer and handling operations
- Maintenance areas for contaminated equipment
- Laboratories, mechanical equipment rooms, electrical equipment rooms, and tooling and maintenance store rooms
- Support areas for administration, personnel, central control, and security access controls
- A large work area for empty disposal container receiving, preparation, and staging

In some staging areas, handling operations will be carried out underwater in pools using remote handling equipment to protect operators from radiation. Operations involving spent nuclear fuel assemblies, canisters, and disposal containers will also be conducted remotely in shielded dry cells to protect workers. The remote equipment will be designed for ease of decontamination and maintenance. Interchangeable components will be provided where possible. Remotely operated equipment will be either manually or automatically controlled.

Representative Waste Package Designs



6.2 GENERAL WASTE PACKAGE DESIGNS

The waste packages will be designed to support the containment and isolation of the waste forms in the potential geologic repository. All of the waste packages in the repository will be fundamentally similar cylindrical containers composed of an inner metal layer for structural strength, and an outer corrosion-resistant barrier. Waste package configurations will differ because they will contain different waste forms, which include commercial spent nuclear fuel, DOE spent nuclear fuel (including naval spent nuclear fuel), and high-level radioactive waste.

The inner cylinder will be composed of stainless steel (Grade 316NG) with a nominal thickness of 5 cm. The outer cylinder will be made of a corrosion-resistant nickel-based alloy (Alloy 22) with a thickness ranging from 2.0 to 2.5 cm. The corrosion-resistant material protects the underlying structural material from corrosion, while the structural material supports the thinner, corrosion-resistant material. The waste package physical dimensions range from about 3.5–6.1 meters in length, 1.3–2.1 meters in diameter, and 21,000 kg–71,000 kg with loaded waste.

An analysis to determine the most efficient set of waste package designs based on varying the number of spent fuel assemblies per waste package, while adjusting the methods of criticality (a self-sustaining nuclear reaction) control and thermal management, resulted in the selection of a set of five waste package designs as the most efficient means of accommodating the anticipated waste stream of commercial spent nuclear fuel. A similar process also led to a set of five designs for the DOE spent nuclear fuel, including the naval fuel, and the DOE and commercial high-level radioactive waste. A brief description of these designs is provided in Table 3.

Table 3. Waste Package Designs

Waste Package Design	Description
21-PWR Absorber Plate	Capacity – 21 commercial PWR assemblies and absorber plate for preventing criticality.
21-PWR Control Rods	Capacity – 21 commercial PWR assemblies with higher reactivity that requires additional criticality control provided by the placement of control rods in all assemblies.
12-PWR Absorber Plate	Capacity – 12 commercial PWR assemblies and absorber plate for preventing criticality; longer than the PWR assemblies placed in the 21-PWR packages. Because of the smaller capacity, may also be used for fuel with higher reactivity or thermal output.
44-BWR Absorber Plate	Capacity – 44 commercial BWR assemblies and absorber plate for preventing criticality.
24-BWR	Capacity – 24 commercial BWR assemblies with higher reactivity that requires a thicker absorber plate for preventing criticality than used in the 44-BWR design.
5-DHLW/DOE SNF	Capacity – 5 short high-level radioactive waste canisters and 1 short DOE SNF canister. When high-level radioactive waste includes immobilized plutonium canisters, no DOE SNF in center.
5-DHLW/DOE SNF Long	Capacity – 5 long high-level radioactive waste canisters and 1 long DOE SNF canister.
2-MCO/2-DHLW	Capacity – 2 DOE multi-canister overpacks and 2 long high-level radioactive waste canisters.
Naval SNF	Capacity – 1 short naval SNF canister.
Naval SNF Long	Capacity – 1 long naval SNF canister.

NOTE: BWR = boiling water reactor; DHLW = defense high-level radioactive waste; MCO = multi-canister overpack; PWR = pressurized water reactor; SNF = spent nuclear fuel.

6.3 COMMERCIAL WASTE PACKAGE DESIGNS

The size of spent nuclear fuel assemblies is used to determine the size and configuration of the fuel within the waste package. The thermal output and reactivity of the spent nuclear fuel is used to determine which waste package can accommodate each given fuel assembly.

Internal interlocking plates of the waste package set the pattern for how the fuel assemblies will be arranged inside the waste package. The interlocking plates are tailored to provide fuel-basket structural strength to maintain geometry and to prevent criticality. The interlocking plates for the designs that include an absorber plate are made of stainless steel and a boron alloy, and for the designs that do not have the absorber plate, the interlocking plates are made of ASTM 516 Grade 70 carbon steel.

Commercial spent nuclear fuel cladding contributes to waste isolation. The cladding is a thin metal tube that encases the fuel-pellet waste form and delays any contact with water, thus retarding any dissolution of the waste and subsequent release of radionuclides. The thermal design of the waste package limits temperatures and protects the integrity of the cladding. The cladding is designed and fabricated to perform in the harsh reactor environment where pressures can exceed 14 MPa (2,000 lbs/in^2) and fuel cladding temperatures can reach 371°C (700°F).

