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**1972 Preliminary Safety Analysis Report
Based on a Conceptual Design of a
Proposed Repository in Kansas**

J. O. Blomeke

MASTER

OAK RIDGE NATIONAL LABORATORY

OPERATED BY UNION CARBIDE CORPORATION FOR THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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1972 PRELIMINARY SAFETY ANALYSIS REPORT BASED ON A
CONCEPTUAL DESIGN OF A PROPOSED REPOSITORY IN KANSAS

J. O. Blomeke

Date Published: August 1977

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Federal Repository

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PREFACE

This preliminary safety analysis report is based on the conceptual design of a proposed Federal Repository, tentatively located at Lyons, Kansas, that will provide facilities for receiving, handling, and depositing radioactive solid wastes in bedded salt during the remainder of this century. Engineering for the conceptual design was performed by Kaiser Engineers, Inc. under the technical direction of Oak Ridge National Laboratory, and under the administrative guidance of the Atomic Energy Commission. A detailed conceptual design report has been prepared for AEC approval.*

Since alternate sites in Kansas are currently under consideration, the safety analysis, per se, is intended to apply to a hypothetical site in central Kansas that is identical in every way to the Lyons site, except that it is free of nearby salt solution-mining operations and bore holes that cannot (without excessive difficulty and expense) be plugged to Repository specifications. As a result of its construction as an independent document, this PSAR contains much information that also appears in the CDR, including frequent references to the Lyons site. Much of the geological-hydrological information was gathered in the Lyons area both during the Project Salt Vault demonstration and during the past 1-1/2 years of developmental work. In no instance, however, is any reference to Lyons intended to restrict the safety analysis in any major respect to that particular site.

This report is organized in the form of 16 numbered sections with the applicable references at the end of each section. Following a rather detailed summary of the entire report in Sect. 1, the considerations that have led to the proposed establishment of the Repository are presented in Sect. 2. Design requirements and criteria are given in Sect. 3; a description of the Lyons site and its environs is presented in Sect. 4; and the land improvements are described in Sect. 5. A description of the Repository,

*Kaiser Engineers, Inc., Oak Ridge National Laboratory, and U.S. Atomic Energy Commission, Conceptual Design Report, Federal Repository, Lyons, Kansas (December 1971).

its support facilities, and utilities are given in Sects. 6 through 9. The different impacts of the Repository's operations are discussed in Sect. 10, and the safety analysis is presented in Sect. 11. A brief discussion of the design confirmation program which is planned for the first several years of the Repository's operation appears in Sect. 12, while operational management and the requirements for eventually decommissioning the facility are given in Sects. 13 and 14, respectively. The final two sections of the report are appendixes containing design criteria for protection from severe natural events, and details of the proposed program of experimental investigations that are to be completed in the course of establishing a fully operational repository.

1. SUMMARY

1.1 Background Information

The quantity of radioactive waste generated in the United States will increase greatly over the remainder of this century as nuclear power assumes an increasingly important role in meeting the nation's electrical energy requirements. The methods used for the storage of radioactive wastes generated to the present time have been of a temporary nature, with the wastes stored either as liquids or slurries in tanks, or as solids in near-surface land burial grounds. Recognizing that a truly permanent solution to this problem is required, the AEC has taken steps to implement a policy that is intended to provide a permanent solution.

The AEC has sponsored studies over the past 15 years, in consultation with the National Academy of Sciences and members of the geologic community, to examine the suitability of bedded salt formations as a final repository for these materials. All studies to date indicate that natural salt formations offer the best possibility for providing the confinement over the extended period of time required for these wastes to decay to harmless species.

Recently, the AEC has been actively engaged in the selection of a site near Lyons, Kansas for a demonstration salt mine repository. Since both "high-level" and "alpha" radioactive wastes contain long-lived radioactive nuclides that require confinement outside the environment for hundreds of thousands of years, the Federal Repository will be designed to receive and permanently and safely store both types of wastes.

The high-level wastes are generated in the reprocessing of spent reactor fuels as nitric acid solutions containing fission products and smaller quantities of uranium, plutonium, and other heavy elements. These wastes are characterized by intense, penetrating radiation and high thermal power. Four processes have been developed for the conversion of these liquid wastes to solid forms suitable for shipment to the Repository and safe storage in salt. These processes include a pot calcination process that produces a calcine cake, a spray solidifier process that produces a

microcrystalline ceramic, a phosphate glass process that produces a glass, and a fluidized-bed calciner process that produces a powder. These solid products average approximately 3 ft³ in volume per ton of reactor fuel processed.

The alpha wastes consist of solid materials generated in nuclear fuel production plants and AEC operations. They may contain plutonium and other transuranium elements in amounts ranging from trace concentrations to several grams per cubic foot. Alpha wastes will be packaged in tightly-sealed steel drums or boxes, and since they are virtually free of penetrating radiation and involve only a negligible amount of heat, they will not require remote handling techniques.

Data on the projected characteristics and amounts of radioactive waste indicate that very sizable quantities will be generated over the remainder of this century and that they will remain hazardous for hundreds of thousands of years.

1.2 Design Requirements and Criteria

The criteria established for selecting a site for the initial waste repository include particularly conservative geologic criteria to provide assurance of long term isolation and efficiency of operations. These criteria provide that the salt formation be of the bedded type, extending several tens of miles horizontally; be at least 200 ft thick; be located at a depth between 500 and 2000 ft; and not be associated with significant known reserves of petroleum or other mineral resources. In addition, the criteria require that the site be in a zone of tectonic stability.

Design criteria established for the shipping and packaging of alpha wastes will provide assurance that these wastes can be shipped, handled, and stored in a safe manner. Shipments will conform to the regulations of the Department of Transportation and the Atomic Energy Commission. During shipment, the alpha wastes will be enclosed within two successive confinement barriers and shipped in a rail car designed for the safe shipment of radioactive materials. The alpha waste itself will be confined within sealed drums or boxes that will be packaged to form palletized "burial

units" approximately 4 ft by 6 ft by 6 ft high and weighing no more than 10,000 lb. The criteria require that the burial unit contents be stable, inert, and in a solid form, and that the outer surfaces of the burial unit meet established cleanliness requirements when shipped to the Repository. The Alpha-Operations Facility will have a design capacity to receive and bury 1,000,000 ft³ per year of alpha waste, based on a 3-shift, 5-day-per-week operation; initial capacity will be 350,000 ft³ per year based on a 1-shift operation.

The criteria established for the packaging and shipping of high-level wastes are intended to assure the safe receipt of solidified high-level wastes from commercial spent-fuel reprocessing plants and the safe handling and storage of these wastes in an underground salt bed. The criteria provide that sealed cans of solidified high-level waste shall be shipped to the Repository in shielded casks conforming to the regulations of the Department of Transportation and the Atomic Energy Commission. Requirements established to facilitate safe receipt, unloading, handling, and disposal of waste cans at the Repository include limits on the cask size and weight and total thermal power of the contents. The waste cans themselves must have the integrity to permit their safe removal from the cask in a shielded cell, transport to a mine-level burial room, and burial in the salt bed. The can will have a maximum overall length of 10 ft, an outside diameter between 6 and 14 in., and a total weight of no more than 4000 lb. As is the case for the alpha waste, cleanliness limits are established for the high-level waste can and cask surfaces. The High-Level Facility will be designed for an ultimate capacity of 300 cans per week based upon a 3-shift, 5-day-per-week operation; projected waste receipt rates for the initial period will require no more than a 1-shift operation.

Safety criteria established for the design and operation of the Repository include radiological safety, mine safety, and industrial safety. Radiation control and monitoring systems for the Repository will be in conformance with the AEC Manual, Chapter 0524, "Standards for Radiation Protection." These standards have basically the same provisions and limits as those required of AEC licensees by 10CFR20. The prescribed standard governing mine and tunnel safety for the Federal Repository will be the

Federal Health and Safety Standards -- Metal and Non-Metallic Underground Mines, 30CFR57, supplemented by other standards which may enhance safe operation. The standards for industrial safety will be in conformance with the AEC Manual, Chapter 0550, "Operational Safety Standards."

Design and construction criteria for the Repository are in conformance with AEC Manual, Chapter 6301, General Design Criteria. Sufficient space shall be provided to store the alpha-contaminated wastes generated in AEC plants and the solidified high-level fuel reprocessing wastes projected for the civilian nuclear power industry over the remainder of the century. The criteria require that all structures, systems, and equipment directly concerned with waste handling be designed to withstand the effects of natural phenomena such as earthquakes and tornadoes so that no loss of function occurs if that function is required for public safety. The criteria also require that confinement systems of the Repository restrict the release of radioactivity to the environment during normal or accident conditions to the minimum practical, but below AEC Standards; that a quality assurance program be developed for the Repository which can be applied to all facets of construction, procurement, and installation; and that secondary backup equipment shall be installed in critical systems to provide a high degree of reliability in case of failure of the primary equipment.

The Repository will be operated as a demonstrational facility during the first several years, and all radioactive materials emplaced in the mine during this period will be readily retrievable. A detailed concept will be developed for the retrieval of those wastes that are to be buried thereafter.

1.3 Site and Environs

Of the approximately 500,000 square miles in the United States underlain by bedded salt deposits, only areas in central Kansas, western New York, and southeastern Michigan satisfy the present criteria established for the initial repository. Considering tectonic stability, transportation costs, land values and population centers, a site in central Kansas appears to be the most favorably situated.

1.3.1 Site Location

The site of the Federal Repository will probably be near the center of the state of Kansas. The Repository will utilize approximately 1020 acres for the storage of solid radioactive wastes. A buffer zone 1 mile wide will be established around the Repository site by acquisition of subsurface mineral rights.

1.3.2 Geology and Hydrology

Regional Setting - The site will probably lie within the Great Plains Province, a broad belt of highlands sloping eastward from the Rocky Mountains to the Central Lowland. Rocks of the Precambrian age (greater than 600 million years old), which form the basement complex, are covered by sedimentary rocks ranging from the Cambrian (about 600 million years) to the Quaternary (about 1 million years) periods. Evidence indicates the major subsurface features of the central Kansas area are inactive and have been so for the past 200 million years.

Stratigraphy - The salt beds in the Lyons-Hutchinson area are Permian rocks about 300 ft thick, extending from a depth of about 800 to 1100 ft. Below the salt are thick beds of anhydrite, layers of shale and limestone, dolomitic rocks, and crystalline rocks, primarily granite. Other Permian rocks (several hundred feet of red-colored shale and siltstone) cap the salt bed, topped by a Cretaceous age layer of shales and the Pleistocene sediments.

Structure and Tectonics - The Repository site will probably be on the eastern flank of the Central Kansas Uplift which extends beneath a large part of that area of the state. There has been an almost complete absence of earthquakes along this structure, which had its major development at the end of Mississippian time some 300 million years ago. As evidenced by the dearth of earthquake activity, this structure is now inactive. Based on the recent seismic history of all of the other structures in Kansas, it is likely they are tectonically inactive.

Rock Salt Deposits - The rock salt column beneath the general area for the Repository site consists of a succession of layers of rock salt, which accounts for about 75% of the section, intercalated with shales and occasionally anhydrite beds. The thickest and most persistent salt zone lies at a depth of about 1000 ft below the surface. This zone is the most uniform and the best quality of the entire sequence and is, therefore, the desired host bed for the waste.

Hydrology - Surface streams flow on the site only during heavy rainfall periods of spring and summer. Fresh groundwater is confined essentially to depths of about 300 ft, with yields from 1 to 5 gpm.

Meteorology - A moderately wide range in temperature occurs in central Kansas with the mean annual temperature being about 56°F. The average maximum temperature in July and August is in the 90-95°F range. The average minimum in January is about 20°F. The maximum high may reach 120°F, however, and the low near -30°F. The annual average precipitation is about 24 in., but the lowest may be near 15 in. and the highest near 45 in. per year. Over half the rainfall events produce 0.75 in. of rain, and from 5 to 10 in. may occur, usually during September. Snowfall may be as low as 1 in. per year to a high of nearly 60 in. per year. A 1-day snowfall of 20 in. or more with attendant transportation problems is possible.

Tornadoes are not uncommon in central Kansas. Based on 34 years of observation and preliminary calculations, the probability of a tornado occurring in a 1-square-mile area was calculated as 1.6 to 3% in a 30-year period.

Winds throughout the area are typical of the Great Plains in general. Seldom calm (less than 5%), over half the recorded wind speeds are greater than 10 knots. The winds blow from the north-northeast through north-northwest about 20% of the time with average speeds of greater than 10 knots. Winds from the south-southeast through south-southwest occur more than 35% of the time with average speeds greater than 12 knots. Sandstorms are not uncommon in the area.

Agriculture and Ecology - The proposed site is presently devoted principally to agriculture (pasture and the growing of wheat and sorghum). The area was originally native prairie and its associated fauna consisted primarily of bison, antelope, prairie dogs, foxes, coyotes, and quail. The imposition of an agricultural economy eliminated the large native grazing mammals. Small rodents, reptiles, quail, and rabbits are able to maintain their populations and mourning dove populations have probably increased.

1.4 Improvements to Land

Because of the present characteristics of the general area, only a minimum of site clearing and grading will be required to prepare it for the Repository. Landscaping will be limited to the restoration of ground cover using local grasses to provide protection against erosion. Road access to the site will be from an existing county road located in the vicinity. The site road network will connect the Alpha-Operations Facility, the High-Level Facility, the warehouse, the main Repository parking lot, and other surface facilities. A 150-vehicle parking lot will be provided adjacent to the High-Level and Alpha-Operations Facilities and a small lot will be provided at the main gate. An 8-ft-high perimeter fence will be provided around the principal Repository buildings and separate perimeter fences will enclose the upcast vent shaft, magazine, and substation.

All present penetrations of the salt deposit, including oil wells and core holes, will be investigated and plugged to protect the salt bed from intrusion of oil, water, and gas from above and below. The procedures for sealing these penetrations will be developed based on a detailed evaluation of the penetration types and the materials through which they penetrate.

1.5 Alpha-Operations Facility

The Alpha-Operations Facility will receive alpha waste in burial units delivered to the Repository in special rail cars. Facilities and equipment will be provided to handle and inspect the burial units for

integrity and for an acceptably low level of radioactivity; transport them by surface, mine shaft, and underground vehicles; and efficiently bury them in a safe manner for permanent storage in underground rooms in the salt mine.

1.5.1 Surface Facilities

The Alpha-Operations Facility will be an integrated facility complex consisting of an alpha waste receiving building, mine operations building, Repository administration building, hoist house, and a mine air supply fan house. The arrangement of facility structures, waste handling systems, and supporting operations will be designed to provide the most economical method of handling and storing alpha waste while maintaining high standards of operational safety and reliability.

The alpha waste receiving building will contain the necessary facilities and equipment to unload, inspect, and transport the waste to the alpha-man and materials (M&M) shaft for lowering into the mine.

The total area of this building will be approximately 15,600 ft² and, except for the container unloading and storage area, all alpha waste handling areas will be in a confined structure. The areas within this building include:

1. The container unloading and storage area; a weather-protected concrete working pad, on which cargo containers enclosing the alpha burial units will be unloaded from rail cars. The cargo containers will be moved on transfer cars through airlocks into the unloading and decontamination rooms.
2. Two unloading and decontamination rooms in which burial units will be unloaded from the cargo containers and checked for integrity and surface contamination prior to removal to the transfer room.
3. A transfer room to provide space for lift trucks to process the burial units through a weigh and nondestructive assay cycle and into an alpha cage for lowering to mine level.

4. A nondestructive assay room for the dual function of weighing each burial unit and monitoring its fissile material content.
5. A waste loading compartment which will provide access from the transfer room to the sealed alpha cage. This compartment will be arranged to permit transfer of the burial unit from the transfer room to the alpha cage while maintaining the confinement integrity of the transfer room.
6. A facility support area adjacent to the confined areas of the alpha waste receiving building to house a counting room, a personnel check station, a change room, a maintenance and battery charge room, and a shift foreman's office.

The confined areas of the alpha waste receiving building will be of reinforced concrete construction designed to permit safe shutdown of waste handling operations without endangering the public health and safety during or following an earthquake or tornado. Confined areas will be maintained at a negative static air pressure with respect to the outside atmosphere to prevent any outleakage of air. All exhaust air from confined areas of the building will be passed through fans and HEPA filters located in a basement exhaust fan-filter room prior to discharge to the atmosphere through a stack. Access into confined areas of the building will be through air locks.

The mine operations building will be located adjacent to the alpha waste receiving building and will provide space for the ground-level facilities required for the mining personnel and operations and direct access to the alpha-M&M shaft. A full basement will be provided under the mine operations building to house the mechanical equipment serving the Alpha-Operations Facility and for the Repository main switchgear, standby electrical power generation, and the central control and monitoring station. The Repository administration building will house all central administrative activities involved in the operation of the Repository.

1.5.2 Alpha-M&M Shaft

The alpha-M&M shaft, located between the alpha waste receiving building and the mine operations building will be a multi-purpose shaft to be used for:

1. Lowering alpha burial units into the mine.
2. Access to the mine for men, materials, and equipment.
3. Supply of fresh air to the mine.

In addition, provisions will be included for the future installation of salt hoisting capability in this shaft as required. To perform these functions, the shaft will be separated into three main compartments (for alpha waste, man and materials, and air supply) and two auxiliary compartments (for counterweight and manway). The shaft will be an 18-ft-I.D., concrete-lined shaft with concrete divider walls to separate the three main compartments.

The alpha waste compartment will be separated from other compartments by an airtight concrete divider wall over the entire length of the shaft to preclude any possibility of the spread of alpha contamination in the unlikely event that the alpha waste compartment becomes contaminated. The alpha cage will be of airtight construction to provide a second confinement barrier for the alpha waste in the burial units. The alpha compartment of the alpha-M&M shaft, together with its head frame, hoisting cable enclosure and hoist house, will be confined areas. The capacity of the alpha hoist will be 20,000 lb.

The cage in the man and materials compartment of the shaft will have a capacity of approximately 26 men and 14,000 lb of materials. The lifting capacity of the M&M hoist will be 24,000 lb.

The mine air supply compartment will be completely isolated from all other shaft compartments by divider walls to avoid any possibility of radioactive contamination of fresh air. The total air flow down this compartment to mine level will initially be approximately 62,000 cfm. The compartment will be sized for a future maximum air flow of 100,000 cfm. At the base of the alpha-M&M shaft the air supply stream will be

divided for distribution to the alpha and high-level mines. Separate stations will be provided at mine level for the alpha compartment and the man and materials compartment. Each of these stations will be isolated from the mine by air locks.

1.5.3 Alpha Mine

Rooms in the existing salt mine will be used for the storage of alpha waste burial units. The sequence of waste storage operations will be as follows:

1. The sealed burial units will be lowered in the airtight cage to the mine-level alpha station.
2. The burial units will be removed from the cage by a battery powered lift truck and placed on a transporter.
3. The transporter will move the burial units to the storage area, where a second lift truck will unload the transporter and stack the burial units in a burial room.
4. Salt will be used to backfill the rows of burial units and to fill any unused space within a burial room.

1.5.4 Mine Ventilation

Supply air will enter the alpha and high-level mines through the air supply compartment of the alpha-M&M shaft. Approximately 20,000 cfm will be directed to the alpha mine and 40,000 cfm will be directed to the high-level mine. Within the alpha mine, temporary closures will be used to direct this ventilation flow first to the cleanup area and then to the alpha waste burial area. The filtered exhaust from the alpha waste burial area will be directed to the upcast vent shaft. In the high-level mine, a separate tunnel system located above the main entries will serve to isolate the exhaust air streams from the working areas and convey it to the base of the upcast vent shaft.

Mobile fan-filter stations will be used to filter dust from ventilation air leaving the active mining and cleanup areas. Mobile fan-filter

stations employing HEPA filters will also be used for filtration of exhaust air from waste burial areas.

The upcast vent shaft will conduct all mine exhaust air to the surface. At the top of the shaft, this exhaust air will enter the subgrade central filter station which will house the mine exhaust fans and exhaust filters. After filtration through prefilters and HEPA filters the exhaust air will be discharged to the atmosphere through a stack that is continuously monitored to detect any radioactivity or noxious gases in the air stream. The central filter station complex, operating in conjunction with the mine air supply system, will provide confinement for both the alpha and high-level mines. Fan and damper controls associated with the supply and exhaust systems will maintain the required confinement. This arrangement will provide assurance that all mine air that may have come in contact with burial areas will be filtered under controlled conditions prior to discharge.