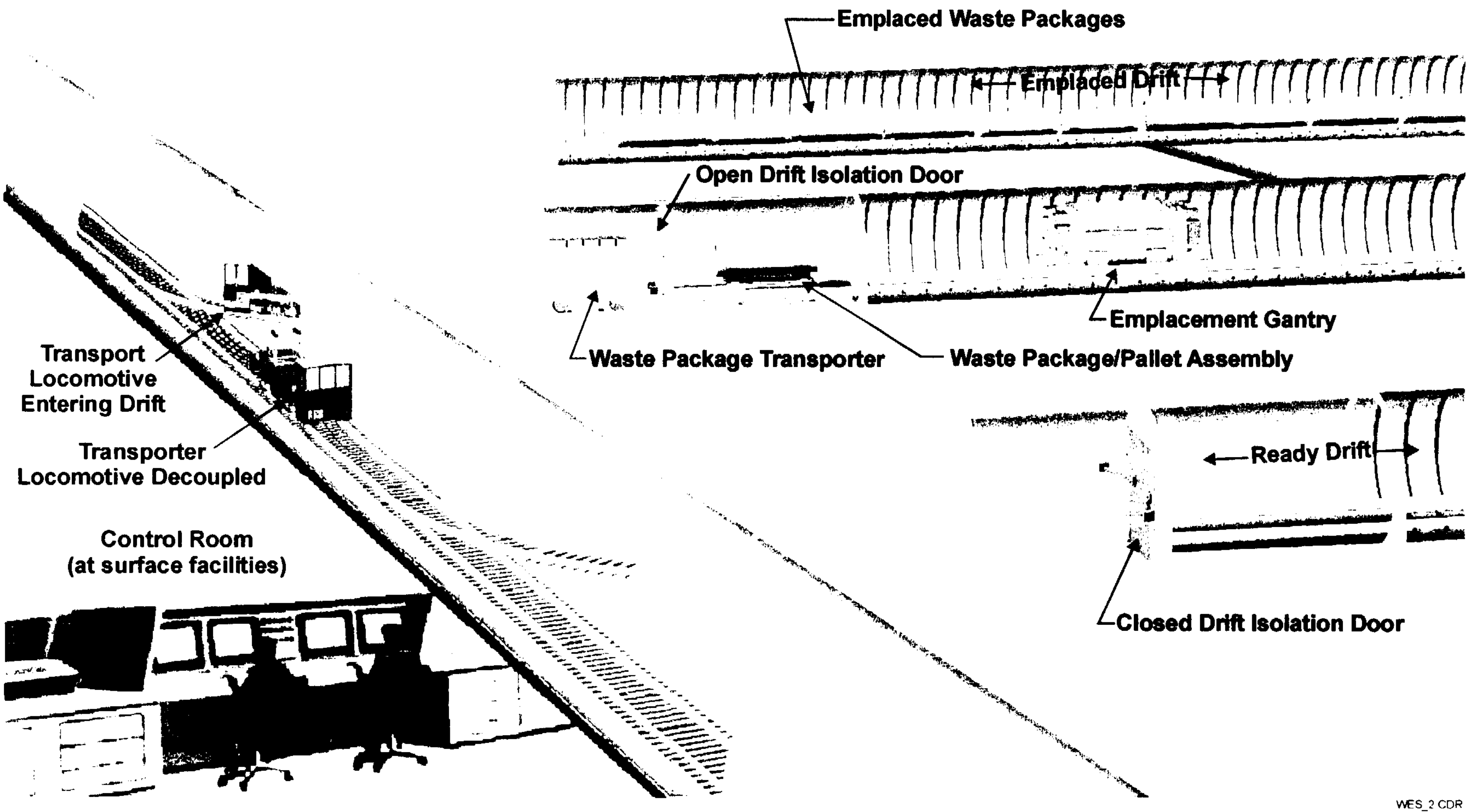
6.4 DOE SPENT NUCLEAR FUEL AND CO-DISPOSAL WASTE PACKAGE DESIGNS

DOE spent nuclear fuel and high-level radioactive waste will be packaged together. Three waste package design configurations for co-disposal have been developed for the DOE wastes. In two designs that differ only in length, the packing arrangement places a DOE spent nuclear fuel canister in the empty space in the center of a ring of five high-level radioactive waste canisters. High-level radioactive waste canisters containing immobilized plutonium will also be placed into the co-disposal type of waste package.

The third waste package design will accept multi-canister overpacks and will have a diameter larger than that of either the canisters for DOE high-level radioactive waste or spent nuclear fuel. To prevent criticality, a maximum of two multi-canister overpacks will be put into a waste package. To improve the packaging efficiency without compromising criticality prevention, two long high-level radioactive waste canisters will be co-disposed with the two multi-canister overpacks.

Naval spent nuclear fuel will arrive at the repository in canisters suitable for disposal. The canisters will fit one to a waste package. Because the naval waste will arrive in canisters of two sizes (one short and one long), two waste package designs based on canister length are needed for the naval spent nuclear fuel. The larger of these two waste package types will be the heaviest and the longest of all the waste packages. No additional features to the waste package design are necessary for structural support, heat transfer, and criticality control, because the waste form and canister already provide these features.

Waste Emplacement System



6.5 WASTE EMPLACEMENT SYSTEM

The Waste Emplacement System will transport the loaded and sealed waste packages, each placed on its dedicated emplacement pallet, from the Waste Handling Building to the emplacement area, which contains the emplacement drifts. Both the waste package and the pallet will then be emplaced along the centerline of the emplacement drift.

Two manually controlled transport locomotives, with radiation shielding to protect the operator, will move the shielded transporter with the waste package down the North Ramp and the main drifts, and stop at the entrance to the emplacement drift. One locomotive will decouple and move away. Operators will then open the drift isolation doors remotely and back the transporter into the drift. The transporter doors open and the waste package and pallet assembly moves, remotely controlled, into position for gantry pickup.

The emplacement gantry, already positioned in the drift, will be moved into position to straddle the waste package/pallet assembly. The gantry will lift the waste package and pallet off the transfer deck and carry the assembly through the drift to its final emplacement location. The gantry will lower the assembly onto the drift floor between the gantry rails and then return to the drift entrance to await the arrival of another waste package.

Four major pieces of equipment will be used to emplace waste packages.

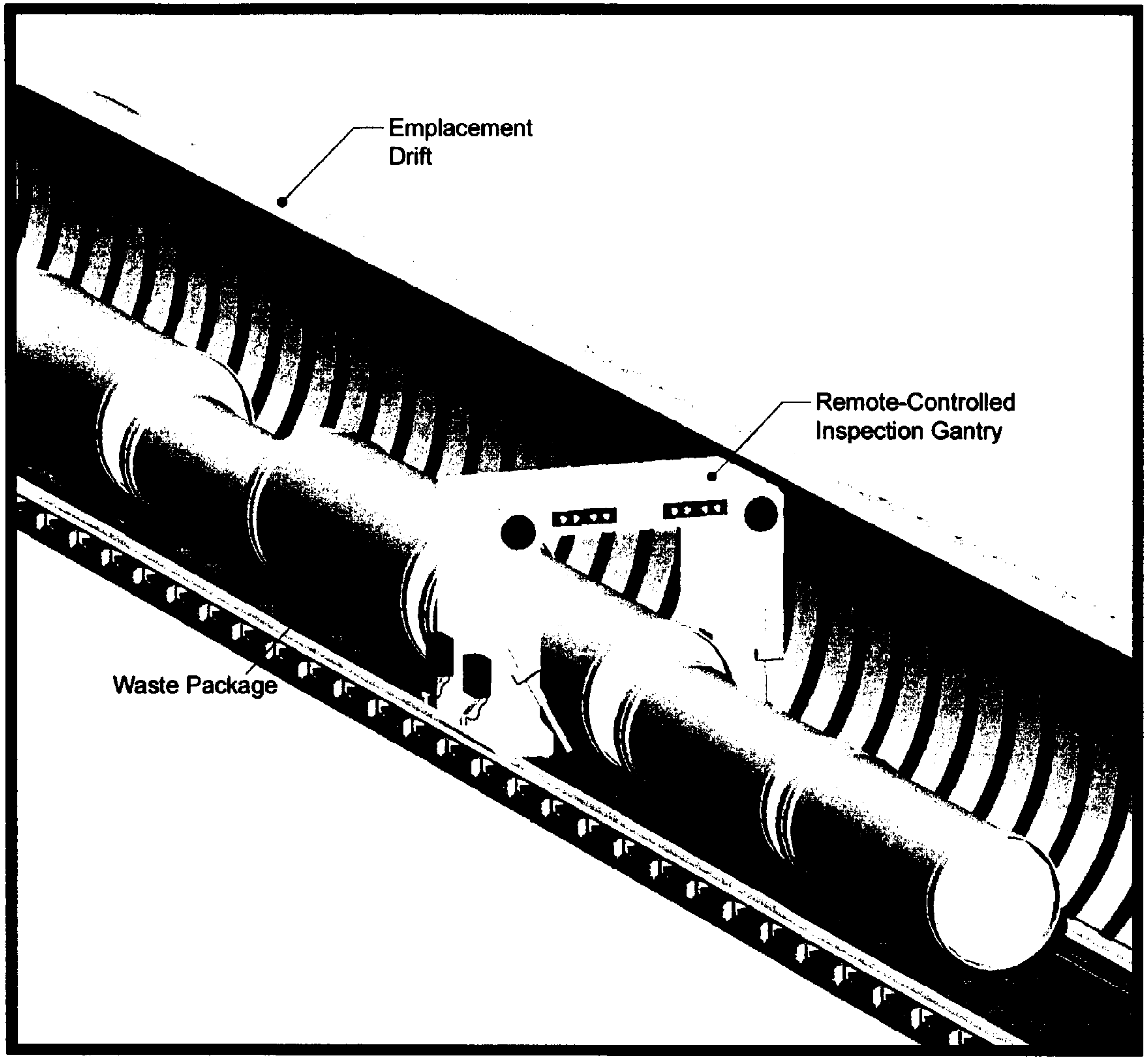
A. Two transport locomotives with the following features:
   - Electrically powered overhead trolley wire system
   - Controls for both manual and remote operations
   - Redundant fail-safe braking system
   - Approximately 340 horsepower each
   - Weight of approximately 50 tons each

B. A waste package transporter with the following features:
   - Empty weight of 300 tons
   - Loaded weight of approximately 400 tons (with heaviest waste package)
   - Integrated, remotely controlled loading/unloading mechanism to accept and deploy each waste package/pallet assembly
   - Radiation shielding of carbon steel and borated polyethylene for gamma/neutron shielding, sandwiched between inner and outer layers of stainless steel
   - Remotely operated doors with manual override
   - Redundant fail-safe braking system with control from transport locomotives and surface control system

C. An emplacement gantry with the following features:
   - Electrically powered through a third rail system
   - Rail mounted with driven wheels on each corner and redundant critical systems
   - Shielded gantry controls for remote controlled functions
   - Capable of handling full range of waste package sizes and weights
   - Suitable for variable waste package spacing, as required

D. A gantry carrier with the following functions and features:
   - Capable of transferring a gantry to all emplacement drifts
   - Can be moved by transfer locomotive
   - Powered third rail for gantry transfer onto carrier