1.6 High-Level Facility

The High-Level Facility will provide the facilities and equipment necessary to receive and handle packages of high-level waste shipped to the Repository in shielded shipping casks. The packages will be cooled within the casks, unloaded individually in shielded cell facilities, lowered to mine level through the high-level shaft, and then transported and buried in the salt bed using a shielded transporter. The components of the High-Level Facility will include the high-level waste receiving building, the hoist house, and exhaust fan-filter house at surface level; the high-level shaft and mine-level receiving station; and the high-level mine with its complement of equipment to develop mine space and transport and bury the high-level waste packages. The process waste system used to concentrate, solidify, and package any radioactive liquid waste originating at the Repository will also be located within the High-Level Facility.

1.6.1 Surface Facilities

The high-level waste receiving building will receive the shipping casks on rail cars which will pass through the rail car air lock into the cask unloading area. The cask unloading area will be a confined high bay

area serviced by a 100-ton bridge crane for above-grade handling of shipping casks. A cask cooling station will be located in the cask unloading area where the cask atmosphere will be sampled, and the waste packages cooled within the cask and decontaminated, if required. The cask will then be lowered into a transfer gallery and moved beneath the transfer cell. Equipment will be provided within the transfer cell to remove the waste packages individually from the cask and transfer them to the high-level shaft cage for lowering into the mine.

The basic architectural and structural guidelines used for the alpha waste receiving building will also be used for the high-level waste receiving building. Differences between the handling of high-level waste packages and alpha waste burial units will be due primarily to the presence of penetrating radiation in the high-level waste. Therefore, all handling operations of waste packages or opened shipping casks containing waste packages must be conducted remotely behind massive shielding. In addition, the waste packages themselves represent significant heat sources. The areas within the high-level waste receiving building, where continued integrity is necessary to permit safe shutdown of waste handling operations without endangering the public health and safety, will be designed to withstand an earthquake or a tornado. Confined areas will be maintained at a negative air pressure with respect to the outside atmosphere to ensure that any air leakage will be into the building. All exhaust air from confined areas of the building will be passed through fans and HEPA filters located in an adjacent exhaust fan-filter house.

The head frame for the high-level shaft will be an integral part of the high-level waste receiving building and will be designed and constructed to provide radioactive confinement and biological shielding. As in the case of the alpha hoist, the high-level cable enclosure and hoist house will be confined areas.

The high-level waste receiving building will contain approximately 18,300 ft³ of building area, including the basement and the structure for a shielded recan cell and transfer gallery. Equipment designed to recan high-level waste packages that have lost their initial integrity during

transport to the Repository will be installed in this cell in the future.

The support facilities area for this building will include a counting room, a personnel check station, a change room, a chemistry laboratory, a shift foreman's office, and a maintenance and storage room. Access into confined areas of the building will be through air locks.

In the basement of the high-level waste receiving building, space will be provided for the mechanical equipment room, waste concentration room, decontamination equipment room, and waste casting room. The hoist house and exhaust fan-filter house will be in separate structures adjacent to the high-level waste receiving building.

1.6.2 High-Level Shaft

The single purpose of the high-level shaft will be to provide access for transporting the waste packages from the high-level waste receiving building to the mine. The top of the shaft will terminate in the high-level waste receiving building transfer cell and, at mine level, it will terminate in a shielded receiving station where the packages will be transferred to a shielded transporter for delivery to the burial rooms.

This shaft will be a 4-ft-I.D., concrete-lined shaft equipped with a 10,000-lb capacity hoist. Twin hoisting cables will be utilized to support the mine shaft cage to preclude dropping of the load in the event a cable breaks. The high-level shaft will be an extension of the transfer cell confinement system.

1.6.3 High-Level Mine

The master plan developed for the high-level mine provides for the burial of packages containing high-level waste in accordance with projected rates of shipment to the Repository through the end of this century. The mine layout and sequence of salt bed utilization considers the requirements for mine ventilation, mine opening stability, heat effects, efficient use of mining and hauling equipment, and efficient use of mine space created.

The master plan utilizes a conventional room-and-pillar layout in which the waste packages are buried in vertical holes bored in the mine floor. The bed of salt in which the packages will be buried is the most uniform and of the best quality of the entire sequence of rock salt deposits.

Continuous mining machines will be utilized for the mining operations. Each mining machine will have shuttle cars associated with it as haulage vehicles. Long hauls of salt will be accomplished by the use of a conveyor system. The use of continuous mining machines will eliminate any requirement for explosives in the high-level mine. This will preclude the shattering effect induced by explosive shock and the attendant weakening of walls and ceilings.

The Project Salt Vault transporter, with necessary modifications, will be used for initial high-level burial operations. This transporter will receive the package at the receiving station at the base of the high-level shaft, transport it to the burial room, deposit it in a hole drilled in the floor, and backfill the hole with salt.

1.6.4 Process Waste System

The process waste system equipment located in the basement of the High-Level Facility will be used to decontaminate any radioactive liquid wastes generated in the operation of the Repository and reduce the wastes to forms suitable for disposal at the site. The process waste system will collect and routinely process all potentially contaminated solutions from sources such as the chemistry laboratory and the cask cooling system. In addition, potentially contaminated waste from areas such as change room showers and sinks will be processed if, after collection in a catch tank, the wastes are found to contain radioactive contamination.

The process waste system will utilize an evaporator and a mixed bed ion exchanger to accomplish concentration and decontamination of the liquid radioactive waste. The evaporator concentrate, containing the bulk of the radioactive contaminants, will be blended with dry cement and solidified in 55-gal drums. Both these drums and the expended replacement cartridges from the ion exchange columns will be buried in the mine. Evaporator

distillate will be decontaminated for reuse as process water or for evaporation to the atmosphere.

1.7 Support Facilities

Repository support facilities will include a warehouse, an underground maintenance shop, a magazine and a gatehouse. The warehouse building will be designed to serve the initial needs of the Repository for warehouse space and a surface-level maintenance shop.

Facilities for underground maintenance work will be provided in mine rooms in the vicinity of the alpha-M&M shaft. These facilities will provide the necessary work space, tools, and machines to permit replacement of mobile equipment components or electrical circuit components required to keep the mine equipment in operating order. Space and equipment will be provided for mechanical and electrical maintenance work, a lubrication pit, and a supply room.

A magazine will be provided for safe storage of the small quantities of commercial dynamite that will be stored on the site. This building will permit the storage of up to 1000 lb of explosives. The design, separation distance between other site buildings, and barricading of this building will be in accordance with the U.S. Army Safety Manual.

A gatehouse will be located at the entrance to the Repository to serve as the information and check point for all employees, visitors, and vehicles entering and leaving the Repository. This building will be provided with the alarms and communication systems necessary for safeguarding and controlling access to the facilities.

1.8 Utilities

The Repository utilities that serve the Alpha-Operations Facility, the High-Level Facility, and the other plant requirements include:

1. The domestic and fire protection water system.
2. The electrical power system, both normal and standby.

3. The sanitary waste disposal system.
4. The fuel gas system.
5. The communications systems.
6. On-site railroad spurs.
7. Site and regional monitoring systems.

1.8.1 Domestic and Fire Protection Water

The water requirements for the Repository will be provided by a combined supply and distribution system for both domestic and fire protection water. The water supply source will be a municipal system, if available, or a well supply system at the site. A looped piping system will be provided around the main Repository plant area, with laterals supplying the individual facilities. A 60,000-gal on-site storage tank at grade will provide a 1-hr reserve for fire protection water flow. Two booster pumps, one of which will serve as a standby, will be provided to furnish the required water pressure and flow during a period of high fire water demand.

1.8.2 Electrical Power Systems

The sources of electrical power supply to the Repository will be:

1. Normal electrical power obtained from the local electrical utility.
2. Standby electrical power obtained from on-site diesel generators.
3. A dc battery supply for small loads requiring noninterruptible power.

The normal power supply will be received by the Repository at 4.16 kV from a utility-owned substation at the site. Distribution to the use points at surface and mine levels will be at 4.16 kV or lower, depending on the individual use requirements.

All standby electrical power, except the M&M hoist, will be provided by two 750-kW diesel generator units; a third 750-kW unit will provide

standby power for the M&M hoist. These units will be located in the basement of the mine operations building.

A 120-volt battery station will be provided to supply emergency lighting and all instrumentation and control systems requiring noninterruptible power.

1.8.3 Sanitary Waste Disposal System

The Repository sanitary waste disposal system will collect and dispose of all sanitary waste generated in surface facilities. The sanitary waste system will discharge into a municipal sewage system if available. If a municipal system is not available, adequate treatment will be provided on-site. Self-contained chemical toilets will be used in the mine with disposal off-site. Wastes from potentially contaminated sources in the buildings will not be discharged to the sanitary waste system, but will be collected separately in catch tanks and processed on-site.

1.8.4 Fuel Gas

The Repository will obtain natural gas fuel from existing lines in the vicinity of the site. The gas pressure will be reduced for delivery to the individual facilities. Fuel oil will be used as backup fuel for the heating system and process steam system boiler.

1.8.5 Communications

The Repository communication system will be a combined telephone-intercommunication system consisting of dial-type telephones served from a local commercial telephone exchange. For emergency backup service, a two-way short-wave radio communication system will allow voice communication between strategic points in the Repository and with outside emergency organizations.

The fire alarm system will be activated by either fire alarm pull boxes, heat-actuated detectors in confined areas, or sprinkler system flow detectors. The fire alarm signals will be transmitted over the paging system and also transmitted automatically to a municipal fire department.

1.8.6 Railroad Spurs

A standard-gage railroad spur will connect the Repository facilities to a nearby railroad (existence of a nearby railroad is included as a site criterion). This spur will branch to serve the Alpha-Operations Facility and the High-Level Facility with car storage at each location.

1.8.7 Site and Regional Monitoring

Site monitoring equipment will include in-stack samplers, alpha and beta-gamma monitors and gas flow measurement equipment in the Repository exhaust air stacks; perimeter air and fallout monitors near the site boundaries; and surface storm water drainage monitors at appropriate locations where the drainage leaves the site.

Radiation monitoring of the region outside the Repository perimeter will include measurements of surface contamination, radiation dosage, and periodic tests of ground and surface water and vegetation to provide a continuing evaluation of the effect of Repository operation on the area.

1.9 Impact of Proposed Operations

1.9.1 Thermal Effects

After the waste is buried in the mine, the heat from radioactive decay is dissipated in the salt and surrounding formations and eventually flows to the surface of the earth, where it is transferred to the atmosphere. A consequence of the subsurface heat release is an increase in the temperature of the mined area and its environs. The temperatures gradually increase and then finally decrease since the heat generation rate in the waste is continuously decreasing.

Thermal design considerations are confined primarily to the high-level portion of the Repository. Power densities in the alpha waste, even with the tentatively proposed maximum compaction factor of 10, are about a factor of 10^5 smaller than those for the high-level solidified waste and constitute no significant thermal problems. The high-level waste, on the other hand, does constitute a thermal problem in the sense that the high-

level portion of the Repository must be carefully designed to achieve adequate safety without excessive cost.

Factors which influence the allowable heat release rate include:

- (1) thermal instability of the waste; (2) structural integrity of the mine during operation; (3) structural integrity of the overlying formations; (4) temperature rise in freshwater aquifers; (5) heating of the earth's surface; (6) temperature increases beyond the boundaries of the mine; and (7) release and migration of brine contained in small cavities in the salt.

Criteria associated specifically with the thermal analysis place limits on temperatures in the solidified waste, in the geologic formations, in freshwater aquifers, and at the earth's surface. The maximum permissible temperature of the waste is presently specified as the maximum temperature that existed during the waste solidification process. It appears that these temperatures will range between 1100 and 2000°F, a specific value depending upon the solidification process used. Maximum permissible temperatures for the salt, based on feedback from the rock mechanics analysis, are as follows:

1. The volume of salt above 482°F that surrounds the waste container and that is confined within a unit cell outlined by horizontal planes at the ends of the container and by the usual vertical planes of symmetry shall constitute less than 1% of the unit cell volume.
2. The volume of salt above 382°F in the above unit cell shall be less than 25% of the unit cell volume.

Other limiting temperatures are: earth's surface temperature rise, $\leq 1^\circ\text{F}$; temperature rise in the geologic formation at the edge of the Repository buffer zone, $\leq 1^\circ\text{F}$; and stagnant aquifer temperature rise at a depth of 300 ft below the earth's surface, $\leq 50^\circ\text{F}$.

Thermal analysis of the Repository is being conducted by both analytical and experimental means. The experimental program has involved temperature measurements in the salt surrounding electrically heated waste containers and the determination of material thermal properties.

Waste Loading Surface Densities - Results from the thermal analysis indicate that compliance with the present salt formation and waste temperature criteria results in a design that more than satisfies the remaining thermal criteria. Based upon the more restrictive criteria, the maximum permissible high-level waste loading for 10-year-old waste is about 6 metric tons of waste nuclides per gross acre.

Temperature Distributions for a Typical Burial Scheme - For a waste package of 4.34 kW of thermal power at burial, the waste temperature increase reaches a maximum of 900°F in about 6 years, while the surface of the container experiences a maximum temperature rise of 550°F, and this is achieved in about 15 years. The maximum temperature rise in the stagnant aquifer is about 38°F (500 years), and at the earth's surface the maximum temperature rise is only approximately 0.26°F (500 years). The permissible 1°F temperature rise for "mineral rights" occurs about 2500 ft out from the edge of the mined area at a depth of approximately 2000 ft.

Formation Stability - Heating of water-bearing shale could present a special formation-stability-related problem because of increased pore pressure, due to expansion of the trapped water, and because of possible chemical changes. Experimental data, however, show no microscopically observable mineralogical changes and no reduction in uniaxial compressive strength of typical shale over a temperature range of 75 to 300°F. The expected maximum temperature at the base of the overlying shale bed in the mine is only 210°F.

Movement of Waste Packages After Burial - Room closure after burial of the wastes may tend to move the burial waste packages upward, but the estimated maximum vertical displacement is 2 ft, which is minimal. Buoyant and other external forces can cause the waste packages to move but the displacement rates are negligible, even over a million years. The generation of steam and gas pressure at the ends of the containers could force the package upward if the crushed salt around the container forms a seal near the upper end. However, experience from Project Salt Vault revealed no tendency for the containers to move.

1.9.2 Radiation and Chemical Effects

The radiation and chemical effects of concern are those due to the presence of small amounts of water close to the waste containers. The water is dispersed in the form of small brine-filled cavities throughout the salt, and it also occurs in the shale which is one of the major impurities of bedded salt. The brine cavities, which range in size up to a few millimeters on a side, occupy from 1/4 to 1/2 percent of the salt volume. When these cavities are subjected to a temperature gradient, they will move either up or down the gradient. A cavity containing only brine will move up the gradient in the direction of the heat source, while a cavity containing some gas can move down the gradient. Under certain conditions, particularly when a free salt surface exists, thermal expansion of the brine can result in fracturing of the salt and a sudden release of the cavity contents.

Shale can release water upon heating, and presumably this water can enter the waste container burial hole where shale layers intersect the hole. It is also possible that this water will migrate from the shale through the salt toward the heat source. However, there is no evidence to date to indicate that the transport of water from the shale to the heat source is significant, and in any event, this effect will be minimized by burying the wastes only in regions of relatively pure salt.

Brine, vapors, and precipitated salts in the vicinity of the waste packages will be exposed to intense gamma radiation and to high temperature. Thus, they will be subjected to radiation decomposition and thermally-induced changes in composition.

Radiation and Thermal-Reaction Products - Predicted radiation and thermal-reaction products include H_2 , HCl , HNO_3 , O_2 , ClO_2 , Cl_2 , Br_2 , chlorates, and bromates. Hydrogen gas can be produced by radiolysis of the brine and by corrosion of the waste containers. The expected maximum H_2 production rate by radiolysis is about 4 moles per year, and this rate would prevail for only the first year after burial. Hydrogen production from corrosion will be no greater than 400 moles per year (for a 5-kW package), which corresponds to 7 liters of brine per year and an average

corrosion rate of 50 mils per year. At the end of the first year, the rates will be down by a factor of 3.5. The HCl is produced by hydrolysis of MgCl_2 , which is present in the encapsulated brine at a concentration of 2-3 moles per liter, and by the reaction of Cl_2 with H_2 . HNO_3 , the oxidized species O_2 , Cl_2 , Br_2 , ClO_2 , and chlorates and bromates are formed by radiolysis of the brine solutions and moist gases around a waste package.

Formation of Explosive Gas Mixtures with Hydrogen Gas - Prior to the time that a tight seal is formed in the hole above a waste package, hydrogen will diffuse out of the hole into the room above. For steady-state conditions, it is predicted that the H_2 concentration at the rear of a 500-ft-long backfilled room will be about 8 vol %, and at 120 ft from the front of the room it will be 4 vol %. It appears that a flame would not propagate through the backfill, but an explosion could take place in the relatively large void space between the top of the backfill and the ceiling of the room. There may be enough time for ceiling-sag and floor-heave to eliminate the void space above the backfill before explosive concentrations are reached. If this is not adequate, the void space might be ventilated. The corrosion rate of the waste containers (and H_2 production rates) could be reduced substantially by reducing the power surface density in the mine or by surrounding the container with a protective material such as calcium oxide which will react with the water and HCl before they contact the container.

Effects of Explosive Reactions of Chlorates, Perchlorates, and ClO_2 - Chlorates and perchlorates are explosive when they are in contact with oxidizable materials. However, decomposition of the chlorates and perchlorates and an unavailability of reducing species will limit the explosive force potential, provided several feet of backfill cover the tops of the holes.

Isotope Migration - A conservative estimate of isotope transport assumes that the high-level waste containment is not regarded as a barrier to migration but rather as an additional component having the potential to interact chemically with its salt and waste environ. Even when viewed on this basis, the research performed thus far suggests that isotope migration within the formation will not compromise the capability of the salt to

maintain the isolation of the high-level radioactive waste from the biological environment over the required period of time. The alpha facility offers no circumstances for additional transport mechanisms over those encountered in the high-level facility.

Since water is the main component of the brine-filled cavities, and many of the calcined wastes are most likely to be in the oxide form, studies of the oxide-water interaction have been performed. As a result of this work, the oxide-water vapor interaction has been discounted as a mechanism for the formation and subsequent transport of volatile radioactive species from the buried wastes. Specifically, the measurements made to date of the surface diffusion of lanthanum oxide (which is being used to simulate the behavior of plutonium dioxide) on salt surfaces result in an estimate of radioactive waste migration amounting to less than 10 meters over a million-year period.

Stored Energy - Radiation damage in solids is comprised of displaced atoms and other lattice disorder. Some or all of the energy associated with this disorder is released when the solid is heated to sufficiently high temperatures subsequent to irradiation. In some cases, all of the energy can be released with a relatively low initiating temperature. In these cases, the initial energy release heats the solid sufficiently to trigger additional energy releases at successively higher transition temperatures.

Experimental data suggest that radiation annealing will limit the Repository energy storage in salt to about 22 cal/g or less, with both β - γ and α rays. The effects of dose rates at high doses are not delineated by these data. Additional experimental information is required, especially with γ -rays, on energy storage at the low dose rates which will prevail in the Repository. There is an indication in these data that thermal annealing at temperatures above about 160°C will limit the stored energy in the Repository salt to a few calories per gram.

The radionuclides within the wastes will include uranium and trans-uranic elements so that the waste will absorb both alpha, beta, and gamma radiations. It is expected that storage of energy in the calcined oxides

will result only from displacements caused by elastic collision of α particles (including, importantly, the recoiling nucleus which is formed by the α disintegration) and, to a lesser extent, energetic electrons. Ionization effects are expected to be of little importance. The available data indicate that for irradiation temperatures less than about 100°C, the stored energy in the wastes at saturation will be in the range of 30 to 200 cal/g. The time to reach saturation is uncertain. Probably the time would be <10 years after reprocessing for a waste can having 5 kW of decay power at 10 years after reprocessing.

Rates of Release of Stored Energy and Effects of Release on Repository - The effects on the Repository of release of stored energy from the wastes and/or from salt will depend upon (1) the amount of energy which is released within a given temperature interval, and (2) the rate of release of the given amount within the temperature interval. In general, it appears likely that, starting with a negligible amount of stored energy in the wastes at burial, the rates of temperature rise within the wastes or salt will never be sufficient to trigger a rapid release of stored energy. More specifically, the stored energy which is accumulated at one temperature would be annealed out slowly at some higher temperature which is below that required for a very rapid release of the stored energy.