Monitoring Phase



Monitoring Phase ai

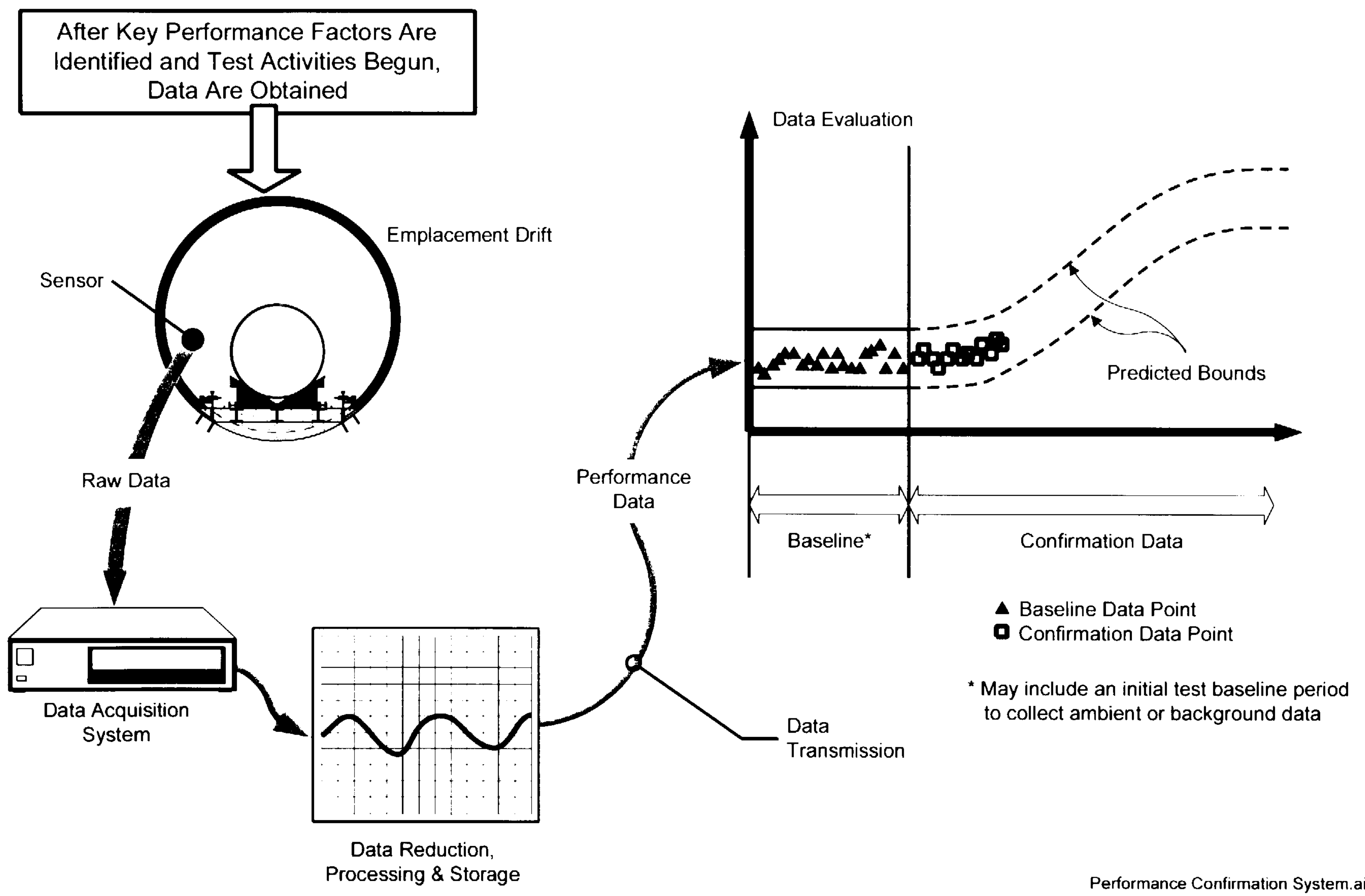
6.6 MONITORING PHASE

During this phase, monitoring and maintenance intensify. The current reference design will allow the repository to be closed as early as 30 years after the last waste emplacement, or to be kept open for at least 100 years. It will allow a period of 34 years for waste retrieval, if needed. In addition, the design will allow for reasonable maintenance that can extend the life of the repository to 300 years, if desired, which will provide flexibility for future decision-makers.

Specific facilities and equipment will be maintained to support monitoring and data analysis. Facilities and equipment needed to respond to emergencies also will be maintained.

During this phase, sensors will monitor selected waste packages, drifts, and the surrounding rock to provide the data for analysis. These subsurface sensors will be accessible for calibration and maintenance from observation drifts that do not contain waste packages and can be safely entered by workers. To limit risk to workers from heat and radiation from the waste packages, a remote-controlled inspection gantry will investigate the conditions within the emplacement drifts. If a decision is made to retrieve the waste packages, the emplacement drift will be cooled down using forced ventilation and the waste packages can then be removed. It is possible to remove the complete inventory of waste packages in 34 years, allowing a 10-year planning period and a 24-year retrieval period.

Performance Confirmation Process



6.7 PERFORMANCE CONFIRMATION PROGRAM AND FACILITIES

The performance confirmation program consists of tests, experiments, and analyses to evaluate the accuracy and adequacy of the information used to determine, that the defined repository postclosure performance objective is met. The performance confirmation program acquires data through test and evaluation activities to verify that subsurface conditions during construction, waste emplacement operations, and the monitoring period are within predicted safe limits. In addition, the performance confirmation program acquires data to verify that natural and engineered barrier systems and their components are functioning as intended and anticipated. The performance confirmation activities will continue from site characterization to closure of the repository.

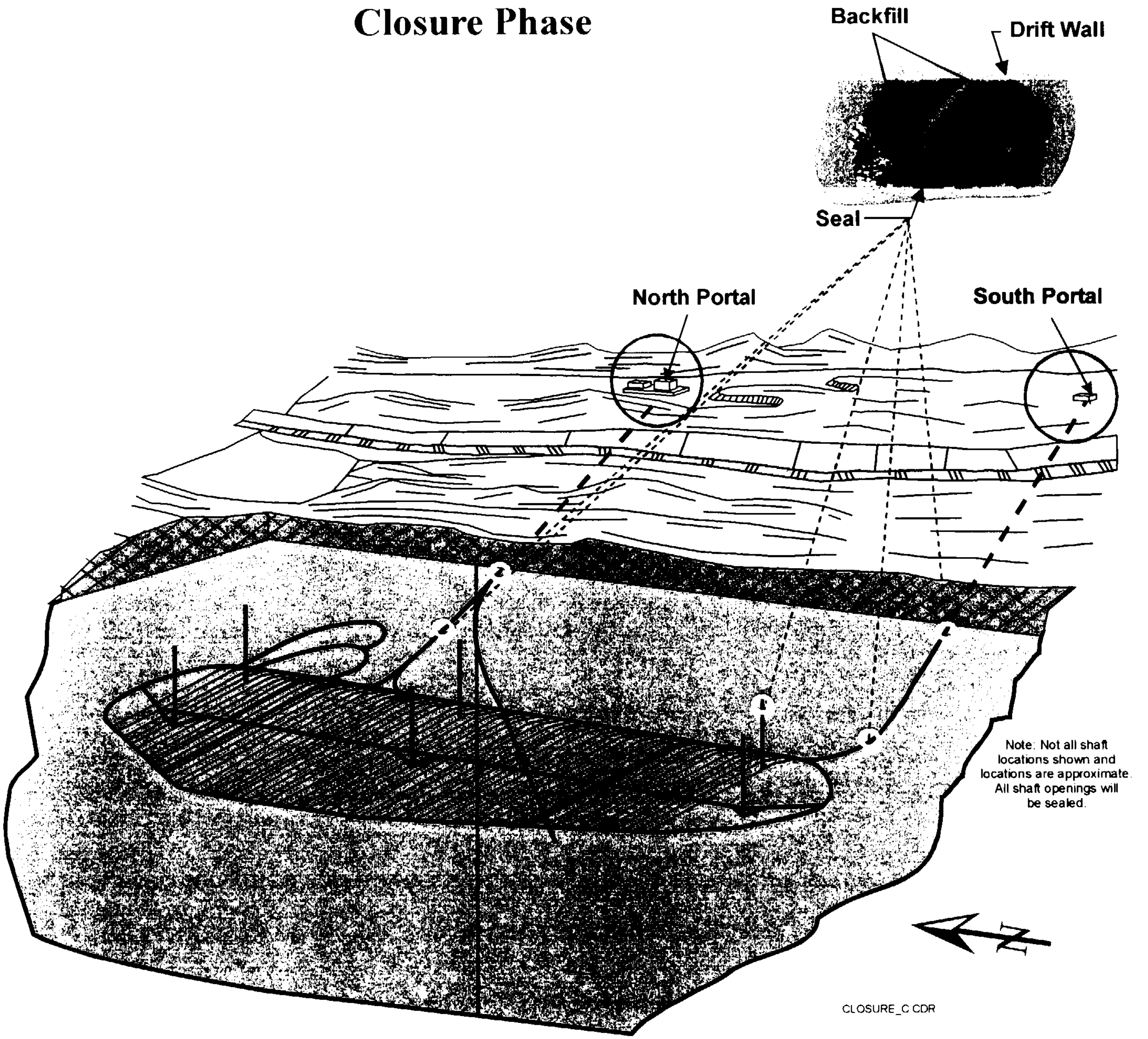
The current efforts of the program are focused on baseline development and continued data collection both by field and laboratory testing. The following specific ongoing performance confirmation activities will be conducted:

- Baseline Data Development
- Performance Confirmation/Data Collection/Evaluation
- Drift Scale Test Program
- Drift Water Seepage Monitoring and Testing
- Waste Form and Waste Package Testing

Performance confirmation activities require the following test facilities and equipment:

- Postclosure simulation test facilities to verify and confirm that measured conditions within a simulated postclosure drift are within the ranges consistent with those defined in the License Application
- Observation drifts and alcoves (three to five positioned in strategic locations) to conduct thermal/mechanical/hydrologic monitoring of the repository rock mass
- Water seepage alcoves for monitoring and testing drift seepage
- In situ seal testing alcoves for testing and monitoring seals including ramp and shaft seals
- Niches for seismic monitoring to monitor the subsurface response at the repository horizon
- Stationary control and monitoring system to periodically collect underground data
- Mobile vehicle operations control system to collect data using mobile performance confirmation systems, and to control equipment remotely from the surface and subsurface control stations
- Surface test facilities, including a performance confirmation support area to maintain testing and monitoring activities for the acquisition, storage, distribution, monitoring, and analysis of all scientific data and samples
- Offsite facilities and support for conducting long-term laboratory testing

Closure Phase



6.8 CLOSURE PHASE

After emplacement of the nuclear waste inventory has been completed, and the monitoring and performance confirmation program has shown that the repository has performed as expected, it will be closed. Closure cannot proceed unless the U.S. Nuclear Regulatory Commission has issued a license amendment to close the repository. Closure will require the following activities:

- Installation of drip shields to protect waste packages
- Sealing and backfilling all openings to the surface
- Dismantling the surface facilities
- Restoring the surface area to conditions specified by the U.S. Nuclear Regulatory Commission
- Preparing a plan for postclosure monitoring
- Protecting the repository from unauthorized intrusion

Sealing all repository openings will discourage human intrusion and retard the flow of water and gas into and out of the closed facility through the drift openings. Sealing will include:

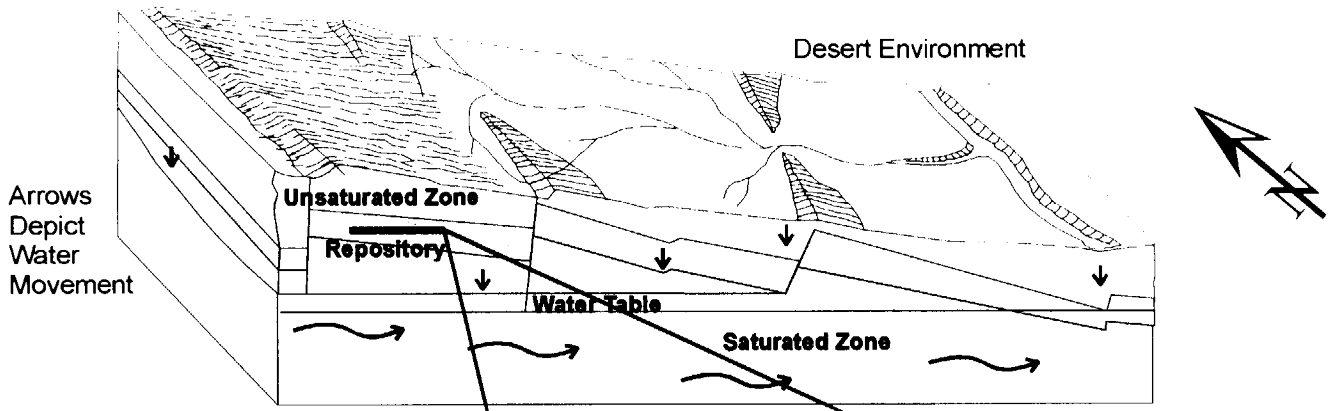
- Removing all nonpermanent equipment from the subsurface facility
- Installing seals and backfill material in all engineered openings to the surface, including shafts, ramps, and any boreholes that have been drilled to the repository level

During the closure phase, surface facilities will be decontaminated, decommissioned, and removed. This will restore the surface site to as near its original condition as is reasonably feasible. To facilitate this process, surface facilities will be designed to simplify final decontamination and decommissioning.

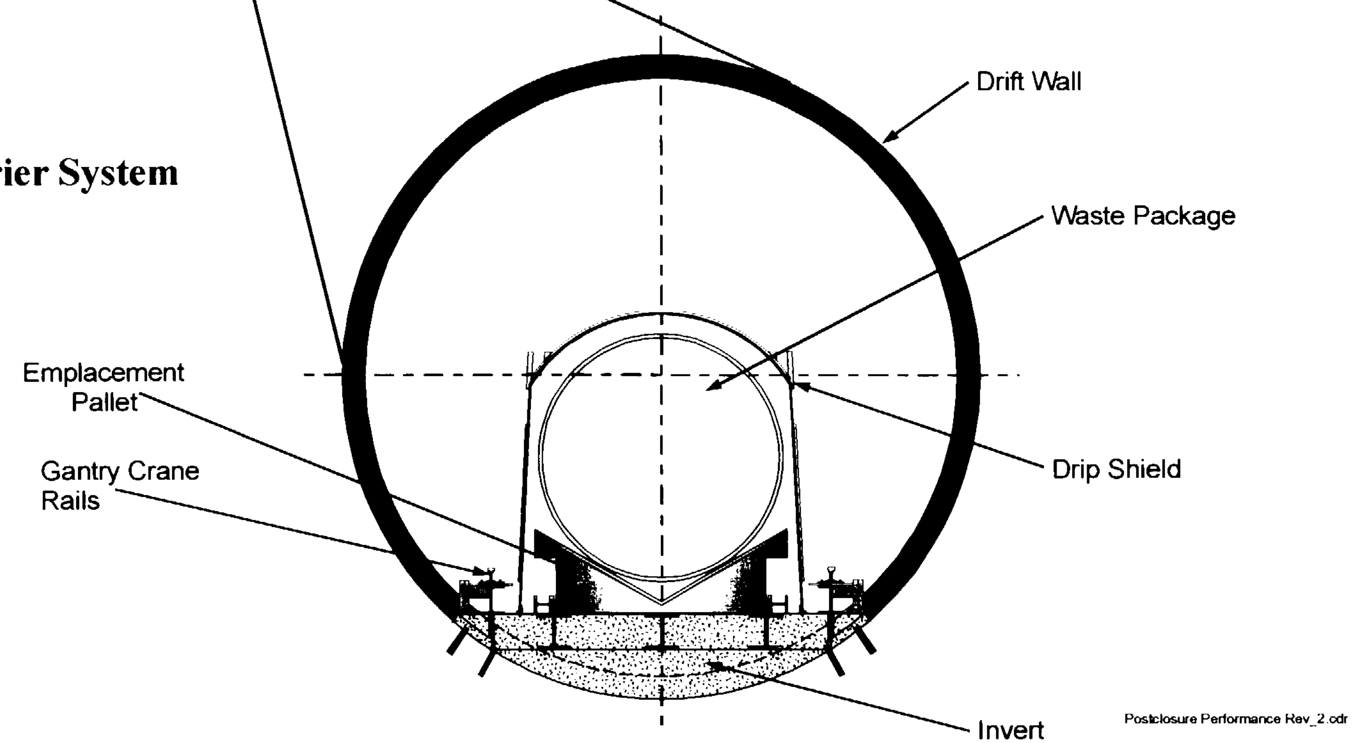
Detailed records and information on the repository will be distributed to government organizations. Permanent monuments will be placed at the closed repository to alert future generations that radioactive waste is buried there.

Postclosure Performance

Natural Barrier System



Engineered Barrier System



7. POSTCLOSURE PERFORMANCE

The primary objective of the potential repository at the Yucca Mountain site is to limit radiation levels and exposures, in both restricted and unrestricted areas, and releases of radioactive materials to unrestricted areas. After permanent closure, the geologic repository is required to limit to an acceptable level the expected annual dose to the public. The combination of the **Natural Barrier System** and the **Engineered Barrier System** of the repository will ensure that annual doses to persons on the surface are well below the maximum doses allowed by regulatory standards. For the vast majority of the radionuclides that could be emplaced in the repository, the Yucca Mountain site alone (the **Natural Barrier System**) appears to be completely capable of containing them and preventing any migration into the groundwater system. That leaves a small fraction of the radionuclides that appear to be mobile and, under some circumstances, could migrate away from the repository if they were exposed to liquid water. This concern can be mitigated by the **Engineered Barrier System's** ability to limit the exposure of these radionuclides to water.

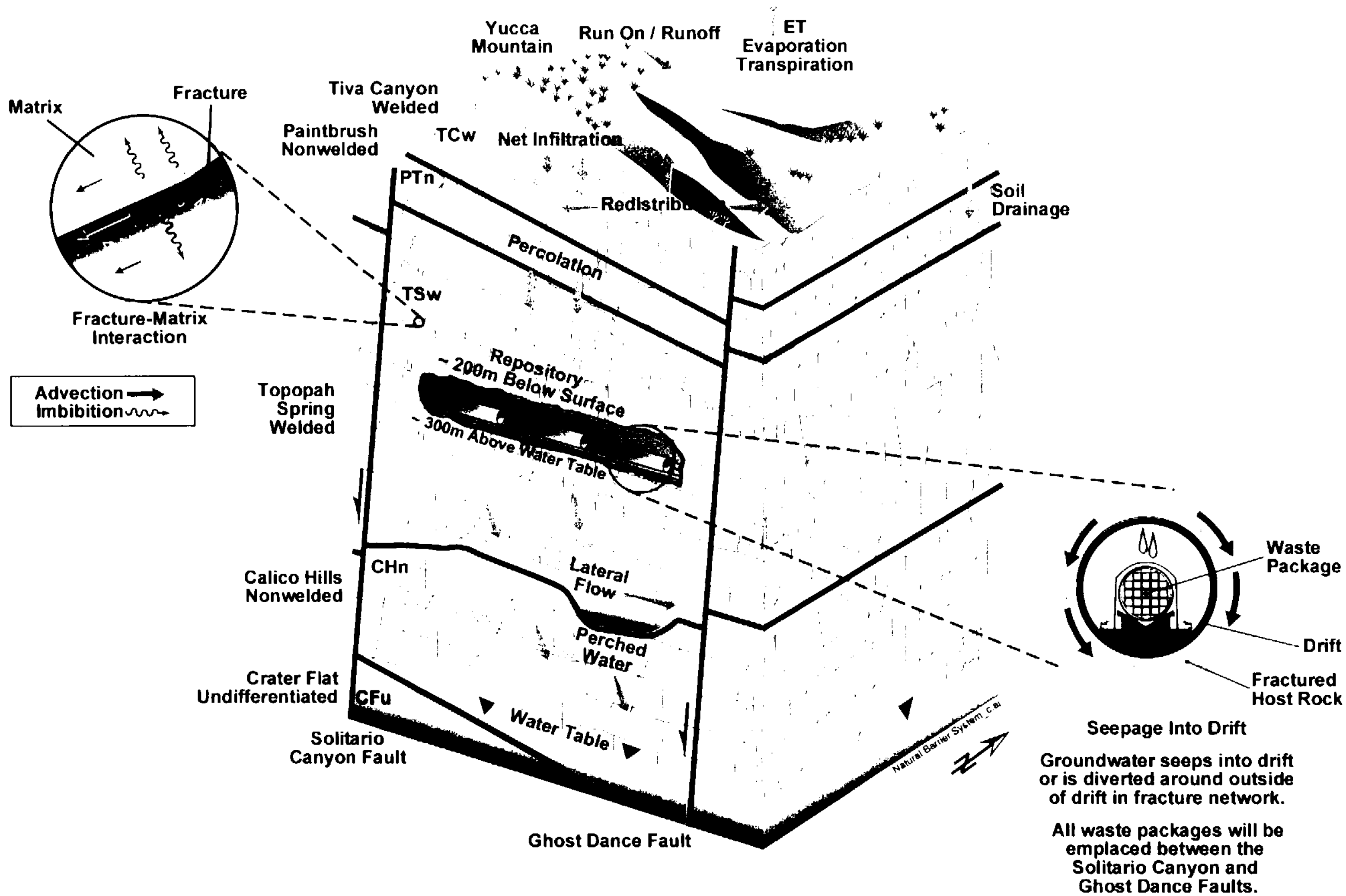
The repository system possesses several key attributes that are important to postclosure performance of the repository:

- Very limited amounts of water contacting waste packages
- Long waste package lifetime
- Slow rate of release of radionuclides from breached waste packages.
- Radionuclide concentration reduction during transport from the waste package

The mountain itself provides a thick, unsaturated zone where waste can be placed deep below the surface, yet well above the water table. This protects the waste packages from changes in conditions at the surface but still keeps them well away from the saturated zone below the water table. Site characterization studies have shown that the repository will not flood, the water table will remain well below the repository, the rocks above the repository will not significantly erode, the seismic effects will be minor, and the likelihood of volcanic disruption is exceedingly small.