1.9.3 Geophysical Impact

Stress-Structural Considerations - Experience with the existing mine shaft indicates that the site has a very stable geological environment for shaft construction. The new shafts will be of circular cross section and lined with reinforced concrete. A shaft pillar with a diameter somewhat less than the shaft depth will be used to prolong the shaft life and provide a thermal barrier between the shaft and the high-level burial operations.

Sizes of horizontal openings through the salt will be determined by safe mining practices and procedures and the equipment which will be used in waste burial operations. All openings will be smaller than those constructed for Project Salt Vault, and the latter have proven to be quite

stable. Rock bolts will be used to increase the stability of the roofs of tunnels, entries, and burial rooms.

Convergence and Subsidence - The sizes of the high-level waste disposal rooms and the support pillars between them will be designed in such a way that, in time, the underground openings will completely close, causing a consolidation and recrystallization of the crushed salt used to backfill the rooms. The pillar deformation necessary to effect this closure results from the overburden load and will occur much more rapidly (65 to 100 years) because of the elevated temperatures than is ordinarily the case. As the mine closes, inducing a net decrease in the volume of the geologic system, the rocks begin to become heated from the radioactive decay with the resulting thermal expansion representing a net increase in the total volume. Preliminary calculations of the rates of these two processes indicate that, during the first 200 years, they almost exactly cancel each other at all locations in the system, including the surface, except in and immediately around the rooms and entries. Beginning about 200 years after waste burial, the heat loss at the surface will exceed the heat input from the waste, and the rocks will begin to contract, resulting in the very slow (thousands of years) development of a very broad, flat, and shallow (about 3-1/2 ft) subsidence basin over the area. The rate of development of this basin will be so slow and gradual that the shale rocks overlying the salt formation and the surface and shallow aquifers will easily adjust to these motions, which are only slightly greater than the current rate of surface erosion in the area. It should also be pointed out that the rate of this subsidence over the waste disposal area will be approximately the same as that over an equally-sized producing salt mine and that the total amount of subsidence will be approximately half that expected in operating mines, because of the backfilled rooms.

Tectonics and Seismicity - Central Kansas is located within the "stable interior," a region where earthquakes occur infrequently. The few earthquakes that have occurred in this area have been centered largely along the Nemaha anticline in eastern Kansas. Based on the recent seismic history of the geologic structures in Kansas, it is expected that they are tectonically inactive. The Repository site will lie within seismic zone 1

(expected minor damage) and will not be associated with any major fault zone.

Boundary Solutioning of Salt Formation - Along most of the eastern boundary of the Lyons-Hutchinson area salt beds, the salt deposit ends abruptly and a series of subsidence ponds and salt water springs overlie the present stratigraphic position of the salt member, which suggests that its original limits extended somewhat farther east. In northwest Saline County, precise dating of subsidence features obtained from river channel migration studies indicates that the salt front has retreated a distance of 5 miles or less in the last 1 million years (or throughout the Pleistocene), while in McPherson and Harvey Counties, westward migration of the salt has been 13 and 12 miles, respectively, from Delmore (Pliocene) to Kansas (a time span of about 5 million years). The natural leaching of the salt body by circulating groundwater depends on the development of secondary permeability in the overlying shales which, in turn, is brought about by erosion when the protective Cretaceous shales and clays are removed. In areas where the overlying shale section is complete, which includes essentially all of the central Kansas salt area west of the eastern boundary of Rice County, it may be considered to be protected for geologic time periods of at least 1 million years or for about the time span of the Pleistocene.

Penetration Solutioning of Salt Formation - In the central Kansas area, a large number (probably thousands) of wells have been drilled through the salt formation in search of oil and gas. Some of these wells date from the last century. In four known cases, a situation has developed where fresh water from near surface aquifers has drained into one of these wells, circulated through a break in the well casing at or near the depth of the salt bed, then discharged down the well into a lower formation, probably the Arbuckle. This circulating water dissolves the salt around the well, eventually causing the collapse, either sudden or gradual, of the overlying beds and the development of a "sink" on the surface. These four known cases of penetration solutioning have in common: (1) a shallow aquifer yielding water at the rate of several hundred gallons per minute; (2) an oil well having a history which suggests the possibility of a casing

break in the salt zone; and (3) a highly permeable deeper zone having a low hydrostatic head. Three of these four wells had been used as salt water disposal wells following their productive life.

A number of steps will be taken to preclude the possibility of solutioning by this mechanism at the site: (1) a survey at and around the site will be made using aerial remote sensing equipment and ground-based geophysical techniques in order to assure that all wells have been located; (2) each of these wells will be cleaned out and replugged using multiple layers of appropriate materials developed for this purpose; and (3) a portion of the long-term geological monitoring program will be designed to give early indication of possible solutioning at any place on or adjacent to the site. It should also be pointed out that any previous solutioning will be detected when the wells are opened and reentered.

Erosion and Denudation - Since a portion of the radioactive wastes to be stored at the proposed Repository will remain active for periods of hundreds of thousands of years, estimates are being made of the expected erosion by stream action and glaciation at the site and its effect on the stability of the underlying salt formation for long periods of geologic time. Based on the present rate of denudation for the Arkansas River basin, it is estimated that perhaps a hundred feet or so of rock cover would be removed from the formations at a site in the vicinity during the effective lifetime of the waste. Another estimate of the expected erosion can be made from measured stream incisions in the bedrock in the vicinity of Lyons, Kansas during the Pleistocene epoch or the last 1 million years of geologic time. It can be concluded that a 200-ft-deep channel could be cut into the present unincised bedrock at the site and/or an additional 200 ft deepening of the present gravel-filled channels in the immediate vicinity of the site could occur. In either case the salt formation would not be breached, since it lies some 800 ft below the present land surface.

1.9.4 Ecological Impact

The ecological investigations of the site will include: (1) a broadly based survey of the biotic resources of the several ecosystems on and immediately adjacent to the site; (2) collection and compilation of published data applicable at the site on climate and meteorological factors as well as available information on the behavior of radionuclides in those environments; and (3) formulation of a model for the dynamics of strontium-90 in a grassland system. This model will provide information for analysis and illustrates the use of the technique for predicting the distribution of contaminants, from either long-term chronic releases or short-term acute releases resulting from an accident. Future work will be directed primarily at establishing similar models and their transfer functions for other nuclides and in the other ecosystems (aquatic, agriculture, etc.).

Additional experimental work is planned to provide a more precise preoperational background of the radiation environment of the site and surroundings. In addition, continuing studies of the chemical interactions of the waste containers and salt will provide a better definition of the concentrations of the materials that may be released to the atmosphere.

1.9.5 Sociological Impact

Employment and Population - The population impact created by the Federal Repository on the area in the vicinity of the site and on the remainder of the state of Kansas has been estimated through the use of an Input-Output Study and the projected Repository employment for 1980 and 1990. The input-output analysis examined the interaction between the various sectors of the Kansas economy and established multipliers for the indirect and induced effects of the employment at the Repository. Local employment effects were established by estimating the fractions of the total employment increase for each sector of the economy that would occur in the vicinity of the site. The results of the study indicate that employment at the Repository can be expected to reach approximately 150 in 1980 and 350 by 1990; that indirect employment resulting from changes in employment in other industries in Kansas would increase by approximately

90 persons by 1980; and that the total indirect and induced employment (the latter resulting from additional income to households, enabling consumers to spend more, thus creating additional demand for materials and services) would total approximately 280 persons by 1990.

The estimated impact on the population of the area surrounding the site, which would result from this employment effect, is an increase of approximately 220 persons by 1980 and 960 persons by 1990. These estimates do not include the possible establishment of satellite industries in the locality.

Land Use - That portion of the Repository site surrounding the surface structures will be a controlled limited access area, and exclusion fences will be installed around the area. Structures inside the controlled area will include the Repository buildings, hoists, magazine, central filter station, and utilities. This area (approximately 150 acres) will be utilized primarily for Repository operations.

Impact on Resources - Establishment of the Repository will have no significant effect on the reserves of such resources as salt, oil and gas, and groundwater.

1.10 Safety Analysis

1.10.1 Effluents During Normal Conditions

Very small quantities of radioactive and other materials will be released to the atmosphere as a result of the normal operations of the Repository. The concentrations of these materials in normal working areas and off-site will be well below concentrations that are considered acceptable for occupational exposure and for exposure of the general public, respectively.

The only significant source of off-site exposure to radioactive or other materials originating from the Repository will be from very small quantities of airborne radioactive materials that escape through high efficiency particulate air (HEPA) filters. It is planned that there will be no discharge of liquid radioactive waste from the Repository. Solid

radioactive wastes generated at the Repository will be packaged and buried in the mine. Aqueous wastes will be recycled with any excess water being evaporated to the atmosphere.

Instrument systems will be provided for continuous monitoring of radiation levels and concentrations of airborne materials in work areas, in stack effluents, and at the boundary of the site.

Present estimates of the rate of release of airborne materials to the atmosphere and the maximum off-site concentrations that will result at the nearest boundary of the site are less than 0.1% of the applicable standards for exposure of the public and, in general, are well below the concentrations of the same materials that exist at present due to natural and man-made sources.

It is estimated that the buildup of off-site surface contamination of various species over the life of the Repository will ultimately result in a level that is less than 1% of the level that presently exists for the same species (including such radioisotopes as ^{90}Sr , ^{137}Cs , and ^{239}Pu which have been deposited by fallout). At these levels of surface contamination, the experience has been that the materials cannot be reconcentrated to hazardous levels in food chains.

1.10.2 Consequences of Upper Limit Accidents

Certain highly improbable dispersive events that could theoretically result from operation of the Repository have been considered to provide some relative appreciation for the maximum consequences that could result from unplanned or unforeseen circumstances. All significant quantities of radioactive materials will be handled as tightly sealed packages of solid materials within confinement zones of the Repository. The only significant mechanism for sudden and acute release of radioactive materials from the Repository must involve rupture of a package and passage of airborne particulates through a series of two High Efficiency Particulate Air (HEPA) filters. These filter systems will be physically isolated from operating areas; preceded by a series of roughing filters; followed by differential-pressure-sensitive, quick-operation check valves; and tested routinely to provide protection against pressure surges, plugging, and deterioration.

Analyses have been made for three such upper limit accidents:

1. Combustion, and subsequent rupture, of an alpha waste package in the alpha waste receiving building is considered the upper limit Alpha-Operations Facility accident. The calculated maximum quantity of plutonium inhaled by a hypothetical person standing at the site boundary during the release corresponds to approximately 20% of the maximum permissible body burden for plutonium.
2. Rupture of a high-level waste can and complete dispersal of the contents within the transfer cell of the high-level receiving building is considered the upper limit High-Level Facility accident. The calculated maximum inhalation of high-level waste particulates by a hypothetical person standing at the site boundary corresponds to approximately 1% of the maximum acceptable body burden for occupational exposure.
3. Possible release of particulates could be occasioned by dropping of an alpha burial unit during unloading of the ATMX car at the alpha waste receiving building. Since this unloading area is not a confinement zone, procedural safeguards will be relied on heavily to prevent spread of contamination to the environs.

1.10.3 Consequences of Loss of Geological Containment

The salt bed and its overlying shale offer high assurance that confinement of the wastes, even in the proximity of man-made boreholes and salt solution-mining cavities, can be maintained with little or no surveillance for the 8 to 10 centuries required for ^{90}Sr and ^{137}Cs to decay to innocuous levels. The projected inventories of radioisotopes in the Repository at the time of its decommissioning are such that the relative ingestion hazard of the salt bed in the High-Level Mine is about 190,000 times the hazard of the average of the earth's crust (6 ppm U and 12 ppm Th). The relative hazard decreases to unity after about 10^6 years. On the same basis, the relative hazard of the salt bed of the Alpha Mine is initially 230, and becomes unity after about 300,000 years. If the

geological containment were lost, and the salt and radioactive constituents were dissolved by water, the ingestion hazard of the resulting brine would be determined more by its salinity than by its radionuclide content.

A 10-ft-thick layer of salt and waste through the disposal horizon in the Alpha Mine will contain 37 ppm of Pu which has an ingestion hazard equivalent to the mineral pitchblende. Similarly, the High-Level Mine (1000 years after decommissioning) will have a hazard equivalent to a commercial grade of uranium ore.

1.10.4 Sabotage

Design and operating procedural safeguards will be instituted to protect the Repository from sabotage. These safeguards will include inspection of incoming waste shipping cars; exclusion fencing and a security guard force; protective lighting; controlled access to the facilities; design of structures for fire, tornado, and earthquake resistance; and adequate locks and key control for operating and vulnerable storage facilities.

1.11 Design Confirmation Program

Prior to acceptance of waste at the Repository, analyses will have been completed to assure safe operation of the facility. However, as an additional precaution, a design confirmation program for the high-level waste will be conducted in situ during the first several years of the Repository's operation. Many aspects of the high-level waste burial concept will be monitored and analyzed. If results indicate that containment integrity will not be adequately maintained, the waste will be removed from the Repository. To minimize the time and effort required for retrieval of the wastes, in the very improbable event that this is required, equipment for this purpose will be on standby. For the duration of the confirmation program, which is expected to be about 5 years, only enough waste to accomplish the objectives of the program will be buried. Many details of the experimental aspects of this program are yet to be developed pending the completion of laboratory studies and theoretical analyses.

1.12 Management

The U.S. Atomic Energy Commission is responsible for the overall direction and administration of the Repository project. Technical direction of the project has been assigned to Oak Ridge National Laboratory which will provide planning, direction, evaluation, and coordination throughout the entire project. Architect-engineering for the conceptual design has been accomplished by Kaiser Engineers, Inc. under contract with the Oak Ridge Operations office of the AEC with optional provisions therein for performance of such Title I, II, and III engineering services as may be requested by the Commission. Facility construction will be accomplished by one or more construction contractors under prime AEC contract. Repository operation will be the responsibility of an operating contractor to be selected, also under prime contract with the AEC.

The operating organization for the Repository will require a unique combination of technologies - mining operations and radioactive waste handling operations. The staff of the operating contractor must, therefore, be an integrated operating unit consisting of a combination of the required skills and experience. After selection, the operating contractor will have a small staff assigned during the design period for project indoctrination and training purposes. At the start of operations, it is estimated that the operating organization will total approximately 125 personnel; this will increase to over 200 by 1985 after multi-shift operations begin.

An emergency plan will be prepared for the Repository to cover not only radiological emergencies, but also major accidents, fires, natural disasters, release of toxic materials, and other unforeseen emergencies. This plan will include planning for both an on-site emergency organization and coordination with off-site groups, and will prescribe the emergency procedures and training program.

The objective of the quality assurance program to be established for the Federal Repository project will be to assure that the quality required for safe, reliable, and economical operation will be achieved.

To attain this objective, assurance must be obtained that the structures, components, systems, and facilities that comprise the Federal Repository are designed, developed, manufactured, constructed, and tested in compliance with established engineering criteria. Further, the quality assurance program will establish the means of control and verification to prevent or detect and correct any deficiencies.

1.13 Decommissioning

Current planning, based on the projected waste burial rates, has established that the salt bed area to be included in the Federal Repository will be sufficient for the burial of wastes until approximately the year 2000. At that time, or when Repository operations are completed, it is planned that the Federal Repository will be decommissioned.

The process of decommissioning the Federal Repository will include the removal of the surface facilities and the sealing of the mine. It is planned that the surface vegetation will be converted back to native grassland. Permanent markers will be placed to designate the mine and former shaft locations and to warn of the potential hazard of drilling operations.

2. BACKGROUND INFORMATION

The quantity of radioactive wastes generated in the U.S.A. will increase greatly over the remainder of this century as nuclear power assumes an increasingly important role in meeting the nation's electrical energy requirements. The wastes of primary concern, designated "high-level" and "alpha" wastes, contain certain long-lived and toxic radio-nuclides which must be contained outside the environment for hundreds of thousands of years. High-level wastes, principally the fission-product concentrates that arise in the reprocessing of spent reactor fuels, are characterized by intense, penetrating radiation and high thermal power. The alpha wastes are principally solid materials contaminated with plutonium that are generated in various manufacturing operations in AEC production plants. They are characterized by radiations of low thermal power and penetrability, but are extremely toxic.

The practice up to the present time has been to store these wastes on a temporary basis as aqueous solutions and slurries in tanks, and as solids in near-surface land burial grounds. Recognizing that a truly permanent solution of this problem is required, the AEC has promoted the development of processes for converting the liquid wastes to stable, solid forms; and in consultation with the National Academy of Sciences and members of the geologic community has sponsored work over the past 15 years to examine the suitability of bedded salt formations as a final repository for these materials. Following a comprehensive study made to help define policy concerning the siting of fuel reprocessing plants and waste management facilities,¹ the AEC has published in the Federal Register an appendix to 10 CFR 50 which requires industry to solidify their high-level liquid wastes and ship them to a federal repository.² Furthermore, to prevent the accumulation of large quantities of plutonium in conventional burial grounds, the AEC has established a policy within its own complex which requires that wastes containing known or detectable contamination of transuranium nuclides be kept segregated, packaged, and stored in a readily retrievable manner for eventual shipment to a repository. In June 1970, the AEC announced the tentative selection of a site near Lyons, Kansas, for a demonstrational salt-mine repository for solid radioactive wastes.

2.1 Projected Requirements for Waste Management

Wastes are produced in every step of the reactor fuel cycle: during mining and milling of uranium and thorium ores; in the preparation of feed materials; in fabrication of fuels; during reactor operation; and, finally, in processing of irradiated fuels. The most important sources of wastes in terms of variety, volume, and radiation levels are the fuel reprocessing plants where the fission products in irradiated fuels appear in the waste effluents from recovery of fissionable and fertile materials. Projections of the size of the fuel-reprocessing industry and the volumes and characteristics of the high-level radioactive wastes that will be generated by that industry are presented in Table 2.1. The isotopes ^{85}Kr and ^3H are currently released to the environment under existing regulations; however, future growth of the industry may necessitate their eventual separation and containment. In addition to wastes from fuel reprocessing, there are substantial quantities of alpha wastes that are contaminated with plutonium and other long-lived alpha emitters (Table 2.1).

2.2 Rationale for the Use of Salt Deposits

Salt formations were first recommended for use in the disposal of radioactive wastes by an advisory committee of the National Academy of Sciences in 1955, and this recommendation has been endorsed by three subsequent committees following reviews of ongoing research and development work. The recommendation was based on a number of characteristics which make salt particularly attractive for this purpose. It is widespread and abundant, underlying about 500,000 square miles in portions of 24 states; it has good structural properties, with a compressive strength and radiation-shielding characteristics similar to concrete; it is relatively inexpensive to mine; its thermal properties are better than those of most other rock types; and it occurs generally in areas of low seismicity. Most importantly, bedded salt deposits are completely free of circulating ground waters and are isolated from underground aquifers by essentially impermeable shale.

Table 2.1. Projected High-Level and Alpha Wastes

	Calendar Year Ending		
	1980	1990	2000
Installed nuclear electric capacity, MW	150,000	450,000	940,000
Fuel reprocessed, metric tons/year	3,000	9,000	19,000
Solidified high level wastes ^a			
Annual volume, 10^3 ft^3	9.7	33	58
Accumulated volume, 10^3 ft^3	44	290	770
Total accumulated activity, MCi	19,000	110,000	270,000
Total thermal power, MW	80	410	1,040
Significant isotopes accumulated			
28.9-y ^{90}Sr , MCi	960	5,700	12,000
30-y ^{137}Cs , MCi	1,300	8,000	20,000
1.6×10^7 -y ^{129}I , Ci	480	3,300	9,700
10.8-y ^{85}Kr , MCi	120	690	1,500
12.3-y ^3H , MCi	7.3	44	110
87.4-y ^{238}Pu , ^b MCi	1.2	10	40
24,400-y ^{239}Pu , ^b MCi	0.022	0.3	1.7
6600-y ^{240}Pu , ^b MCi	0.041	0.5	2.4
14.3-y ^{241}Pu , ^b MCi	6.6	58	240
433-y ^{241}Am , MCi	2.3	28	150
18.1-y ^{244}Cm , MCi	30	170	330
Number of shipments to repositories ^c	23	240	590
Alpha wastes			
Annual volume, 10^6 ft^3	0.36	0.92	2.5
Accumulated volume, 10^6 ft^3	4.6	10.4	27.0
Total activity, MCi	31	150	420
Total thermal power, MW	0.03	0.17	0.66
Significant isotopes accumulated, MCi			
87.4-y ^{238}Pu	0.51	2.6	8.4
24,400-y ^{239}Pu	0.11	0.58	2.0
6600-y ^{240}Pu	0.16	0.83	2.8
14.3-y ^{241}Pu	30	146	400
433-y ^{241}Am	0.14	1.0	6.6
Number of shipments to repositories ^d	930	1,200	3,030

^a Assumes 1 ft^3 of solidified waste per 10,000 MWd(th).