The design of the repository will not rely on a single barrier but will rely on defense-in-depth (i.e., multiple barriers). These multiple barriers will mitigate uncertainties in conditions, processes, and events so that failure of any one barrier does not cause failure of the entire system. Evaluations indicate that the containment barriers will last tens of thousands of years and perhaps hundreds of thousands of years. Work in the next few years will include testing the performance and stability of the individual barrier materials and designs, and evaluating specific combinations of barriers from the viewpoint of cost and confidence in postclosure system performance.

Natural Barrier System



7.1 NATURAL BARRIER SYSTEM

The Natural Barrier System is the natural environment of the Yucca Mountain site itself, which establishes the processes and conditions under which engineered barriers operate. The Natural Barrier System consists of interdependent geological, climatological, hydrological, and geochemical subsystems, which provide various containment barriers that contribute to isolating radioactive waste and achieving the objective of the repository.

The **geological subsystem** provides the fundamental framework for waste isolation within the repository. Yucca Mountain is part of the Basin and Range Geologic Province of the western United States, and it consists of a north-south aligned, tilted, fault-bounded mountain block. The waste emplacement area of the repository is bounded on the west by the Solitario Canyon fault and bounded on the east by the Ghost Dance fault, but has no significant faulting within the emplacement area itself. The rocks comprising the mountain are of late-Tertiary age (7.5 million to 15 million years old), and consist mainly of volcanic rocks formed from hot ash ejected from extinct volcanic vents that were located north of Yucca Mountain. Depending on the temperature and pressure, these ash deposits formed either high-temperature consolidated units (welded tuffs) that are relatively dense, or lower temperature poorly consolidated units (non-welded tuffs) that are less dense and more porous. The sequence of main units comprising the mountain (from the surface downward) are the welded Tiva Canyon Tuff (TCw); the non-welded Paintbrush Tuff (PTn); the welded Topopah Spring Tuff (TSw), which is the repository host rock; the non-welded Calico Hills Formation (CHn); and the variably welded Crater Flat Group (CFu). At greater depths, pre-Tertiary rocks that include a Paleozoic (older than about 245 million years) carbonate aquifer are present. The rock sequence comprising Yucca Mountain is itself a barrier that isolates waste materials. The repository horizon is located at a minimum depth of 200 meters to ensure adequate protection from surface events (such as erosion). Depending on location, the repository horizon is also located from approximately 200 meters to 400 meters above the water table; this substantial distance ensures that the repository would not be flooded by a rise in the water table, in the event that future climatic conditions should become wetter that present-day conditions.

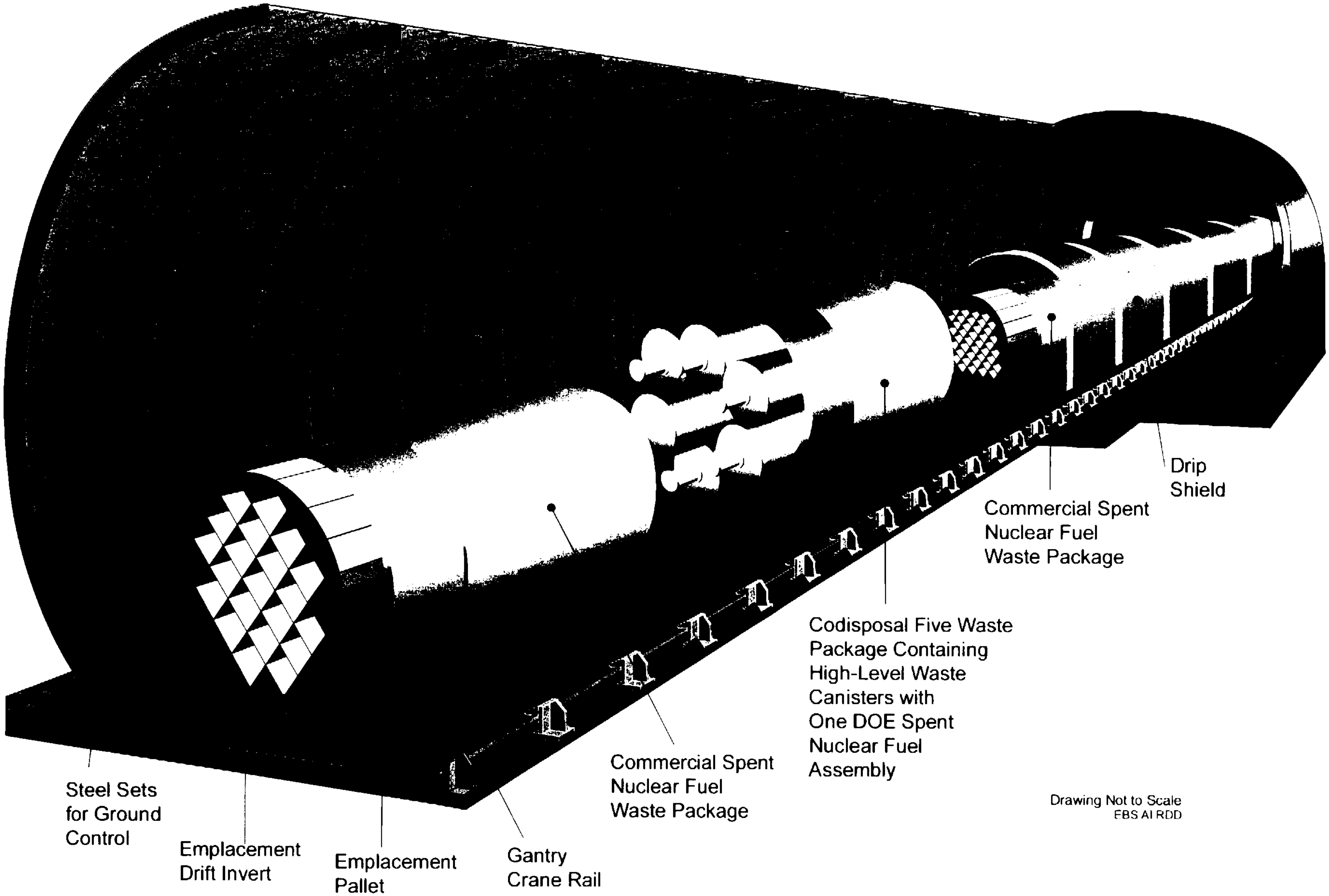
The **climatological subsystem** at Yucca Mountain includes the amount and timing of precipitation, runoff, evaporation, and plant transpiration. In turn, these factors control the amount of surface water, landscape erosion rates, and the amount of water infiltration into the mountain. The present-day climate in the area is semi-arid to arid, with hot summers and mild winters. Infiltration into the mountain bedrock is modest and occurs mostly in wet years that are linked with El Nino cycles. Studies of the past climatic history of the Yucca Mountain region concentrated over the last 500,000 years provide a basis for predicting future climatic changes in the region over the next 10,000–100,000 years, which are addressed in evaluating future repository performance. This evaluation provides bounds on the amounts of possible future water infiltration into the mountain and future effects on the hydrologic subsystem.