^b Assumes 0.5% of plutonium in fuel is lost to waste.

^c Each shipment consists of 57.6 ft^3 of waste in thirty-six 6-in.-diam. cylinders. Half of the waste is aged 5 years and half is aged 10 years at the time of its shipment.

^d Each shipment contains 832 ft^3 of waste.

Other possibilities that have been studied or seriously considered either require excessive surveillance, are more costly, or are more limited in their applicability. "Perpetual" storage as liquids in tanks requires continuing surveillance, mechanical means for removal of decay heat for several centuries, and periodic replacement of the tanks. Disposal as liquids in bedrock caverns would be restricted only to those sites with the proven geological characteristics necessary to ensure long-term safety, and the relative scarcity of potential sites and the extensive explorations required to verify their suitability would place a serious limitation on the siting of reprocessing plants. Disposal as solids in surface vaults and granite caverns would cost several times more than would the use of salt formations, and would result in an undesirable proliferation of disposal sites. And finally, the practical application of such advanced techniques as transmutation, or disposal into space, are dependent on the development of sophisticated and expensive technologies in the distant future which can be justified only for reasons other than waste disposal.

2.3 Project Salt Vault

A field-scale experiment called Project Salt Vault³ was carried out at a disused salt mine at Lyons, Kansas, to demonstrate the feasibility and safety of this waste-disposal concept, to demonstrate the equipment and techniques for handling packages of highly radioactive solids, and to obtain data for the design of an actual disposal facility. Fourteen irradiated fuel assemblies from the Engineering Test Reactor, two in each of seven containers, were used to simulate solidified wastes. These were placed in arrays of holes in the floor of the mine. Electrical heaters were used to raise the temperature of a large quantity of salt in the central pillar in order to obtain information on its in situ deformational properties.

This experiment was very successful. A total of about 4 million curies of fission-product activity, in 21 containers, was handled both into and out of the mine without incident. During the 19-month course of the experiment, the average dose delivered to the salt at the walls

of the array holes was about 8×10^8 rads with a peak dose of 10^9 rads. In spite of these high doses, there were no measurable radiolytic or structural effects in the salt. Much useful information was gathered with respect to thermal stresses, migration of brine-filled cavities, and salt flow characteristics as a function of temperature.

2.4 Characteristics of the Wastes

The wastes vary widely in their physical, chemical, and radiation characteristics, depending on their origin and previous history of treatment. They can, however, be processed and packaged so that they can be safely shipped and stored as solids, under carefully prescribed conditions, in a salt mine.

2.4.1 Alpha Wastes

Solid wastes containing plutonium and other transuranium elements, frequently referred to as alpha wastes, are routinely produced during the operation of nuclear fuel production and spent-fuel reprocessing plants, as well as during the operation of AEC laboratories and production facilities.^{4,5}

These wastes consist of a wide assortment of solid materials generated inside glove boxes during work with transuranium elements and outside the boxes during contamination control measures. They include items made of paper, cloth, wood, plastic, rubber, glass, ceramic, and metal, as well as salts and sludges that arise in the treatment of liquid waste streams and filters from cleanup of off-gas. The significant isotopes contaminating the wastes include 87.4-y ^{238}Pu , 24,400-y ^{239}Pu , 6,600-y ^{240}Pu , 4.3-y ^{241}Pu , and 433-y ^{241}Am . The transuranium-element contents of these wastes range from trace amounts to several grams per cubic foot. The densities of the uncompacted wastes vary from about 2 lb/ft³ to as much as 200 lb/ft³. About one-half to two-thirds of these wastes (by volume) are combustible and can be reduced via incineration by factors of about 50 and about 20 in volume and in weight, respectively; however, reliable and efficient incinerators for reducing

their volumes have not as yet been developed. About one-half to three-fourths of the wastes (by volume) can be reduced in volume by factors of 2 to 10 through compaction. The densities of the combustible wastes which are compactable generally vary from about 2 to 8 lb/ft³, averaging about 5 lb/ft³.

For shipment to the Repository, alpha wastes will be packaged in tightly-sealed steel drums and boxes, and since they are virtually free of penetrating radiation and evolve only a few hundredths of a watt per cubic foot, they will not require remote handling techniques.

2.4.2 High-Level Wastes

As generated at the fuel reprocessing plants, the high-level wastes are nitric acid solutions containing fission products and smaller quantities of uranium, plutonium, and other elements. They can be generally characterized by their very intense, penetrating radiation and their high heat-generation rates. The radiation characteristics of a typical waste and the identity of the significant radionuclides are presented in Tables 2.2, 2.3, and 2.4.

Four processes have been developed for converting these liquid wastes to solid forms which we believe can be shipped and stored safely in salt. The fluidized-bed waste calcining facility in Idaho (ICPP) has been operational for several years and has converted to granular solids about 2 million gallons of wastes generated by the processing of highly enriched fuels.⁶ In the Waste Solidification Engineering Prototypes (WSEP) at Battelle-Northwest, the solidification of wastes from reprocessing power reactor fuels has been demonstrated using the pot, spray, and phosphate glass processes.⁷ In the course of 33 runs at the WSEP, more than 50 million Ci of radioactive fission products were processed in containers that were 6 to 12 in. in diameter and 8 ft long, yielding solid products with thermal power densities ranging up to 320 W/liter.

The products from the pot calcination, spray solidification, phosphate glass, and fluidized-bed calcination processes can be described, respectively, as calcine cake, microcrystalline or rocklike material,

Table 2.2. Radioactivity and Thermal Power of Typical High-Level Waste as a Function of Time Since Processing^{a,b}

Time Since Processing (years)	Radioactivity (Ci/metric ton of fuel charged to the reactor)			Thermal Power (W/metric ton of fuel charged to the reactor)		
	Fission Products	Actinides	Total	Fission Products	Actinides	Total
0	4,380,000	22,700	4,440,000	19,300	811	20,100
0.5	2,390,000	12,100	2,400,000	10,800	421	11,200
1	1,680,000	7170	1,690,000	7540	240	7780
2	1,000,000	3800	1,000,000	4400	117	4520
3	691,000	3010	694,000	2890	89	2980
4	533,000	2770	536,000	2110	81	2190
5	448,000	2640	451,000	1680	77	1760
7	365,000	2460	367,000	1260	72	1330
10	311,000	2210	313,000	1010	65	1080
11	300,000	2140	302,000	959	63	1020
12	289,000	2070	291,000	919	61	980
15	264,000	1870	266,000	828	55	883
17	250,000	1750	252,000	781	52	833
20	231,000	1590	233,000	720	47	767
25	204,000	1350	205,000	634	41	675
30	181,000	1160	182,000	560	35	595
35	160,000	1010	161,000	495	30	525
40	142,000	875	143,000	438	27	465
50	112,000	679	113,000	344	21	365
75	61,500	417	61,900	188	13	201
100	34,100	309	34,400	103	9	112

^aThe fuel from a light water reactor with an initial uranium enrichment of 3.3% is assumed to have been irradiated at an average specific power of 30 MW/metric ton to an exposure of 33,000 MWd/metric ton. The waste consists of all fission products plus the actinides remaining after removal of 99.5% of the uranium and plutonium following a postirradiation decay period of 150 days.

^bA typical container of solidified waste having inside diameter of 6 in. and an active height of 8 ft contains waste from 0.476 metric ton of fuel charged to the reactor.

Table 2.5. Radioactivity and Mass of Radionuclides in Typical High-Level Waste as a Function of Time Since Processing^{a,b}

Nuclide	Radioactivity (Ci/metric ton of fuel charged to the reactor) After:			
	1 year	3 years	5 years	10 years
²³⁹ Np	18	18	18	18
²³⁸ Pu	91	110	109	105
²³⁹ Pu	2	2	2	2
²⁴⁰ Pu	3	3	3	4
²⁴¹ Pu	488	444	404	318
²⁴¹ Am	154	155	156	157
²⁴³ Am	18	18	18	18
²⁴² Cm	4160	189	12	3
²⁴⁴ Cm	2220	2060	1910	1580
⁹⁰ Sr	74,700	71,100	67,700	59,900
⁹⁰ Y	74,800	71,200	67,700	59,900
⁹⁵ Zr	5610	2	0	0
⁹⁵ Nb	11,900	5	0	0
⁹⁹ Tc	14	14	14	14
¹⁰⁶ Ru	205,000	51,600	13,000	413
¹⁰⁶ Rh	205,000	51,600	13,000	413
¹²⁵ Sb	6280	3760	2250	623
^{125m} Te	2590	1560	934	258
^{127m} Te	604	6	0	0
¹²⁷ Te	597	6	0	0
¹³⁴ Cs	153,000	77,600	39,400	7270
¹³⁷ Cs	104,000	99,300	94,900	84,500
^{137m} Ba	97,300	92,900	88,700	79,000
¹⁴⁴ Ce	316,000	53,100	8930	104
¹⁴⁴ Pr	316,000	53,100	8930	104
¹⁴⁷ Pm	76,000	44,800	26,400	7030
¹⁵¹ Sm	1140	1120	1100	1060
¹⁵⁴ Eu	6550	6000	5510	4430
¹⁵⁵ Eu	4350	2020	939	138
Total ^c	1,690,000	694,000	451,000	313,000

Mass (g in waste per metric ton of fuel charged to the reactor)				
Fission products	28,900	28,900	28,900	28,900
U	4780	4780	4780	4780
Np	486	486	487	487
Pu	50	53	54	56
Am	140	140	140	141
Cm	29	26	24	20
Total ^c	40,500	40,500	40,500	40,500

^aThe fuel from a light water reactor with an initial uranium enrichment of 3.3% is assumed to have been irradiated at an average specific power of 30 MW/metric ton to an exposure of 33,000 MWd/metric ton. The waste consists of all fission products plus the actinides remaining after removal of 99.5% of the uranium and plutonium following a postirradiation decay period of 150 days.

^bA typical container of solidified waste having inside diameter of 6 in. and active height of 8 ft contains waste from 0.476 metric ton of fuel charged to the reactor.

^cTotal includes all radionuclides.

Table 2.4. Photon and Neutron Source Strength of Typical High-Level Waste as a Function of Time Since Processing^{a,b}

	Photons/sec or Neutrons/sec per Metric Ton of Fuel Charged to the Reactor			
	1 year	3 years	5 years	10 years
Photons				
0.30 MeV	3.55×10^{15}	9.06×10^{14}	3.65×10^{14}	1.87×10^{14}
0.63 MeV	2.20×10^{16}	1.16×10^{16}	7.20×10^{15}	3.59×10^{15}
1.10 MeV	1.50×10^{15}	5.56×10^{14}	2.87×10^{14}	1.45×10^{14}
1.55 MeV	4.87×10^{14}	1.91×10^{14}	8.71×10^{13}	2.04×10^{13}
1.99 MeV	1.95×10^{14}	3.81×10^{13}	7.76×10^{12}	2.00×10^{11}
2.38 MeV	5.49×10^{13}	1.38×10^{13}	3.46×10^{12}	1.10×10^{11}
2.75 MeV	1.78×10^{12}	4.48×10^{11}	1.13×10^{11}	3.57×10^9
3.25 MeV	3.23×10^{10}	8.12×10^9	2.04×10^9	6.49×10^7
Neutrons				
	3.98×10^8	3.35×10^8	3.12×10^8	2.58×10^8

^aThe fuel from a light water reactor with an initial uranium enrichment of 3.3% is assumed to have been irradiated at an average specific power of 30 MW/metric ton to an exposure of 33,000 MWd/metric ton. The waste consists of all fission products plus the actinides remaining after removal of 99.5% of the uranium and plutonium following a postirradiation decay period of 150 days.

^bA typical container of solidified waste having inside diameter of 6 in. and active height of 8 ft contains waste from 0.476 metric ton of fuel charged to the reactor.

phosphate glass, and granular solids (Table 2.5). The pot calcination and fluidized-bed products have lower thermal conductivities and higher leach rates than do the spray solidification and phosphate glass products; however, the pot calcine material is more stable at elevated temperatures. The water leachability of the glasses is increased by devitrification. The spray melt, the phosphate glass, and the fluidized-bed product can be packaged in mild-steel containers, while stainless-steel containers must be used in the pot calcination process. A more recent modification of the spray and pot calcination processes permits the incorporation of the waste solids in borosilicate glass to produce a glassy product. Similarly, the granular product from a fluidized bed may be converted to a dense solid by embedding the particles in a solid matrix or by fusing to form a glass.

2.5 References

1. Oak Ridge National Laboratory Staff, Siting of Fuel Reprocessing Plants and Waste Management Facilities, ORNL-4451 (July 1970).
2. "Siting of Fuel Reprocessing Plants and Related Waste Management Facilities," Federal Register 35, No. 222, 17530 (November 14, 1970).
3. R. L. Bradshaw, and W. C. McClain (eds.), Project Salt Vault: Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines, ORNL-4555 (March 1971).
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7. J. L. McElroy, A. G. Blasewitz, and K. J. Schneider, "Status of the Waste Solidification Demonstration Program," Nucl. Technol. 12, 69-82 (September 1971).

Table 2.5. Characteristics of Solidified High-Level Wastes

	Pot Calcine	Spray Melt	Phosphate Glass	Fluidized- Bed Calcine
Form	Calcine cake	Monolithic	Monolithic	Granular
Description	Scale	Microcrystalline ^a	Glass	Amorphous ^b
Chemical composition, mole %				
Fission product oxides	15 to ~ 80	5 to 30	5 to 25	5 to 50 ^c
Inert metal oxides	10 to 50	40 to 50	10 to 30	10 to > 90
Sulfur oxides (if in waste)	0 to 40	0 to 40	0	0 to 40
Phosphorus oxides	~ 0	25 to 40	~ 60	~ 0
Bulk density, g/ml	1.1 to 1.5	2.7 to 3.3	2.7 to 3.0	1.0 to 1.7
Thermal conductivity, Btu hr ⁻¹ ft ⁻¹ °F ⁻¹	0.15 to 0.25	0.4 to 1.0	0.4 to 1.0	0.10 to 0.25
Maximum allowable thermal power, W/liter of solid ^d	85	205	190	70
Leachability in cold water, g cm ⁻² day ⁻¹	10 ⁻¹ to 10 ⁻²	10 ⁻³ to 10 ⁻⁶	10 ⁻⁴ to 10 ⁻⁷	10 ⁻¹ to 10 ⁻²
Hardness	Soft	Hard	Very hard	Moderate
Friability	Crumbly	Tough	Brittle	Moderate
Residual nitrate, wt % of product	≤ 0.05	≤ 0.005	≤ 0.005	≤ 4.0
Volume, liters/1000 MWd (thermal)	1 to 2.5	1.2 to 3	1.5 to 5	1.5 to 5
Maximum stable temperature, °C	~ 900	Phase separation at ~ 900	Devitrifies at ~ 500	~ 600
Container material	Stainless steel	Mild steel or stainless steel	Mild steel or stainless steel	Mild steel or stainless steel

^aGlassy products can also be made with some difficulty.

^bMicrocrystalline products can also be made.

^cComposition ranges for fluidized bed are also for Purex waste and are estimated.

^dApproximate values for storage in air in 8-in.-diam cylindrical pots to maintain pot center-line temperatures at less than 900°C and pot wall temperatures at less than 425°C. Average k values were used.

3. DESIGN REQUIREMENTS AND CRITERIA

3.1 Site Criteria

In selecting the site for the initial waste repository, geologic criteria have been established to assure long-term isolation and efficiency of operations. These criteria may prove to have been conservative; as more information and experience are gained from the operation of this first facility, some of these criteria will probably be relaxed and perhaps new ones added. The criteria are as follows:

1. The salt formation shall be of the bedded type, approximately horizontal, and relatively undisturbed structurally so that the previous research and development work for this disposal concept will be applicable.
2. The formation shall have a considerable horizontal extent, amounting to at least several tens of miles to provide adequate isolation of the disposal area.
3. The formation shall not be less than 500 ft below the surface and 200 ft thick to provide for adequate heat dissipation as well as to provide a margin of isolation above and below the disposal plane.
4. The depth of the formation shall not be greater than 2000 ft because of both the increased cost and the increased difficulty of operating at greater depths.
5. The formation shall not be associated with, or be in the immediate vicinity of, potentially valuable reserves of petroleum or other mineral resources.
6. The site shall be situated in a zone of tectonic stability.

3.2 Alpha Waste Criteria

The function of the Alpha Facility of the Repository is to receive packages of low radiation level, transuranium solid wastes from AEC and commercial sources and to dispose of these wastes in the existing salt

mine in such a manner that they will constitute minimal long-term hazard to man's environment. These wastes, which are denoted "alpha" waste for brevity, consist of suitably packaged solid wastes that have transuranium alpha radioactivity greater than $10 \mu \text{ Ci/kg}$ and sufficiently low external radiation level to permit direct handling without benefit of supplementary shielding.

The following sections present criteria for shipment and acceptance of the waste and a design basis projection of the volumes of these wastes that will be received at the Repository.

3.2.1 Alpha Waste Shipping Criteria

Alpha wastes shall be shipped to the Repository as "Type B" or "Large Quantity" radioactive materials shipments in a manner that is approved by the Atomic Energy Commission and in accordance with a certification of compliance that is granted by the Department of Transportation. The shipments shall conform with regulations of the Department of Transportation (49CFR173.389 through 173.399) and the Atomic Energy Commission (AEC Manual, Chapter 0529 for AEC contractors or 10 CFR 71 for AEC licensees).

In addition to the above criteria, the following criteria - together with those of Sect. 3.2.2 - are imposed to facilitate unloading, handling, and disposal of wastes at the Repository.

1. Shipments shall be received by rail in ATMX-600 series rail cars which serve as a rugged secondary line of confinement that is resistant to possible collisions and fires.
2. Returnable 8 ft by 8 ft by 20 ft cargo containers shall be utilized to facilitate unloading of the rail car and provide a nominal secondary confinement barrier during the outside unloading operations. These containers shall be made of painted, low carbon, open hearth or electric steel and shall comply with USASI-ISO standard MH 5.1.
3. The rail car and cargo containers are to be provided with fittings (to be specified later) to permit withdrawal of a sample of air for analysis.

3.2.2 Alpha Waste Acceptance Criteria

This section defines criteria for packages of waste that will be stored in the Repository. Wherever used in the following, "package" will denote a sealed outer container - denoted by "container" - that is filled with waste. A "burial unit" shall denote a single package or a banded-together array of packages which has nominal outer dimensions of 4 ft by 6 ft by 6 ft.

Container. - The waste container shall be a drum or box made of painted, low carbon, open-hearth or electric steel or an approved substitute. The minimum uncoated wall thickness shall be 16 gauge. All body seams shall be welded. Heads shall be either gasketed or seal-welded.

Burial Unit

1. Individual burial units shall have nominal outside dimensions of 4 ft by 6 ft by 6 ft. These shall either be in the form of a steel box or a metal-strapped, square-pitch array of twelve 55-gal steel drums with a 0.25-in.-thick steel base plate having outer dimensions of 46-1/2 in. wide by 69-3/4 in. long by 70-3/8 in. high.
2. The maximum allowable weight of a burial unit shall be 10,000 lbs.
3. The burial unit shall be braced and metal-strapped as necessary to provide that when supported at any two points in any orientation there will be no gross detectable deformation of the unit or sealing surfaces on waste containers.
4. Skids shall be utilized to facilitate loading and unloading of burial units using a fork lift truck. Criteria for these skids will be supplied later.

Each burial unit shall be marked uniquely using a ten-character alphameric code. The first four characters are to be an alphabetic code designation of the sender. This marking shall be die-stamped, brazed, or welded in a conspicuous location on the unit and shall

not impair the integrity of the package. Also, each shipment shall be accompanied by a manifest that presents best estimates of the contents of each marked burial unit. This listing should present the gross weight of the burial unit and identify the masses of principal inert components, fissile materials, and isotopes which (when contributions are summed) will account for at least 90% of the initial thermal power and total nuclear energy of the burial unit.

Restrictions on Package Contents. - Packages will not be accepted that are known to contain liquids, potentially explosive chemicals, pyrophoric materials, oxidants (other than air), and sealed inner containers filled with gas under pressure. These materials must be converted by the shipper to stable, inert, solid forms by mixing with Portland cement or an approved substitute.

Surface Contamination. - Upon receipt at the Repository, the maximum levels of fixed and transferable contamination on the surface of burial units, as determined by direct survey and smear samples, shall be as follows:

	<u>Disintegrations/min/100 cm²</u>	
	<u>α Radiation</u>	<u>β-γ Radiation</u>
Fixed Material	3000	
Transferable Material	300	10,000

Penetrating Radiation. - The dose-rate from penetrating radiation at 3 ft from the surface of a burial unit shall not exceed 2.5 mrem/hr.

Nuclear Criticality Safety. - Each package shall be a net neutron absorber when exposed to neutrons having energy spectra that may be generated by slowing down of fission neutrons in such materials as natural water, carbon, sodium chloride, iron, and similar packages. This criterion shall apply for the package in the normal condition and for the following conditions that may pertain after extended storage in the salt mine:

1. Combustion limited by the available oxygen in the package and with release of all gaseous products.
2. Complete pyrolysis with release of gaseous products.
3. Corrosion of the outer container and migration of a saturated (at 100°F) aqueous solution of sodium chloride into the container.

Nuclear Thermal Power. - Upon receipt at the Repository the average nuclear thermal power density of a burial unit shall not exceed 0.01 watt/ft³ from decay of ²³⁹Pu. If other isotopes are present, the average nuclear thermal power of a burial unit, q(t), in watts/ft³ as a function of time, t, in years since receipt at the Repository shall satisfy the following equation:

$$3.3 \geq \int_0^{\infty} \frac{q(t)}{\sqrt{t}} dt .$$

Upper limit values for various single isotopes that meet these criteria are as follows:

	<u>Power</u> <u>(watts/ft³)</u>	<u>Activity</u> <u>(Ci/ft³)</u>	<u>Mass</u> <u>(g/ft³)</u>
²³⁹ Pu	0.01	0.32	5.2
²³⁸ Pu	0.17	5.0	0.30
²⁴¹ Am	0.075	2.3	0.66
²⁴⁴ Cm	0.37	10.0	0.13

External Pressure Resistance and Leak-Tightness

1. The container (either empty or filled with typical contents and closed as for use) shall be capable of submergence below 10 ft of water for 5 min without permanent deformation resulting in greater than 5% decrease in the internal volume and any detectable leakage of water into the container.
2. The container (either empty or filled with typical contents and closed as for use) at ambient temperature shall withstand a sustained internal hydrostatic pressure of 15 psig for 5 min with no detectable leakage from the container.

Resistance to Accidents in Repository. - Within a period of 10 min following subjection to the following tests the quantity of material that is released from a package or burial unit - when assumed to be dispersed uniformly in 100,000 m³ of air - shall not have concentrations exceeding those specified in Table 1, column 1 of 10 CFR 20. Also, the quantity of noxious chemicals released from a package or burial unit - when assumed to be dispersed uniformly in 100,000 m³ of air - shall not exceed the most current values established by the American Conference of Industrial Governmental Hygienists. (These values may be obtained from the Secretary-Treasurer, American Conference of Governmental Industrial Hygienists, 1014 Broadway, Cincinnati, Ohio 45202.)

1. Burial units with typical contents shall be subjected to a free drop of 4 ft onto solid concrete so as to strike diagonally the most vulnerable seam or chime.
2. A package with typical contents surrounded by ambient air and closed as for use shall be subjected to ignition of its combustible contents.

Resistance to Propagation of Combustion. - Packages containing combustible materials shall comply with the following:

1. A sealed package with typical contents, at a uniform surface temperature of 250°F and thermally insulated, shall not attain a surface temperature greater than 400°F following ignition of the contents of the package.
2. A sealed package with typical contents having steady-state temperature distributions and a surface temperature of 250°F shall act as a net heat sink when immersed in an insulated medium at 450°F having at least three times the heat content (above 0°F) as the package.

3.2.3 Design Basis Capacity of the Alpha Facility

The design basis projection of the required capacity of the Alpha Facility, as shown in Table 3., makes the following major assumptions:

Table 3.1. Projected Inventories of Alpha Wastes at the Repository

Calendar Year	Number of Shipments ^a	Assumed Compaction Factor	Volume After Compaction (thousands of ft ³)		Pu Content ^b (kg)		Alpha Activity (MCi)	
			Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
1975	421	1	350	350	88	88	0.02	0.02
76	421	3	350	700	263	349	0.07	0.09
77	421	3	350	1050	263	609	0.07	0.17
78	421	3	350	1400	263	867	0.07	0.25
79	421	3	350	1750	263	1130	0.07	0.30
1980	421	3	350	2100	263	1380	0.07	0.40
81	841	3	700	2800	525	1900	0.14	0.60
82	841	4	700	3500	700	2590	0.18	0.80
83	841	4	700	4200	700	3270	0.18	1.00
84	841	5	700	4900	875	4130	0.23	1.3
85	841	5	700	5600	875	4990	0.23	1.6
86	841	7.5	700	6300	1313	6270	0.35	2.0
87	1202	7.5	1000	7300	1875	8110	0.49	2.6
88	1202	10	1000	8300	2500	10,600	0.66	4.
89	1202	10	1000	9300	2500	13,000	0.66	4.
1990	1202	10	1000	10,300	2500	15,500	0.66	5.
91	1202	10	1000	11,300	2500	17,900	0.66	6.
92	1202	10	1000	12,300	2500	20,300	0.66	6.
93	1202	10	1000	13,300	2500	22,700	0.66	8.
94	1202	10	1000	14,300	2500	25,100	0.66	9.
95	1202	10	1000	15,300	2500	27,500	0.66	10.
96	1202	10	1000	16,300	2500	29,900	0.66	11.
97	1202	10	1000	17,300	2500	32,200	0.66	12.
98	1202	10	1000	18,300	2500	34,600	0.66	12.
99	1202	10	1000	19,300	2500	37,000	0.66	13.

^aAssumes shipments are made in ATMX-600 rail cars. Each rail car (shipment) contains a total of 832 ft³ of waste in two 8-ft by 8-ft by 20-ft cargo containers.

^bThe average concentration of Pu before compaction is 0.25 g/ft³. The isotopic composition of Pu is approximately 1% ²³⁸Pu, 60% ²³⁹Pu, 24% ²⁴⁰Pu, 11% ²⁴¹Pu, 4% ²⁴²Pu.

1. All alpha (low radiation level, transuranium solid) waste having alpha radioactivity greater than $10 \mu\text{Ci/kg}$ and capable of being packaged in sufficiently small unit size is shipped to the Repository.
2. The facility will have a capacity of $350,000 \text{ ft}^3/\text{year}$ of waste initially, based on one shift, five-day per week operation, and 1 million ft^3/year of waste ultimately, based on three-shift, five-day per week operation.
3. Wastes will be shipped in ATMX-600 rail cars using two 8 ft by 8 ft by 20 ft returnable cargo containers per car.
4. Wastes will be prepalletized in individual burial units having maximum overall dimensions of 4 ft by 6 ft by 6 ft. Sixty percent of the waste will be packaged as burial units consisting of a dozen 55-gal steel drums, and the remaining 40% will be packaged as steel boxes; therefore, the weighted average waste volume per burial unit is 104 ft^3 .
5. Eight burial units will be shipped per rail car, corresponding to $832 \text{ ft}^3/\text{car}$.

3.2.4 Projected Inventories of Alpha Wastes

The projected inventories of alpha wastes at the Repository (Table 3.1) include wastes from both the AEC and industry. It is assumed that:

1. The regulatory code (10 CFR 50) will be changed to require that industrial wastes be shipped to the Repository on a current basis beginning in 1975.
2. The wastes will be compacted or otherwise reduced in volume by factors of 3 to 10, beginning in the mid-70's.
3. The average concentration of plutonium before compaction is 0.25 g/ft^3 .
4. The isotopic concentration of plutonium at the time of receipt at the Repository is approximately 1% ^{238}Pu , 60% ^{239}Pu , 24% ^{240}Pu , 1% ^{241}Pu , 4% ^{242}Pu .

3.3 High-Level Waste Criteria

The function of the high-level facility of the Repository is to receive containers (cans) of solidified high level wastes from commercial spent-fuel reprocessing plants and to dispose of these wastes in the underground salt bed in such a manner that they will be removed essentially from man's environment. Solidification and shipment of these high-level wastes to a Federal Repository is required by Appendix F of 10 CFR 50.

The following sections present criteria for shipment and acceptance of the waste and a design basis projection of the quantity of wastes that are to be received at the Repository.

3.3.1 High-Level Waste Shipping Criteria

Cans of solidified high-level waste shall be shipped to the Repository in shielded casks in a manner that is approved by the AEC and in accordance with a certification of compliance that is granted by the Department of Transportation. The shipments shall conform with regulations of the Department of Transportation (49 CFR 173.389 through 173.399) and the Atomic Energy Commission (10 CFR 71).

In addition to the above, the following criteria - together with those of Section 3.3.2 - are imposed to facilitate safe receipt, unloading, handling, and disposal of waste cans at the Repository.

1. The high level waste shall be received in rail cars that have maximum length over the couplings of 66 ft.
2. The high-level waste cask shall have outside diameter no greater than 10 ft and outside length no greater than 15 ft.
3. The loaded cask shall weigh no more than 100 tons and the contents shall have thermal power no greater than 76 kW.
4. The cask shall utilize air for venting internal pressure and for an internal coolant.
5. The cask shall be provided with connections approved by the AEC that are suitable for cooling of the waste cans.
6. The cask shall be provided with a lid and a top sealing surface of a design to be specified later by the AEC to facilitate unloading from the top into a shielded transfer cell.

7. The design of the Repository shall not preclude future truck shipments.

3.3.2 High-Level Waste Acceptance Criteria

The dry, solid waste shall be chemically, thermally, and radiolytically stable, and shall be packaged in cans that are designed to maintain their integrity for at least 90 days after they have been buried in salt, assuming they are buried promptly after their receipt at the Repository.

Waste Containers. - Upon receipt at the Repository, the cans will meet the specifications given below. In the analysis for conformance, all factors that might influence the integrity of the can must be considered, including the previous conditions of corrosion, temperature, and pressure to which it has been exposed, and the formation of gases that may have occurred since sealing as a consequence of thermal or radiolytic decomposition of the waste.

1. The waste shall be encapsulated in a sealed, cylindrical metal container having outside diameter between 6 and 14 in. and overall length between 2 and 10 ft. The total weight of the container and its contents shall not exceed 4000 lb.
2. The container shall be equipped with a standardized connector of a design to be specified later by the AEC for its lifting and handling.
3. The container shall be fabricated of a metal that will maintain the waste in a "leak-proof" condition* for at least 90 days when buried in an infinite medium of crushed salt containing 30 vol % air and 0.5 vol % brine at an initial temperature of 70°F.
4. The filled container shall be no more than 1/8 in. out-of-round radially, and shall be bowed no more than 1/2 in. axially from end to end.

*A container is considered to be in a "leak-proof" condition when it exhibits a leak rate $\leq 10^{-7}$ atm-cm³/sec, as measured with a helium leak detector.

5. The filled container shall remain "leak-proof"* following a free fall of 10 ft onto an unyielding surface.
6. The outer surface of the container shall not be contaminated with transferable radioisotopes in excess of 300 dis/min/dm² alpha radiation, and 10,000 dis/min/dm² beta-gamma radiation.

Solidified Waste. - The solidified waste shall meet the following specifications upon its receipt at the Repository:

1. The thermal conductivity, density, heat capacity, thermal power, and homogeneity of the solid shall be such that (1) when buried at an initial temperature of 400°F in an infinite medium of crushed salt containing 30 vol % air, the temperature at no point within the solid will exceed that at which it was formed; and (2) the temperature of the outer surface of the container will not exceed 600°F when standing in air at an ambient temperature of 80°F.
2. The waste solids shall be compatible with moist salt to the extent that they do not react to form unstable solids, liquids, or noxious gases at temperatures up to the maximum value achieved at the waste-salt interface when the waste is buried in an infinite medium of crushed salt containing 30 vol % air initially at 400°F.
3. The identities and concentrations of those isotopes which, when contributions are summed, account for at least 90% of the initial thermal power and total nuclear energy in the waste shall be specified.
4. In no case shall (1) the initial thermal power in any container exceed 5000 watts; or (2) the neutron source-strength of any container exceed 5.2×10^8 neutrons/sec; or (3) the contribution to the initial thermal power in any container from isotopes having half-lives $\geq 10,000$ years exceed 1.0 watts.

*A container is considered to be in a "leak-proof" condition when it exhibits a leak rate $\leq 10^{-7}$ atm-cm³/sec, as measured with a helium leak detector.

Nuclear Criticality Considerations. - A tightly-packed array containing an unlimited number of identical containers in the condition that will prevail upon receipt at the Repository shall be subcritical when dry, or with any degree of water moderation and reflection.

3.3.3 Design Basis Capacity of High-Level Facility

This facility will be designed for an ultimate capacity of 300 cans per week based on the projections of Table 3.2. This table is based on the following assumptions:

1. Only wastes from commercial reprocessing of spent fuel from nuclear power reactors are considered. This includes waste currently in storage at Nuclear Fuels Services, Inc.
2. The installed nuclear electrical generating capacity is 6000 Mw by the end of 1970; 150,000 Mw by 1980; 450,000 Mw by 1990; and 940,000 Mw by the end of the year 2000.
3. A delay of two years occurs between power generation and fuel reprocessing (waste generation).
4. Waste containers have inside diameter of 6 in. and active length of 8 ft. Each cylinder contains 1.6 ft^3 , which is the residual solid waste resulting from a nuclear fuel burnup of 16,000 Mwd(thermal).
5. Half the waste is aged 5 years and half is aged 10 years before shipment to the Repository.
6. Waste is shipped in casks containing 36 cylinders, and weighing as much as 100 tons.

3.3.4 Projected Inventories of High-Level Wastes

The inventories of high-level wastes at the Repository are given in Table 3.2. They are based on the assumptions presented in Sect. 3.3.3. It is also assumed that, at the time of reprocessing (150 days after discharge of the fuel from the reactors), all of the actinides and 0.5% of the uranium and plutonium in the fuel appears in the waste.

Table 3.2. Projected Inventories of High-Level Wastes at the Repository

Calendar Year	Number of Shipments ^a	Number of Cans ^b		Area of Salt Used (net acres) ^c		Cumulative Beta Activity (MCi)	Cumulative Alpha Activity ^d (MCi)	Thermal Power (MW)
		Annual	Cumulative	Annual	Cumulative			
1976	3	88	88	0.2	0.2	15.5	0.09	0.05
77	5	184	272	0.4	0.6	46.8	0.28	0.16
78	9	329	601	0.8	1.4	102	0.58	0.37
79	16	561	1162	1.3	2.7	195	1.11	0.70
1980	23	819	1981	1.9	4.6	327	1.89	1.18
81	34	1240	3221	2.9	7.5	527	3.05	1.89
82	48	1720	4941	4.0	11.5	800	4.64	2.87
83	62	2220	7161	5.2	16.7	1150	6.69	4.07
84	80	2880	10,041	6.7	23.4	1590	9.31	5.60
85	102	3660	13,701	8.4	31.8	2160	12.6	7.62
86	127	4580	18,281	10.5	42.3	2850	16.7	10.1
87	154	5530	23,811	12.7	55.0	3680	22.3	13.1
88	180	6470	30,281	14.8	69.8	4640	27.3	16.3
89	208	7490	37,771	17.0	86.8	5740	33.8	20.2
1990	239	8600	46,371	19.5	106.3	6980	41.3	24.4
91	269	9690	56,061	21.9	128.2	8360	49.5	29.2
92	303	10,900	66,961	24.6	152.8	9900	58.7	34.5
93	333	12,000	78,961	27.2	180.0	11,600	68.7	40.4
94	367	13,200	92,161	29.8	209.8	13,400	79.5	46.4
95	406	14,600	106,761	32.7	242.5	15,400	91.5	53.3
96	439	15,800	122,561	35.5	278.0	17,500	104	60.6
97	478	17,200	139,761	38.6	316.6	19,800	118	68.4
98	511	18,400	158,161	41.4	358.0	22,200	132	76.8
99	550	19,800	177,961	44.4	402.4	24,800	148	85.5
2000	592	21,300	199,261	47.7	450.1	27,500	164	94.9

^aA typical shipment consists of thirty-six 6-in.-diam cans in a cask weighing as much as 100 tons.

^bAll cans are assumed to be 6 in. in diameter and filled to a height of 8 ft with solidified waste. Half of the waste is aged 5 years, and half is aged 10 years at the time of its receipt at the Repository.

^c"Net" acres can be converted to "gross" acres by multiplying by 2.

^dWaste contains all the heavy elements in the fuel after removal of 99.5% of the uranium and plutonium following a post irradiation decay period of 150 days.

3.4 Operational Safety Criteria

3.4.1 Radiological Safety Criteria

Radiation control and monitoring systems for the Repository shall be in conformance with the AEC Manual, Chapter 0524, "Standards for radiation Protection." These standards have basically the same provisions and limits as those required of AEC licensees by 10 CFR 20. The policy of these standards is to "protect the general public, AEC and AEC contractor personnel, and property," and that "operations shall be conducted in such a manner as to assure that radiation exposures to individuals and population groups are limited to the lowest levels technically and economically practical." The following are supplementary criteria for use in the design of the Repository.

Protection of Repository Personnel.

1. Radiation shields and contamination limits, together with the degree of occupancy of the affected zones, shall be selected such that the weekly averaged dose or dose commitment to operating personnel shall be no more than 40% of the radiation protection standards prorated for one week of exposure. For continuously occupied zones, these limits are considered to correspond to a penetrating radiation dose-rate no greater than 1.0 mrem/hr and levels of transferable surface contamination no greater than 300 d/min/dm² from alpha radiation and 10,000 d/min/dm² from beta-gamma radiation. Massive shields for normally occupied work areas such as the operating gallery of the high-level hot cells shall be designed to provide a basic dose rate of 0.25 mrem/hr to provide contingency for shield penetrations and dose accumulation in zones of high radiation.
2. Posted, controlled access "Radiation Zones" shall be established in those areas (such as the high-level cask receiving and decontamination zones) in which the weekly averaged penetrating radiation dose rate is greater than 1 mrem/hr.

3. Posted, controlled access "Contamination Zones" shall be established in those areas (such as the alpha waste unloading area) which have significant potential for direct reading surface contamination in excess of 300 d/min/dm^2 of alpha or $10,000 \text{ d/min/dm}^2$ of beta-gamma or for transferable surface contamination in excess of 10% of these values. Contamination control shall be accomplished through the use of physical confinement barriers and, where possible, the maintenance of a flow of air in the direction of increasing contamination potential. Wherever possible, a face velocity of air of at least 150 ft/min will be provided to isolate zones of potential contamination from their surroundings. Air shall be exhausted from zones of highest potential contamination through high efficiency particulate air (HEPA) filters.
4. "Regulated" zones with physical confinement barriers will be provided as a buffer between contamination zones and the environment. Such zones will consist principally of air locks and change rooms for entry and egress of personnel and materials.
5. Area radiation monitors equipped with alarms shall be provided in all areas in which there is potential hazard from penetrating radiation or airborne contamination.
6. Film badges shall be provided for all Repository personnel. Pocket dosimeters shall be provided for personnel who have operating responsibilities in radiation or contamination zones. Portable survey equipment and/or hand and foot counters shall be provided for use by personnel who are leaving zones of potential contamination.
7. A health physics surveyor who has no operating responsibilities shall be on duty in each of the major sections of the Repository in which there is significant potential for exposure to internal or external radiation. The duties of the surveyor shall include routine surveying of work

areas and the site, testing and calibration of instruments, and providing time-distance criteria for operating personnel.

Protection of the Public. - The only significant source of off-site exposure to radiation or radioactive materials originating from the Repository will be as the result of the routine release of small quantities of airborne radioactive materials that have passed through high efficiency particulate air filters.

1. Personnel and vehicle access to zones of any significant radiation or contamination hazard within the Repository site will be limited by a chain link exclusion fence that surrounds surface facilities of the Repository. Plant guards will man all unlocked gates and check personnel, vehicles, and equipment into and out of the exclusion area. All potentially contaminated equipment and vehicles (including rail cars and casks) will be monitored and decontaminated as necessary before they are removed from the exclusion area.
2. There will be no normal discharges of radioactive materials to the sanitary sewer system. Solid wastes generated within the Repository will be packaged and buried in the mine. Aqueous wastes will be recycled through an evaporator and ion-exchange treatment system. The bottoms from the evaporator and the spent ion exchange resin will be converted to an inert solid, packaged, and stored in the mine. Distillate from the evaporator and other waste water shall be processed for reuse or evaporation to the atmosphere.
3. Releases of airborne radioactive materials from the Repository will be maintained at the lowest practical levels and well below applicable standards by:
 - a. Accepting no radioactive nuclides in gaseous form (other than the very small quantities that result from nuclear transmutation of solid species).