The **hydrologic subsystem** consists of the unsaturated zone extending from the ground surface to the water table, and the saturated zone below the water table. Both zones provide barriers that contribute to isolating waste materials. There are no permanent surface water bodies at Yucca Mountain to provide infiltration water into the unsaturated zone of the mountain; therefore, infiltration results directly from precipitation and is relatively low at present. Consequently, the amount of deeper water percolation through the mountain is also low under present climatic conditions. Water percolation in the unsaturated zone occurs by flow through both rock fractures and through pores within the rock matrix. Water flow through the porous rock matrix is substantially slower than through rock fractures, and some of the fracture water is attenuated by matrix imbibition (suction into the rock), which slows down the overall

flow process. Below the water table, water in the saturated zone flows laterally through both rock fractures and matrix to the publicly accessible environment. During transport in both the saturated zone and the overlying unsaturated zone, any radionuclides in the groundwater would be reduced in concentration by various dilution processes. These processes include dispersion of the contaminant plume during migration, mixing of groundwater from different sources, and dilution during pumping within the accessible environment.

The **geochemical subsystem** of Yucca Mountain includes the mineralogy and chemical properties of the volcanic rock sequence that comprises the mountain, which provides additional barriers to radionuclide migration. Some of the rock units, such as the Calico Hills Formation below the repository, contain abundant zeolite minerals that have sorptive properties which cause them to bind to some types of radionuclides. This constitutes another barrier to radionuclide migration. In addition, abundant clay minerals and some manganese oxides in the rock sequence also react with radionuclides and retard their migration, further contributing to the overall effectiveness of the Natural Barrier System in isolating radioactive waste materials.

Engineered Barrier System



7.2 ENGINEERED BARRIER SYSTEM

Water is the primary substance that, over time, could corrode waste packages, break down waste, and carry radioactive particles into the accessible environment. Therefore, a major objective of a potential geologic repository at Yucca Mountain is to keep the waste dry and isolated for as long as possible. Engineered barriers have been designed, in conjunction with the natural system, to minimize the amount of radioactive material that could eventually travel from the potential repository to the human environment.

The Engineered Barrier System includes components within the emplacement drift that contribute to waste containment and isolation. The current design includes the following components as engineered barriers: waste package (discussed earlier), emplacement drift invert, emplacement pallet, and drip shield.

The **emplacement drift invert** supports the waste packages and provides drainage away from the waste packages of any seepage water. The invert includes the structures and materials that form a platform which supports the emplacement pallet and waste package, the drift rail system, and the drip shield. The invert is composed of two parts: the steel invert structure, and the ballast, or fill, composed of granular material. The properties of the fill are chosen to provide an additional barrier to radionuclide migration. The invert structures must support repository preclosure operations for up to 300 years, with limited maintenance, in the emplacement drift environment. Additionally, the invert design, in conjunction with the emplacement pallet design, fulfills the requirement for maintaining the waste packages in a horizontal emplacement position for 10,000 years after closure of the repository.

The **emplacement pallet** provides a means to transport and emplace the waste packages, and will hold the waste package off the drift floor to keep the waste package dry and allow heat to be removed more evenly. The emplacement pallet supports the line loading of waste packages by allowing placement of waste packages end to end within 10 cm of each other. The emplacement pallets will be fabricated from Alloy 22 plates welded together to form the waste package supports. Two supports, one at each end of the pallet, are connected by four, square stainless steel tubes to form the completed emplacement pallet assembly.

Drip shields will be uniformly sized, so one design will suffice for any waste package design. The geometry of the drip shield design will divert any dripping water around the waste package and onto the emplacement drift floor. The drip shield will be fabricated from Grade 7 titanium plates for the water diversion surfaces, Grade 24 titanium for the structural members, and Alloy 22 for the feet. The design requirements for drip shields include corrosion resistance as well as structural strength. Corrosion resistance is required so the drip shields can perform their moisture diversion function with high reliability for 10,000 years. Structural strength is required so the drip shield can protect the waste package against damage by rockfall resulting from earthquakes or degradation of the drift walls.

8. DESIGN AND OPERATIONS OPTIONS

In addition to the features of the Engineered Barrier System previously described, some design and operational options are presently being evaluated. One option is to increase the disposal capacity of the repository from a present design capacity of 70,000 MTHM, to as much as 118,000 MTHM, which could be required if the law (Nuclear Waste Policy Act of 1982) that limits repository capacity changes in the future and additional disposal capacity is required. This could happen in the event that existing commercial nuclear power plants obtain extensions of their operational lifetime from the U.S. Nuclear Regulatory Commission. This increase in disposal capacity would be accomplished by excavating more emplacement drifts within the repository.

DOE is also considering a thermal option as part of the flexibility of the Repository. This option would keep the temperature of the emplacement drift walls below the boiling temperature of water (96°C at the elevation of Yucca Mountain). A decision on utilizing this option will be made at a later time, based on additional new information.

The repository design will not preclude the possible use of backfill in the repository emplacement drifts. If used, the backfill would be placed in the emplacement drifts just before closure of the repository.

9. SUMMARY STATEMENT

Yucca Mountain has been studied extensively for more than 15 years to evaluate its scientific suitability as the site for a geologic repository to safely dispose of spent nuclear fuel and high-level radioactive waste. During this time, it has been determined that the engineered barrier system within the repository can be designed to contain radioactive materials for thousands of years. It also has been determined that the natural barrier system, consisting of the mountain itself, can further delay and dilute any radioactive materials that might migrate from the repository. Uncertainties regarding repository performance over the next 10,000 years certainly do exist and may never be completely eliminated. However, the design concepts and operational procedures described in this document do provide reasonable assurance that the safe disposal of spent nuclear fuel and high-level waste can be achieved through a combination of both the natural and engineered barrier systems.

NOTE: For more information regarding the Yucca Mountain Project, call 1-800-225-6972 or go to http://ymp.gov.