- b. Providing routine decontamination operations to maintain surfaces in contact with ventilation streams as free of transferable contamination as possible, and
 - c. Passing all air from zones of potential contamination through HEPA filters which are suitably equipped to permit periodic in-situ testing, and replacement without compromising the integrity of the confinement system.
- 4. The Repository monitoring systems for airborne radioactive effluents will consist of monitors on each of the exhaust stacks and a ground-level array of site monitors that surround structures of the Repository. In addition, the State of Kansas will maintain an array of environmental radiation monitors at strategic off-site locations.
- 5. Confinement barriers (including critical structures and ventilation systems) and critical personnel protection and instrument systems will be designed, tested, routinely inspected, and maintained to ensure that the necessary confinement potential and radiation safety are maintained following exposure to any credible internal and external forces.

3.4.2 Mine Safety

The prescribed standard governing mine and tunnel safety for the Federal Repository will be the Federal Health and Safety Standards, "Metal and Non-Metallic Underground Mines," 30 CFR 57. In addition, the California State Mine Safety Orders will be used as a guideline on mining safety wherever the Federal Code 30 CFR 57 is silent on a particular subject or where the California Mine Safety Orders contain specific provisions which will enhance safe operation without being inconsistent or incompatible with the corresponding Federal Code provisions.

3.4.3 Industrial Safety

The standards for industrial safety shall be in conformance with the AEC Manual, Chapter 0550, "Operational Safety Standards." The policy of these standards is "for the protection of AEC and AEC contractor employees, the general public, and the environment, and for minimizing damage to, or the loss of, property from the hazards resulting from AEC operations." One of the general safety prescribed standards of Chapter 0550 is the General Design Criteria, AEC Chapter 6301, which establishes criteria to be used for the purpose of incorporating economy, safety and sound practices in the design and construction of facilities. Other standards listed in Chapter 0550 that will be particularly applicable to the design and construction of the Repository are listed below.

General Safety. - 41 CFR 50-204, Regulations pursuant to the Walsh-Healy Act (except for radiation exposure limits and reporting requirements).

Construction Safety

1. Safety Code for Building Construction, ANSI A10.2 (and related revisions in A10.4 through A10.8).
2. General Safety Requirements, EM 385-1-1. U.S. Corps of Engineers (Department of Army) and ORO Minimum Safety Requirements.

Explosives Safety

1. Safety Manual, AMCR 385-100, U.S. Army Material Command (AMC), (supersedes AMCR 385-224).
2. Blaster's Handbook. E.I. du Pont de Nemours & Company.
3. Safe Storage, Handling, and Use of Commercial Explosives at Metal Mines, Non-Metallic Mines, and Quarries, Information Circular 7674, Bureau of Mines (DOT).

Motor Vehicle and Traffic Safety

1. Manual on Uniform Traffic Control Devices for Streets and Highways, Bureau of Public Roads (DOT).
2. A Policy on Geometric Design on Rural Highways (AASHO).

Transportation of Radioactive Material

1. Safety Standards for the Packaging of Radioactive and Fissile Materials, AEC Manual Chapter 0529.
2. DOT Regulations 49 CFR 173.389 through 173.399.

Fire Protection

1. Industrial Fire Protection, AEC Manual Chapter 0552.
2. National Fire Codes (NFPA).
3. Uniform Building Code (ICBO).

Industrial Hygiene. - Current Threshold Limit Values (ACGIH).

Environmental Sanitation

1. Water:
 - a. Federal Water Pollution Control Act as amended, 33USC466h.
 - b. Prevention, Control, and Abatement of Air and Water Pollution, AEC Manual Chapter 0510.
 - c. Standards and Specifications for Water Supply, Treatment, Distribution System, and Storage Equipment, Materials and Procedures (AWWA).
 - d. National Plumbing Code, ANSI A40.8.
 - e. Water Pollution Control Facilities, AEC Appendix 6301.
2. Air: Prevention, Control, and Abatement of Air and Water Pollution, AEC Manual Chapter 0510.

3.5 Facility Design Criteria

3.5.1 Confinement and Ventilation Systems

The confinement systems of the Repository shall be used to restrict release of radioactivity to the environment during normal or accident conditions. Confinement systems consist of structures or part of structures (including the mine as a structure), waste containers, closures, air movement systems, and filter systems. To prevent the release of radioactivity, areas where radioactive waste will be handled will be confined. The following criteria shall apply to confinement systems:

1. Two sealed barriers shall be maintained between the radioactive waste and the environment at all times.
2. The structures shall be designed to prevent the dispersal of radioactivity to the environment in the event of an accident.
3. Under emergency conditions, the structures shall be capable of being maintained at a negative pressure relative to the atmosphere. For increased reliability and simplicity, structures will normally operate in this condition.
4. All entries into and from confinement areas shall be made through air locks to preclude loss of confinement and the possible escape of contaminants to the atmosphere.
5. Air in the structures shall flow from areas of least contamination potential to areas of increasing contamination potential.
6. Recirculation of air within zones of similar contamination potential, or from zones of lesser to greater contamination potential is permitted, if passed through HEPA filters.
7. Ventilation systems shall be backed up by standby systems to maintain confinement in the event of fan breakdown, filter failure, or normal power outage.
8. Air discharged from confinement systems shall be exhausted through prefilters and HEPA filters. Air from areas of highest contamination potential (alpha handling rooms or cell exhaust) shall be exhausted through two individually testable HEPA filter banks in series. Air which is normally clean but which has the potential of becoming slightly contaminated requires only one bank of HEPA filters.
9. Corrodents or moisture in the exhaust air capable of damaging the filters shall be removed or neutralized prior to discharge to the filters.
10. HEPA filter systems shall be tested in place at a prescribed frequency (normally twice a year), using dioctyl phthalate (DOP) aerosol, and shall have a minimum test efficiency of 99.95%.
11. Confinement systems shall be designed to maintain their integrity in the event of fire.

Alpha Facility Ventilation and Confinement System: Surface Facilities. - The waste receiving building shall be operated at a negative pressure with respect to the atmosphere. Ventilation flows shall be controlled by pressure differential from areas of low contamination potential to areas of successively higher contamination potential. Pressure differential shall be maintained by the resistance of individual items or a combination of items consisting of dampers, backflow preventers, filters, grilles, louvers, and fans.

The nonrestricted and the confinement zones of the waste receiving building shall be ventilated by independent exhaust and control systems. The nonrestricted zones shall be air conditioned and ventilated with a minimum of six air changes per hour. Fresh makeup air shall be filtered through a prefilter (30% NBS) and main filter (90% NBS) before distribution. The exhaust air shall be passed through, in series, a 30% NBS filter, 90% NBS filter, and a HEPA filter before discharge to the atmosphere. Since the air that is being processed has a low contamination potential, the exhaust system need not have auxiliary backup capabilities. Neither shall the system be tied into the standby power network.

The confinement zone system shall supply air conditioning and ventilation air to the unloading and decontamination rooms, transfer room, alpha hoist house and head frame, shaft and exhaust fan-filter room. All confinement zones, except the exhaust fan-filter room, shall be ventilated with six to ten air changes per hour; the exhaust fan-filter room shall be ventilated with a minimum of four air changes per hour. Fresh makeup air shall flow through prefilters (30% NBS), main filters (90% NBS), HEPA filters, and a backflow preventer before being distributed to these rooms. The system shall be designed so that the shaft, transfer room, and the unloading and decontamination rooms will be maintained at successively lower pressures. The exhaust air from the confinement zones shall be processed through a 30% NBS filter, a 90% NBS filter, two HEPA filters in series (separately DOP testable),

and then discharged to the atmosphere. Except for the alpha hoist house, a duplicate filter bank and exhaust fan installation shall be provided for continuous operation reliability. Both fans shall be tied into the standby power distribution system. Upon loss of normal power the confinement zone ventilation supply system shall automatically shut down, and the exhaust fan shall automatically operate at half speed.

The shaft shall be ventilated with filtered air at a rate designed to maintain a 150-ft/min face velocity across the opening between the shaft and the alpha cage during loading and unloading operations.

Appropriate instrumentation and access ports shall be installed on all filter installations to permit in-place testing, effluent sampling, and pressure drop recording. The instrumentation and suitable alarms shall be tied into the building control panelboard and the central monitoring console at the Repository operations building.

Alpha Facility Ventilation and Confinement System: Alpha Mine. -

The ventilation air for both the high-level and the alpha mines shall be supplied from the surface. The flow shall be split at mine level and the required air flow diverted to the alpha mine. The alpha mine air flow shall be split between the waste burial and mine cleanup areas, using air-tight brattices to control the flow. The exhaust air from the mine cleanup area shall be filtered locally in the mine through a series of 7%, 30%, and 90% NBS filters and serve as the fresh air supply to the waste burial area. The total exhaust from the burial area shall then be filtered locally through a series of 7% NBS, 30% NBS, 90% NBS, and HEPA filters and passed through a backflow preventer before it is recombined with the exhaust from the high level mine and carried to the surface through the upcast vent shaft. The combined exhaust streams shall be passed through 90% NBS filters, followed by two HEPA filters in series, and blast dampers (for protection of the filters from tornado pressures) before discharge to the

atmosphere. A minimum distance of 500 ft shall be established between the upcast vent shaft and the nearest Repository boundary.

The filter installation shall be designed to permit shutdown of a single filter bank while retaining a minimum of 80% of design air flow through the mine. The exhaust blowers shall be tied into the standby power system. Appropriate instrumentation and access ports shall be installed on each filter bank installation to permit in-place testing, effluent sampling, and pressure drop measuring. The instrumentation and suitable alarms shall be tied into the operations building central monitoring console.

High-Level Facility Ventilation and Confinement System: Surface Facilities. - The high-level waste receiving building shall be operated at a negative pressure with respect to the atmosphere. Ventilation flows shall be controlled by pressure differential from areas of low contamination potential to areas of successively higher contamination potential. Pressure differentials shall be maintained by the resistance of individual items or a combination of items consisting of dampers, backflow preventers, filters, grilles, louvers, and fans.

Normally inhabited areas of confinement zones shall be ventilated with six to ten air changes per hour, except for the cask unloading area which shall have a minimum of three changes per hour. Fresh make-up air to all confinement zones shall flow through prefilters (30% NBS), main filters (90% NBS), HEPA filters, and a backflow preventer before being distributed to these areas. Exhaust air from all confinement zones shall be processed through a (30% NBS) filter, a (90% NBS) filter, two HEPA filters in series (separately DOP testable), and then discharged to the atmosphere. A duplicate filter bank and exhaust fan installation shall be provided for reliability of operation, except for the high-level hoist house. Both fans shall be tied into the standby power distribution system. Upon loss of normal power the confinement zone ventilation supply system shall automatically shut down, and the exhaust fan shall automatically operate at half-speed.

The non-restricted areas of the building, except the maintenance area, shall be supplied with fresh air filtered through 30% NBS and 90% NBS filters. The exhaust from non-restricted areas, except the maintenance area and the operations office, shall be filtered through 30% NBS, 90% NBS and a single bank of HEPA filters before discharge to the atmosphere. The maintenance area and operations office shall be given conventional ventilation treatment. Ten air changes per hour shall be supplied to the change room, chemical laboratory, and health physics office.

High-Level Ventilation and Confinement System: High-Level Mine. - Mine ventilation air will be supplied to all underground facilities from the surface. The high-level mine air shall be directed through the areas where mining operations are being carried out, filtered, then routed through the areas where wastes are being buried, filtered locally again, and finally exhausted through the upcast ventilation shaft and filtered at the surface, after being combined at mine level with the exhaust from the alpha mine, in accordance with the provisions described above for the Alpha Facility.

Earthquake, Tornado, and Flood Protection. - Structures, systems, and equipment within the Repository shall be designed to withstand natural phenomena such as earthquakes and tornadoes so that no loss of function occurs if that function is required for public safety. The following specified levels of operational reliability and shutdown capability shall be met in the event of such natural phenomena:

Category I: All structures, systems and equipment whose failure could cause release of excessive amounts of radioactivity; or those structures, systems and equipment that are essential for the safe shutdown of waste handling operations without endangering the public health and safety during or following a design basis earthquake or design basis tornado.

Category II: Those structures, systems and equipment that are required to permit continuation of waste handling operations

without endangering the public health and safety during and following an operating basis earthquake or design basis winds. Category III: Those structures, systems, and equipment whose failure will not result in release of excessive amounts of radioactivity, or are not essential to continued waste receipt and burial operations.

All vulnerable components of the Repository shall be designed to withstand the "probable maximum flood," as determined by the procedure set forth in Civil Engineer Bulletin No. 52-8, Revised March 1965, Office of the Chief of Engineers, Department of the Army.

3.5.2 Quality Assurance and Reliability

A quality assurance program for the Repository shall be developed which can be applied to all facets of construction, procurement, and installation. This program must include management, methods, and engineering standards which can be applied throughout the Repository project, with appropriate levels of quality to be applied to each phase. Furthermore, a reliable backup method shall be supplied for any operation which, once commenced, must be completed. Such operations are those whose failure might expose operating personnel to intolerable radiation levels, endanger the public or environment, or require the Repository to cease operating.

3.5.3 Retrievability

The Repository will be operated as a demonstrational facility for the first several years for the purpose of obtaining that information which is required to confirm all important aspects that bear on the safety of its design and operation. During this demonstrational period, the emplacement of all radioactive materials in the Repository shall be done in a manner that renders them readily retrievable. A detailed concept shall be developed for retrieval of those wastes that are to be buried thereafter.

4. SITE AND ENVIRONS

4.1 Site Selection Factors

Salt deposits are extensive in the continental United States, underlying approximately 500,000 square miles in portions of 23 states (Fig. 4.1). Only three general areas, however, satisfy the site criteria presented in Sect. 3.1 for the Federal Repository. These areas are: (1) a large area of central Kansas (approximately 10,000 sq miles), (2) a smaller area in west-central New York (approximately 1,000 sq miles), and (3) a still smaller area in southeastern Michigan (in general, underlying metropolitan Detroit). An examination of the geologic aspects of these three areas indicates that, based on current information, all three would be suitable.

The principal advantage of the central Kansas area and the Lyons site are:

1. The depth of the disposal horizon is generally less.
2. The thickness and areal extent of the salt bed are greater.
3. The area lies in seismic risk zone one.
4. More is known about the nature and properties of the formation and its environs since extensive experimental work has been performed in the area.
5. The Lyons mine of the Carey Salt Company appears to be uniquely suitable in that it is the only available, accessible, and nonproducing salt mine known to be in any of the geologically acceptable areas.
6. The Lyons site is served by three railroads and a U. S. highway.
7. The Lyons site is conveniently located in the approximate geographic center of the continental United States.

4.2 General Location and Site Description

4.2.1 Geography

The proposed site of the Federal Repository is near the center of Rice County, Kansas, immediately northeast of Lyons, the county seat.

Fig. 4.1. Rock Salt Deposits in the United States and Those Portions Suitable for the Initial Demonstration Repository.

Rice County is located near the center of the state of Kansas and is about 100 miles south and slightly east of the geographic center of the 48 contiguous states. The site includes the inactive mine of the Carey Salt Company, which was opened in 1890, and an additional area to the north and east of the mine.

The location of the site is shown on Fig. 4.2, which shows the location of Rice County, Lyons, the adjoining Carey Mine and the Repository site. A part of the site, consisting primarily of old mine workings, is within the Lyons city limits.

Rice County has an area of 452,480 acres which is principally used for agriculture. It is located approximately on the line between eastern Kansas, which is characterized by greater industrialization and more dense population, and western Kansas, which is very thinly populated and has very little industry.

4.2.2 Recommended Site Acquisition

The Repository will utilize approximately 1,020 acres of salt bed area for the storage of high-level and alpha wastes. The inactive Carey Salt Mine will be reconditioned and used for the storage of alpha wastes; a new area to be developed north and east of the Carey Mine will be used for the storage of high-level waste.

It is planned that the land and associated subsurface mineral rights over the burial areas be obtained in "fee simple title," subject to existing easement for public roads and highways, public utilities, railroads, and pipe lines. A 1-mile buffer zone consisting of all subsurface mineral rights will be acquired in this zone.

4.2.3 Transportation

Lyons and Rice County are served by three railroads, by a number of state highways, and by a main east-west U. S. highway.

Railroads. - A branch off the main Missouri Pacific line between Kansas City and Pueblo, Colorado, runs from Wichita to Geneseo. It passes over the existing Carey Mine at Lyons and constitutes the western boundary of the Repository. The Missouri Pacific

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Fig. 4.2. Site Location for Proposed Repository.

main line runs east-west near the Rice-Ellsworth County line about 12 miles north of Lyons. There has been no passenger service on these lines for several years.

A Santa Fe branch line runs east-west through Lyons connecting the main line at Florence with the former main line at Ellinwood, about 20 miles west of Lyons. This branch line borders the Repository site on the south. Other Santa Fe trackage in the area consists of a branch line running northwesterly from Little River through Geneseo into Ellsworth and Barton Counties, and the former main line which runs northwesterly from Hutchinson through Sterling and Great Bend before turning back south. Passenger service on all these lines has been discontinued for some years.

A branch of the St. Louis - San Francisco Railway Company runs from Wichita generally northwest through Lyons to Ellsworth, about 30 miles north of Lyons, where it joins the Union Pacific. No passenger service has been offered in many years.

Air Service. - No scheduled air passenger service is available in Rice County. Lyons has an airport equipped for business and private flying. Scheduled feeder-line service is available to Hutchinson and Great Bend, each about 30 miles distance. Wichita, approximately 85 miles from Lyons, is served by Trans World Airlines, Braniff Air Lines, and Continental Air Lines, as well as the feeder line.

Highways. - U.S. Highway 56 runs east and west through Lyons and Rice County. It enters Kansas at Kansas City in the east and leaves at Elkhart in the extreme southwest corner. State Highway 14 runs north and south through Lyons, and State Route 96 connects Hutchinson and Great Bend through Lyons. All section-line roads through the proposed site are open and graveled.

Continental Trailways operates bus service from Wichita to Denver through Lyons. A connecting line operates east to McPherson.

4.2.4 Population and Population Centers

The population of Rice County is approximately 12,130, according to preliminary figures for the 1970 census. Population centers are shown in Fig. 4.3. The population has gone down in recent years, which is typical of areas in which the economy is based on agriculture. Population in 1960 was 13,260, and in 1950 it was 14,020.

Populations of the principal towns in the county are also becoming smaller. The population of Lyons has been somewhat variable over the past five years (Table 4.1), but since 1968 it has been on a downward trend.

Table 4.1. Population Data^a for Lyons

Year	Population
1965	4701
1966	4729
1967	4767
1968	4922
1969	4739
1970	4510

^aData from Lyons Daily News, April 3, 1970. Population of Lyons was 36.4% and 36.9% of Rice County for 1969 and 1970 respectively.

The neighboring city of Sterling, eight miles south of Lyons, is reported to have 2,300 people in 1970.

No other town in the county has as many as 1,000 people. Census records include them with the township in which they are located. The towns such as Chase, Geneseo, Little River, Bushton, Alden, and Raymond are primarily residential with the necessary service businesses. An exception is Bushton, which has a large compressor station and natural gas processing plant located just outside the town.

Fig. 4.3. Population Centers in Rice County, Kansas. (The numbers in parenthesis are populations taken from the official 1970 U. S. census.)

4.2.5 Current Land Use

Urban. - Rice County has only two cities which may be considered urban areas: Lyons and Sterling. The area occupied by these two municipalities is insignificant compared to the total area of the county.

A part of the proposed site falls within the corporate limits of Lyons. This includes 34.46 acres owned by the Carey Salt Company, 44.37 acres of land in various ownerships, and a part of the railroad rights-of-way. While most of this land has been platted and some streets and utilities installed, there has been little development. The land is zoned for industrial use, but is used largely for agriculture.

Agricultural. - The county is largely devoted to agriculture, with wheat and milo the principal crops. In 1970, wheat averaged approximately 35 bushels to the acre and the 1969 milo crop averaged about 40 bushels per acre. The livestock industry is very active both in pastured herds and in small-to-moderate-size feed lot operations. Substantial areas are under irrigation along the Cow Creek and Arkansas River flood plain.

A total of 924.40 acres of rural property, plus the rural portion of the 16.99 acres of railroad rights-of-way mentioned previously, is required in fee simple. This is tillable land now used for both crop and pasture. There are three sets of farm improvements, and the farm fences are good to poor in quality and condition.

Utilities. - Four pipelines traverse the area of the proposed Repository. They are 8-in. and 12-in. natural gas lines owned by Cities Service Gas Company, a 6-in. natural gas line owned by Northern Natural Gas Company (formerly known as Plateau Natural Gas Company), and a 4-1/2-in. liquid line owned by the Skelly Oil Company.

Underground facilities will not necessitate relocation of these pipelines. However, interference with surface facilities and safety considerations will require some relocation.

Mineral Resources. - Minerals which occur in commercial quantities in Rice County are salt, oil and gas, and sand and gravel. All of the county is underlain by salt beds, and development has been intensive in salt and petroleum. Sand and gravel are produced primarily for local needs.

Salt was discovered prior to 1890 and the first mine shaft was sunk beginning in 1890. This was the present Carey mine which continued in operation until 1948. The American Salt Corporation mine located about two miles south of the Carey mine was opened in about 1918 and continues to produce salt from the same level as the Carey mine. The American Salt mine with the associated surface facilities has been modernized and the capacity increased. About 1000 tons of salt are shipped daily. The American mine is one of the three operating rock salt mines in Kansas. Others are the Independent Salt Company at Kanopolis, Ellsworth County, and the Carey Salt Company at Hutchinson, Reno County.

Gas was first discovered in Rice County, Kansas, in 1887; however, it was not until the discovery of oil in the Welch pool in 1924 that a significant number of wells were drilled to test the oil and gas possibilities of the area. Fields discovered in the first years following the Welch discovery included the Raymond Field in 1929, Chase-Silica in 1931 and Geneseo-Edwards pool in 1934. The most significant Kansas discovery of the last decade was the Tobias Field which was discovered in 1961. Production in the Tobias Field is obtained from the Simpson sand and the Arbuckle lime. Cumulative production from this field now exceeds seven million barrels. The Tobias Field is located about six miles west and six miles south of the proposed site.

Only one producing oil well has been developed on the Repository site. It was drilled in 1964 and has been a very marginal producer. Three dry holes have been drilled in the area between 1963 and 1965. Other oil tests and gas wells have been drilled in the 1700-ft-wide buffer zone around the Repository site. All oil tests were dry. Some gas has been produced in the past, but all wells are now thought to be plugged.

All of the land involved in the Repository is leased for oil and gas, except that owned by Carey and that within the city limits. Most of these leases were obtained in early 1970 and are for three-year terms.

Sand and gravel are produced by dredging from deposits in the flood plain of the Arkansas River and Cow Creek. Pits are in operation about two miles south of Lyons and near Sterling. A quarry has operated in the Stone Corral dolomite near Little River for the production of crushed rock.

4.2.6 Socio-Economy

Rice and the surrounding counties in central Kansas are largely rural and agricultural, with light to intensive petroleum development in some areas. The service industries associated with these activities are present and in some cases are of considerable magnitude. In recent years some industry has been established in the towns; in most cases this may be described as "light industry." Some typical industrial operations are production machine shops, specialized farm implements, "add-on" components for farm implements, and miscellaneous metal fabrication. Oil drilling, production, and refining and salt production are the "heavy" industries in the area.

Farming has become the province of large operators. The original homesteader quarter-sections have been broken up and recombined to produce larger farming units which will allow profitable operation. A substantial amount of acreage is held by retired persons, widows, and estates. Some farmers are able to assemble an economic unit using rented land. When unable to farm full time, many farm operators work at outside jobs to supplement their income.

The result of the increased size of farm units has been a drop in population and the razing of many farmsteads. It is not uncommon to find the farm operators residing in town.

Lyons also has some manufacturing enterprises which include Lyons Manufacturing Company - a producer of precision tools, a mobile home manufacturing industry, a grain elevator and handling facility, and a number of smaller agricultural and petroleum industry-related enterprises.

4.2.7 Baseline Reference Studies

Initially, all waste shipments will be made to the Repository by rail. A competent authority will be engaged to assess the conditions of the two rail spur lines that serve the Repository. Existing load capacities will be determined and the degree of upgrading necessary to meet Repository load requirements will be defined. The study will be completed well in advance of startup to permit sufficient time for remedial action by the railroads.

4.3 Physiography and Geology

4.3.1 Physiography

Physiographically, the proposed repository site at Lyons, as well as a large part of the state of Kansas, lies within the Great Plains Province of the United States (Fig. 4.4). This broad belt of highlands, which extends from Canada to Mexico, slopes gradually eastward from the Rocky Mountains to the Central Lowland. The Province is essentially a broad syncline with the beds on the west dipping eastward off the flanks of the Rocky Mountains and those on the east dipping gently westward. Tertiary and Mesozoic beds cover the surface over much of the Great Plains; however, a few outcrops of the underlying Paleozoic formations occur in discontinuous bands along the western edge of the Province. The central part of the Province is generally flat and featureless, but erosion has dissected the plain to some extent along its eastward and westward margins. Most of west central Kansas, including the Lyons site, lies within the Plains Border section of the Province which is the erosional transition belt between the smooth fluviatile plains to the west and the Central Lowlands to the east¹ (Fig. 4.4). In general, this physiographic section is characterized by maturely dissected east-facing escarpments that appear as broad hilly belts. Differential resistance to erosion of the various rock types and the slight westward dip of the strata afford the conditions for the topographic development within the section.

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Fig. 4.4. Physiographic Map of a Portion of the United States Showing the Location of the Proposed Repository.

At the proposed Lyons repository site, which is situated along the eastern edge of the Plains Border section, the irregular and uneven topography of the eroded and underlying Cretaceous rocks is blanketed with a thick mantle of eolian silt that accounts for the present relatively flat surface (Fig. 4.5).

Geographically, Lyons is located in the exact center of Rice County, which is situated in the approximate center of the state (Fig. 4.6). In general, the land surface in Kansas slopes toward the east at a rate of about 10 to 15 ft/mile with the highest elevation of 4135 ft occurring along the western edge of the state and the lowest elevation of 703 ft occurring near the southeastern corner of the state. The elevation of Lyons is 1696 ft. In general, the land surface at the 1-square-mile site slopes gradually from the north, where the maximum elevation is near 1750 ft, to the south, where elevations are as low as 1690 ft.

4.3.2 Regional Geology

General. - Kansas is located in the heart of the stable mid-continent area of North American which is characterized by subdued topography and flat-lying beds. Within the state a relatively thin and simple succession of sedimentary rocks cover the Precambrian basement complex. These crystalline rocks represent the buried southern extension of the Canadian Shield. In general, the sedimentary rocks, which range in age from the Cambrian to the Quaternary, all dip gently toward the west (Fig. 4.7). This slight westward dip of the rocks, coupled with the gradual change in elevation from east to west, has resulted in the general succession of the surface outcropping of the oldest rock in the east to progressively younger ones in the western part of the state. Unconsolidated Quaternary deposits of loess, alluvium, and some glacial deposits provide a thin cover over much of the land surface of Kansas and also form thick section of valley fill deposits. Tertiary deposits, which are widespread and, for the most part, unconsolidated like the younger Quaternary deposits, are thickest in the western part of the state. Mesozoic rocks, mostly of Cretaceous age, extend only as far eastward as

Fig. 4.5. Photograph Showing the Surface Topography at the Proposed Repository Site.

Fig. 4.6. Location Map Showing the Proposed Repository.

Fig. 4.7. Generalized Geologic Map and Cross Section of Kansas Rocks. (After Special Distribution Publication 5, State Geological Survey, The University of Kansas, December 1963.)

central Kansas. Permian and Pennsylvanian rocks crop out extensively in eastern Kansas, while Mississippian rocks, which are exposed at the surface only in the extreme southeastern portion of the state, are the oldest outcropping rocks.

Even though Kansas and the stable interior of the continent have not been subjected to diastrophic movements since Precambrian time, some areas have been structurally positive (rising) in the geologic past, while others have been structurally negative (subsiding) (Fig. 4.8). These ancient structural features, while largely masked by surface rocks, are extremely important in the subsurface, especially in regard to petroleum explorations. Principal events in the geologic history of the state and region include, during the early Paleozoic, the submergence and deposition of marine sediments on an irregular and long eroded surface of Precambrian igneous and metamorphic rocks. Erosion then reduced most of eastern Kansas to an extensive peneplain before the region was again inundated by ocean waters and Mississippian rocks were laid down. During late Mississippian and Pennsylvanian time, the state was alternately submerged and elevated before experiencing a period of aridity during the late Permian as evidenced by the extensive salt and gypsum deposits of that age. Another major period of emergence and erosion occurred over most of the state during the Mesozoic Era before the deposition of marine and continental deposits of mostly Cretaceous age. Erosion was prominent during the early Tertiary, but later eastward flowing streams left thick accumulations of gravel, sand, and silt over the entire state, forming the plains character. Continental ice sheets invaded northeastern Kansas during the Pleistocene, while the remainder of the state was subjected to wind and water erosion which has continued to modify the landscape of the area to the present.

Stratigraphy. - A generalized columnar section of rocks underlying Rice County and the proposed site is shown in Fig. 4.9. Some variations in the rock column, especially in the thicknesses of the shallow formations, will occur at the site and throughout the county because of topographic differences and changes in the structural and

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BASINS		UPLIFTS	
A	ARKANSAS	1	OZARK
B	ANADARKO	2	AMARILLO
C	SALINA	3	LAS ANIMAS
D	FOREST CITY	4	CENTRAL KANSAS
		5	CAMBRIDGE
		6	SIOUX
		7	NEMAHA

Fig. 4.8. Major Structural Features of a Portion of the Midcontinent (After F. G. Snyder, "Tectonic History of Midcontinental United States," UMR Journal, No. 1, pp. 65-67, April 1965). (Publication of the University of Missouri at Rolla.)

Fig. 4.9. Generalized Geologic Section, Rice County, Kansas (after Type Log for Rice County, Catalog 20-19-8W, published by Kansas Geological Society).

stratigraphic characteristics of the rock formations. Nonetheless, the column is representative of the rocks that are found most frequently at the surface and in the subsurface in this part of the state.

The Sanborn formation of Pleistocene age, which consists of unconsolidated deposits of sand, silt, and gravel, comprises the surface material at the location of the rock column (Sec 20 - Range 19S - Township 8W). The thickness and extent of Pleistocene sediments, which typically are deposits of unconsolidated sand, gravel, and silt, vary throughout the area. They are up to several hundred feet thick and offer the most complete record of Pleistocene deposition in buried stream valleys near the site, such as Cow Creek and the Arkansas River, but are totally absent in large areas north and south of Rice County. Rocks of Tertiary age are absent in the rock column at the sample location and toward the north; however, they are preserved as erosional remnants in a few isolated areas throughout the county. Shales of Cretaceous age unconformably underlie the Pleistocene sediments. The eastern limit of Cretaceous rocks, which for the most part consist of ferruginous sandstones, clayey shales, and chalky limestones, passes diagonally through central Kansas or through the extreme eastern part of the county; hence, the rocks are thinnest to the east of the site and thicken to the west of it.² Cretaceous formations crop out over a rather wide area a few miles east of Lyons. Jurassic and Triassic rocks are not found at the site. Jurassic age sediments are present only in the extreme northwestern part of central Kansas, while Triassic rocks occur only in the extreme southwest corner of the state.²

In the columnar section, it is seen that a thick section of Permian rocks underlies the Cretaceous rocks in an unconformable manner. Perhaps the most important aspect of these rocks is the presence of the thick accumulation of salt. The salt beds are seen to be about 300 ft thick and capped with several hundred feet of red-colored shale and siltstone. The nature and extent of the salt are discussed in detail later. A useful marker bed in subsurface investigations above the salt is the Stone Corral formation of Upper

Permian age. Thick beds of anhydrite lie below the salt, while the remainder of the Permian rocks consist mostly of alternating layers of shale and limestone. Permian rocks are exposed at the surface just east of the site in the valley of the Little Arkansas River. Here and in the wide outcrop band further east, much of the section, which is present toward the west, has been beveled by erosion. Important stratigraphic changes also occur laterally in some of the upper and middle Permian rocks. For instance, the Stone Corral formation is almost entirely dolomite and is only about 6 ft thick in Rice County; however, the formation thickens to the west and may be represented there by anhydrite, shale, and/or saliferous beds.²

Pennsylvanian rocks lie unconformably beneath the Permian formations as seen in the columnar section (Fig. 4.9). This thick sequence of mostly alternating beds of shale and limestone with a few sandy members contains many oil and gas horizons, especially in the lower half. Many of these oil and gas horizons are associated with structures along the central Kansas uplift which is discussed later. However, other accumulations of oil and gas are found where lateral changes occur in rock porosity. While oil and gas are of primary importance in Pennsylvanian rocks in the subsurface of central Kansas, coal beds are found in surface exposures of these rocks in southeastern Kansas as well as in the subsurface in the eastern part of the state. In general, the contact between Pennsylvanian and Permian beds in central Kansas is conformable; however, locally, as in the case at the location of the columnar section, continuous deposition was interrupted temporarily by a cycle of uplift and erosion.

Mississippian and Devonian rocks are represented in the columnar section only by a relatively thin section of the Chattanooga shale formation while age has not been definitely established. Mississippian rocks are characterized by the abundance of limestone with shale, sometimes occurring as the lower member. All Mississippian and Devonian formations have been removed from the crest of the central Kansas uplift, and only the lower shales remain on the eastern flank

of this major structural feature. Mississippian and Devonian rocks in central Kansas are separated from the rocks above and below by prominent unconformities. Large quantities of gas are produced from Mississippian rocks in the southern part of central Kansas.

Silurian and Devonian rocks, commonly undifferentiated in Kansas, are absent in the columnar section and over most of the general area of the Repository. They are found only in the northeast quadrant of the state and consist mainly of limestones and dolomites.

Ordovician rocks in the column are predominantly shale and limestone. These rocks are also absent along the crest of the central Kansas uplift and generally in the northwest and southeast corners of the state. Gas pools have been found in Ordovician rocks at several localities in central Kansas.

The "Arbuckle" group of rocks lies unconformably between the overlying Ordovician rocks and the Precambrian basement. This thick sequence of predominately dolomitic rocks includes Lower Ordovician as well as Cambrian rocks. It is present throughout Kansas with the exception of isolated areas of the central Kansas uplift and the Cambridge Arch and also underlies large areas in Oklahoma and Missouri. These rocks contain the most important oil and gas reservoirs in Kansas. In general, the Arbuckle thickens toward the south, southeast, and east.²

Precambrian crystalline rocks lie at a depth of 4000 ft at the site of the columnar section. At this location, as well as throughout most of the area surrounding the site, these rocks are primarily granite.

Structure. — Figure 4.10 is a map of Kansas showing the major structural features of the state. The central Kansas uplift, which is the largest positive area in the state, is the dominant structure in the central part of Kansas. It is flanked on the northeast by the Salina Basin and on the southwest by the Hugoton embayment of the Anadarko Basin (Fig. 4.10). Further to the southwest is the northernmost extension of the Las Animas uplift. The north-south trending Nemaha uplift and portions of the Forest City and

Fig. 4.10. Map of Kansas Showing Major Structural Features and Locations of Earthquake Epicenters (after P. F. Merriam, 1956, "History of Earthquakes in Kansas," Seismological Society of America Bulletin, Vol. 46, No. 2, pp. 87-96).

Cherokee basins are important structures in the eastern part of the state. Indeed, these major structures, which developed gradually throughout geologic times, constitute the "framework" of the geology of Kansas and have influenced greatly the accumulations of oil and gas as well as the groundwater resources in the state.

The central Kansas uplift had its major development at the end of Mississippian time. It came into existence prior to the Mississippian through the rejuvenation of an older arch and continued its rise during Pennsylvanian and Early Permian time.² As seen in Fig. 4.11 the uplift of this area of about 5700 square miles resulted in stripping Mississippian rocks and older formations from the surface and thinning the Pennsylvanian sediments. Weathering of the exposed rocks along the uplift increased greatly their porosity and permeability which subsequently was instrumental in the accumulation of oil and gas deposits in the area. At the time of the deposition of the Hutchinson salt, the uplift was no longer active. Indeed, several thousand feet of sediments separate the salt rocks from the underlying oil and gas deposits which also for the most part lie to the west of the Lyons site. In part, contemporaneous with the formation of the central Kansas uplift was the development of the adjacent Salina and Anadarko basins. The corresponding rock sequences in these areas are largely continuous and thick.

The Nemaha anticline is a pronounced, northeasterly trending structural feature that traverses the entire state. It became active prior to Pennsylvanian time and its development continued until mid-Permian time.² Even though this structure lies outside the central Kansas area, it is of interest here because earthquakes along it may be felt at the site in central Kansas.

Salt Deposits in the Permian Basin. - The salt deposits of central Kansas lie in the northernmost extension of the Permian Basin which stretches from central Kansas through the Oklahoma Panhandle and into western Texas and eastern New Mexico, covering an area of about 120,000 square miles (Fig. 4.12). In general, salt deposits within the basin become progressively younger, thicker, and deeper toward the southwest; however, in most areas the salt body is found at

Fig. 4.11. Generalized Geologic Cross Section of a Portion of Central Kansas.

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Fig. 4.12. Map of Kansas Showing Area and Thickness of the Hutchinson Salt Member of the Wellington Formation.

depths of less than 2000 ft. The thickest and most widespread salt deposit in Kansas is the Hutchinson salt member of the Wellington formation, a part of the Sumner Group of gently westward dipping Upper Permian rocks. Salt deposits have also been found in the younger Nippewalla Group of Permian rocks toward the southwest, but their distribution and thickness are not precisely known.

The Hutchinson salt, as seen in Fig. 4.12, underlies central and southcentral Kansas and extends southward into Oklahoma. The eastern edge of the salt body lies approximately 400 ft below the land surface. Near its western edge in Kansas, it is found at a depth of more than 1500 ft. Thicknesses of the unit in the state range up to 700 ft.³ In general, the Hutchinson consists of a complex mixture of salt, anhydrite, and shale, with salt being the predominate fraction throughout most of its extent in Kansas. As seen in Fig. 4.12 the salt is thickest in the south central part of the state. At Lyons the salt is about 300 ft in thickness but is of a higher purity than in the thicker section to the southwest. In general there is a gradual thinning of the salt deposit from the central part of the basin toward its western and northern boundaries in Kansas; however, the eastern margin shows an abrupt termination of the deposit which is indicative of a subsurface dissolution boundary. The nature and rate of dissolution of the salt beds along this margin of the basin are discussed in Sect. 10.3.3.

4.3.3 Site Geology

General. - To determine and define the geological as well as the hydrological conditions at the site and its immediate surroundings, an investigative program has been initiated that includes surface mapping, core drilling, auger and rotary drilling, geophysical well logging, hydrologic testing, and measurements of the physical, chemical, and thermal properties of the rocks. To date two core holes about 1300 ft deep have been completed at the northeast (Test Hole 1) and southeast (Test Hole 2) corners of the site. In addition four 300-ft hydrologic test holes have been drilled at the

approximate corners of the 1-square-mile site. Also a series of some 45 auger borings have been made within a 9-square-mile area centered on the Repository site to aid in delineating the unconsolidated surface sediments and in appraising the shallow groundwater aquifers. Data from this test program, coupled with the available and pertinent information obtained from such things as the existing mine shaft logs, mine workings maps, oil and gas well logs, and previous geologic and hydrologic studies of the county, will provide, when complete, the desired knowledge to acclaim the suitability of the site for the safe operation of the facility and for the confinement of the radioactive wastes.

Stratigraphy. - The stratigraphic section at the site as revealed by the first two core holes is shown in Fig. 4.13. The uppermost material in both holes (71 ft in No. 1 and 35 ft in No. 2) consists mostly of lean, stiff, moist, light-brown clay that is occasionally silty and contains sporadic nodules of caliche or calcium-cemented silt. According to Angino,⁴ this material blankets the surface of the Repository site and much of the surrounding area (Fig. 4.14). The rather wide variation in thickness of the eolian or wind-blown sediments is not unexpected, since the underlying Cretaceous rocks were subjected to a long period of erosion that created an irregular topographic surface before deposition of the Pleistocene deposits. This old erosional surface was found by Angino to consist of a thin zone of clay mixed with residual gravels and a thin layer of caliche. Outside the boundaries of the Repository in the valleys of Cow Creek and Little Cow Creek, the Pleistocene deposits consist of fluvial or water lain materials of clay silt, sand, and gravel (Fig. 4.14). These unconsolidated sediments range from a few feet in thickness to about 180 ft and are by far the most important water-bearing deposits in the general area.

The Kiowa formation of Cretaceous age underlies the Pleistocene deposits at the site and is the youngest consolidated rock encountered. It consists primarily of weathered, light-brown, fissile, clay shale that contains occasional nodules of phosphate in the upper part and generally dark gray, clay shale with a few thin beds of fossiliferous

Fig. 4.13. Generalized Stratigraphic Sections at Test Holes 1 and 2 (Data obtained from cores and logs of core borings performed for USAEC by U. S. Army Corps of Engineers, Aug.-Nov. 1970).

Fig. 4.14. Geologic and Hydrologic Map of the Proposed Repository Area, Lyons, Kansas (after Charles K. Bayne and John R. Ward, Chapter I, "Surface Geology and Ground-Water Hydrology," in Final Report Geology and Hydrology of the Proposed Lyons, Kansas Radioactive Waste Repository Site, prepared by the State Geological Survey of Kansas and the University of Kansas Center for Research, Inc., for the USAEC and the Union Carbide Corporation, March 1971).

limestone in the lower part. Low- to high-angle fractures with slickenside surfaces are common throughout the formation. One of the most outstanding features of the Kiowa is the occurrence of water-bearing sandstone lenses that may range from a few inches to tens of feet in thickness. In Test Hole No. 1 it is seen that a 7.5-ft-thick sandstone bed with another 11 ft of underlying interbedded shale and sandstone occurs near the middle of the 100-ft-thick section of the Kiowa formation, while, in Test Hole No. 2, where the formation is about 74 ft thick, an 8-ft-thick section of shale and interbedded sandstone was encountered near the bottom of the formation. An oscillating shoreline during Kiowa time was probably instrumented in the development of the highly variable sandstone beds of the formation. The variable thickness of the Kiowa throughout the area is accounted for by the irregular nature of its pre-Pleistocene erosional surface at the top and by the similar uneven erosional surface of the underlying Permian rocks at its base. The Kiowa does not outcrop at the Repository site being completely covered by alluvium; however, surface exposures of the formation occur 1 to 2 miles southeast of the site (Fig. 4.14). Although the Kiowa persists over the 1 square mile of the Repository, it is not present a few miles to the west, beneath the bed of Little Cow Creek, and to the south in the alluvial valleys of Cow Creek and the Arkansas River, having been eroded completely, probably during the Pleistocene, by these down-cutting streams. Toward the north of the site, the Kiowa formation is complete being about 150 ft in thickness and underlain by the Cheyenne sandstone of Cretaceous age and overlain by the Dakota formation, also of Cretaceous age.

Permian age rocks underlie the Kiowa shale formation at the site (Fig. 4.13). Here, as well as throughout the Permian Basin, these rocks reflect the conditions prevailing during this time period. In general the sequence of beds encountered in Test Holes No. 1 and No. 2 include, from the top, red beds, salt, anhydrite, and limestone and shale (Fig. 4.13). The Harper siltstone formation is the youngest Paleozoic age rock present at the site. This formation is the lowermost member of the Nippewalla group of rocks in Kansas, which is

progressively more complete toward the western part of the state. At the close of the Permian, uplift, followed by a long period of erosion, removed most of the Upper Permian rock section from this part of the state, leaving only the Harper in the Nippewalla group. In both test holes the Harper was found to be about 125 ft thick. The formation is predominantly reddish, massive siltstone and reddish silty to clayey shale, except for the uppermost shales and siltstones which are generally soft and gray in color from weathering. The Harper is undoubtedly present beneath the entire waste Repository site; however, it extends only some 10 miles further to the east before being beveled by pre-Cretaceous erosion.

Underlying the Harper sandstone at the site is the Stone Corral formation. This well-known "marker" bed, which is easily identified in well samples and on electric and radioactivity logs, is seen to be about 18 ft thick in Test Holes No. 1 and No. 2. It is mainly white to light gray anhydrite and dolomite with a few thin beds of varicolored clay shale. The formation contains numerous gypsum filled vugs and fractures throughout and in the upper half, some open fractures. The Stone Corral is probably consistent in thickness and lithology beneath the Repository although some changes occur in the formation throughout its extent in western Kansas. It is the uppermost formation of the Sumner Group of rocks in Kansas which like the Nippewalla Group mentioned above consists mainly of red beds and evaporites. The Ninnescah shale and the Wellington Formation comprise the two remaining formations of the Group.

Red beds of the Ninnescah Formation unconformably underlie the Stone Corral Formation and conformably overlie the Wellington Salt Formation at the Repository site, as well as throughout south central Kansas. As seen in Fig. 4.13 the formation is about 300 ft thick in Test Hole 1 and 2. The Ninnescah shale here is predominately reddish silty shale that frequently shows red and green mottling. Fracture fillings of gypsum are numerous throughout the formation as are bands, partings, and thin beds of gypsum, anhydrite, and dolomite. In some places the bedding is nondistinct and the shale is massive in

appearance. Although all fractures appear to be filled and/or tightly sealed, slickenside surfaces are present in some parts of the formation.

The Wellington Formation is the lowermost member of the Sumner Group of rocks and consists, in general, of a gray and red shale sequence at the top with rock salt beds in the middle and anhydrite and shale at the base. These members are approximately 185 ft thick, 260 ft thick, and 170 ft thick, respectively, at the site as revealed by Test Holes 1 and 2 (Fig. 4.13). The upper member of the formation consists largely of silty gray shales at its top and base, separated by a rather prominent red shale zone. Thin beds and partings of anhydrite occur frequently in the lower shales, but are less common in the upper gray shales, which also contain some blue clays, and in the red shales. Fractures in the upper gray shale and the red shale zone are usually found to be filled with gypsum, while in the lower shale fracture fillings are of anhydrite, except near the contact with the underlying salt beds where salt-filled vugs and fractures exist.

Rock salt, interbedded with clay shale and anhydrite stringers, comprises the rock section from a depth of 755 ft to 1084 ft below the land surface in Test Hole No. 1 and for an approximate comparable depth in Test Hole No. 2. Owing to the complexities of the depositional environment of the rock salt deposit, both vertical and horizontal, persistence of the salt and its interbedded impurities is difficult to assess, even for the relatively small 1-square-mile area of the Repository. However, from the available data, it appears that the section of salt being considered for hosting the wastes is perhaps the least variable within the entire column of salt. A comprehensive discussion of the salt rocks at the site is given under Rock Salt Deposits, below.

The predominately anhydrite rocks that lie immediately below the rock salt comprise the basal member of the Wellington Formation. For the most part the anhydrite, as revealed in Test Holes 1 and 2, is light to dark gray in color and contains numerous inclusions and partings and clay shale with some interbedded siltstone and dolomite

members. The thickness of the member is about 170 ft in Test Holes 1 and 2 (Fig. 4.13) and is believed to be rather consistent in thickness beneath the entire site.

In contrast to the Sumner Group of evaporitic rocks, described above, the underlying Chase Group consists of a sequence of alternating beds of carbonate rock and shale. Only the upper part (the Nolans limestone and the Odell shale) of this group was encountered in Test Holes 1 and 2 (Fig. 4.13). The Nolans was found to be about 35 ft thick and for the most part consists of interbedded dolomite and shale beds in the upper part with a dense, gray limestone bed at its base. Only about 10 ft of Odell shale was penetrated in Test Holes 1 and 2, and it was observed to consist of variegated, calcareous, hard, and massive shales.

Structure. — The rocks beneath the proposed Repository site have been subjected to a long and complex history of deformation with the older formations showing, as would be expected, a more complicated regime than successively younger beds. Locally, movements along the Central Kansas uplift have been instrumental in fabricating the existing structure, while the inclinations of the rocks at the site have also been affected by broad regional warping of the earth's crust. The Repository site lies on the western flank of the Geneseo uplift which extends beneath a large part of the eastern half of Rice County and into the southern tip of Ellsworth County and the southwestern corner of McPherson County (Fig. 4.15). This egg-shaped structure is separated from the genetically related but semi-detached main lobe of the Central Kansas uplift on the west by a rather sharp syncline and on the east and northeast by another synclinal structure. As seen in Fig. 4.15, several north-south trending anticlinal structures, some of which have associated oil and gas fields, are superimposed on the uplift along its western edge. One of these, the Lyons Gas Field structure, is centered a short distance east of the repository site and has been instrumental in establishing the present configuration of the rocks at the site. A generalized east-west cross section through the site and the adjoining Lyons Gas Field structure is shown in Fig. 4.16. From this

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Fig. 4.15. Structural Contour Map of the Geneseo Uplift (after Stuart K. Clark *et al.*, "Geneseo Uplift, Rice, Ellsworth, and McPherson Counties, Kansas," in *Structure of Typical American Oil Fields*, A Symposium, Vol. III, edited by J. V. Howell, published by the AAPG, Tulsa, Oklahoma, 1948).

Fig. 4.16. Generalized Geologic Cross Section at the Proposed Repository Site.

section it appears that during Arbuckle, Simpson, Viola, and Maquoketa time the area was relatively stable. Some uplift of the Lyons Gas Field structure may have occurred after deposition of the Maquoketa section, but the greatest deformation unquestionably occurred between Mississippian and Pennsylvanian deposition, as evidenced by the erosion of the entire Mississippian section along the crest of the anticline. This structural high remained topographically high during the deposition of succeeding beds which, along with recurrent uplifts, account for the persistence of the structure upward through the geologic columns. Structural contour maps of the Nolans limestone below the salt body and the Stone Corral above the salt at the Repository site reflect the underlying structure (Figs. 4.17 and 4.18). The regional dip of the pre-Pennsylvanian sediments within the area is southeast, while the Pennsylvanian and Permian beds are west and the Cretaceous rocks are northward. Regional tilting accounts for this discordance in the direction of dip of the various age rocks within the area.

Rock Salt Deposits. - The rock salt column beneath the proposed Repository site consists generally of a succession of layers of rock salt intercalated with shales and occasionally anhydritic beds. As seen in Fig. 4.19, the principal salt zones can be traced laterally from the northeast corner to the southwest corner of the site, although some irregularities in thickness and in lithology occur. In general, lateral consistency in the column is greatest in the lower to middle part of the columns and least at the extreme bottom and upper part of the formation. As discussed earlier, the salt deposit at Lyons lies in a marginal portion of the Permian Basin (Fig. 4.12). In addition the site is seen in Fig 4.15 to lie on the northeast flank of the Lyons Gas Field anticline. With these conditions, some variation in the thickness and lithology of the entire salt sequence as well as individual beds over the 1-square-mile site area would be expected. In Fig. 4.20 it is seen that the salt is thickest in the southcentral part of the site. The principal uplift associated with this structure occurred in Late Mississippian

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● WELL LOCATION
(VALUES INDICATE FEET ABOVE SEA LEVEL)

Fig. 4.17. Structural Contour Map of the Nolans Limestone.

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Fig. 4.18. Structural Contour Map of the Stone Corral Formation.

Fig. 4.19. Cross Section of the Salt Rocks at the Proposed Repository Site.

ORNL-DWG 71-2820R1

● WELL LOCATION
VALUES INDICATE THICKNESS OF SALT DEPOSIT (IN FEET)

Fig. 4.20. Salt Thickness Map at the Proposed Repository Site.

to Early Pennsylvanian time or long before the deposition of salt in the Permian. Nevertheless, through recurrent uplift movements during the deposition of the evaporites and/or through the prevailing topographic relief of the anticlinal structure during Pennsylvanian and Permian times, some local thickening and thinning of the salt rocks occurred. This explanation as the cause for the measured thinning of the salt is strengthened further by the absence of any observed solutioning and collapse of the overlying shale in the top parts of the salt sections in cores from Test Holes 1 and 2, which, if present, could account for gross thinning of the salt column.

In the marginal areas of the evaporitic Permian Basin, such as at Lyons, it is apparent that the precipitation and deposition of salt was periodically interrupted by the influx of clay-bearing waters from nearby land masses. These local intrusions not only created irregularities in thickness and composition of the sediments but may also have created solution channels and slump features at various stratigraphic levels in the previously deposited salt section. It is likely that the discontinuous zones of brecciated salt observed in Test Holes 1 and 2 were formed in this manner. Irregularities in the salt section may also be due in part to periodic subareal exposure of some areas of the salt resulting from a fluctuating water level within the basin.

The thickest and also the most persistent salt zone is seen in Fig. 4.19 to occur in the bottom half of the column at a distance of between 673 and 710 ft above sea level in the Project Salt Vault (PSV) charging shaft well. A 9-ft-thick bed in the lower part of the zone comprises the mined unit at The Carey Salt Company's Lyons mine a short distance south of the site. This bed of salt is unquestionably the most uniform and the best quality of the entire sequence and is therefore the desired host bed for the canisters of waste.

Within the mined unit at the Carey mine, 1- to 6-in. layers of relatively pure sodium chloride are separated by clay and shale laminae that are usually less than 1 mm in thickness. These laminae constitute the major impurity in the salt and are characteristic of

most bedded salt deposits. Shale beds, several inches in thickness and separated by about 15 to 18 ft of salt, lie above and below the mined unit and thus limit the vertical extent of mining. The mine floor was usually cut within a few inches of the underlying shale bed, while the roof is normally several feet below the overlying shale bed. The least contaminated salt, and thus the source of most of the production in the mine, lies in a 9-ft-thick section that extends from the top of the shale below the floor upwards to a thin shale parting, approximately $1/16$ in. thick. Another prominent shale parting lies about $3\text{-}1/2$ ft above the 9-ft roof. In some parts of the mine, this section was also mined. However, the additional excavation has resulted in a weak roof that buckles and fractures and frequently allows a 3-ft section of overlying impure salt to fall.

Two 2-in.-diam, 30-ft-deep core holes were drilled in the floor of the mine in Entry 9 (Fig. 4.21), while two cores, approximately 20 ft in length, were obtained from the roof of the mine at the same locations. These cores, along with the log of a third hole drilled previously in Entry 7 (ref. 5), were used to construct a geologic cross section of a portion of the salt section from the northwest end of Entry 7 to the southwest end of Entry 9 (Fig. 4.22).

Considerable quantities of shale and some anhydrite are included in the salt section from the floor down to a depth of about 115 in. in Entry 9 and to a depth of approximately 135 in. in Entry 7 of the mine. The shale, which is noncalcareous and greenish gray to black in color, commonly occurs in beds 1 in. to as much as 15 in. thick that usually contain a few crystals of clear-to-orange halite and some stringers of fine-grained anhydrite. As seen in Fig. 4.22, these beds thicken and thin considerably over relatively short distances. Frequently, the beds grade, both laterally and vertically, into salt that contains many pods and irregularly shaped lenses of shale. This unit of the section is underlain by about 80 to 125 in. of relatively pure salt. The salt consists essentially of medium to coarsely crystalline, clear-to-brownish halite, that

Fig. 4.21. Map of a Part of the Carey Salt Company Mine Showing Location of Bore Holes and PSV Test Area.

Fig. 4.22. Generalized Geologic Cross Section of a Portion of the Hutchinson Salt Member of the Wellington Formation in the Mine of The Carey Salt Company, Lyons, Kansas.

contains disseminated blebs and inclusions of dark-colored clay that, in places, gives the salt a dark smoky appearance.

A second zone of interbedded salt, shale, and anhydrite, about 40 to 50 in. thick, lies beneath the relatively pure salt sequence. The shale and anhydrite are similar to that described higher in the section, but the shale beds are thinner, and a larger amount of anhydrite in the form of layers and lenses is present. For the remaining part of the section in Entry 9, which was cored to a depth of about 360 in. below the mine floor, the cores show a relatively pure salt sequence like that described above. In Entry 7, the same salt is interbedded with thick shale and anhydrite beds at a depth of about 360 in. It is likely that the same thick shale and anhydrite unit would have been intercepted in Entry 9 had the drilling proceeded a few feet deeper.

The sediments above the ceiling of the mine, up to about 250 in., consist of a relatively pure salt sequence that is interbedded with four separate shale zones. These shales, like those below the mine floor, are greenish gray to black in color and frequently contain lenses and crystals of clear-to-orange halite and stringers and lenses of anhydrite. The thickest of the shale beds lies at a minimum distance of about 20 in. above the present roof of the mine. (In the PSV demonstration test excavation, this shale bed lies about 2-1/2 ft above the mine floor.) The bed was observed to be about 12 in. thick in Borehole 2, Entry 9, but it had thinned to about 3 in. in the core from Entry 7 of the mine. The other shale zones, as shown in Fig. 4.22, lie between about 130 and 230 in. above the roof. (The shale bed at about 180 to 200 in. comprised the ceiling in the demonstration test area.) The salt from the ceiling cores is composed mainly of medium-to-coarse grained, clear-to-brownish halite crystals that contain, in places, many blebs and irregularly shaped masses of clay that give the material a smoky appearance. In addition, from about 70 in. above the mine roof to the end of the cored section, the salt contains many scattered blebs of an orange-to-red colored microcrystalline mineral that has been identified as polyhalite.

In summary, the salt unit that has been mined in the Lyons mine consists of relatively pure salt that contains minor inclusions of clay and shale. The first 115 to 135 in. of the section below the floor in the westernmost portion of Entries 7 and 9 contains between 20 and 40% shale. The shale is present in beds that vary greatly in thickness over relatively short distances and may grade vertically and laterally into zones of salt that contain many pods and irregularly shaped lenses of shale and anhydrite. A second shaly zone, approximately 40 to 50 in. thick, is present, generally from about 220 to 235 in. below the floor. Four separate shaly zones occur in the first 250 in. of section above the mine roof. The thickest shale bed lies at a minimum distance of about 20 in. above the ceiling of the mine, while the other less prominent zones of shale lie between about 130 and 230 in. above the roof. These zones are usually only a few inches thick and contain, in addition to shale, lenses and stringers of anhydrite and salt.

The proposed mined area will lie at a level of about 20 ft above the preexisting mine floor and extend upward a distance of about 15 ft. (See Fig. 4.22.) The floor of the newly mined area will be rock salt, while a thin shale parting will mark the roof. A prominent shale bed that varies from a few inches to more than 1 ft in thickness will lie approximately 2-1/2 ft below the floor. Several easily distinguishable shale beds that are about 1/2 in. to 1/4 in. in thickness will probably persist in the walls of the mined area at distances of about 6-1/2, 7, 10, and 12 ft above the floor. The salt in the proposed excavation area contains numerous blebs of polyhalite that are commonly concentrated along bedding, giving the salt a banded appearance.

Due to the structural attitude of the rocks at the proposed site, some variation in the levels of individual salt and shale beds is apparent. A measure of this level change is seen in Fig. 4.23 which is a structural countour map of the prominent shale bed that exists as the "high top" or "17-ft" shale in the Carey mine workings and which will lie a few feet below the floor of the proposed working area. This shale bed, which is easily identifiable

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● WELL LOCATION
(VALUES INDICATE FEET ABOVE SEA LEVEL)

Fig. 4.23. Structural Contour Map of the "17-ft Shale Parting" in the Salt Column.

in cores as well as recognizable in the geophysical logs from the noncored borings, is observed in Fig. 4.23 to be about 10 ft higher in Test Hole No. 1 and 40 ft higher in elevation in Test Hole No. 2 than in the vicinity of the PSV charging shaft. Thus a constant rise in the mining level will be experienced from the southwest corner of the site to the southeast corner, while there will be essentially no change in the mining level along the western boundary of the site. From the southwest corner to the northeast, the mining level will rise constantly to the apex of the fold and then show a gradual decrease.

4.4 Hydrology

4.4.1 Surface Water

As seen in Fig. 4.24 the proposed Repository site is drained by Owl Creek and an unnamed tributary of Cow Creek. These intermittently flowing streams originate a few miles to the north of the site and flow southwestwardly through it before joining Cow Creek a few miles to the south. These streams would be expected to flow and thus carry runoff from the site only during periods of heavy rainfall which occurs most frequently during the late spring and early summer months. Flow measurements of Cow Creek at Lyons recorded over a period of 18 years show an average flow rate of 68 cfs with a maximum flow of 12,000 cfs and extended periods of no flow in 1938 and 1946.⁶ Downstream Cow Creek flows generally parallel to the Arkansas River before joining that stream some 50 miles southeast of the site. Flow measurement records of the Arkansas River compiled at Hutchinson for 6 years and at Wichita for 31 years show an average discharge for the stream of 1000 cfs with maximum and minimum flows of 30,000 cfs and 3 cfs.⁶ The Arkansas River has its source near the summit of the Rockies in Central Colorado and flows eastward into Kansas along its westward border. The volume of the river increases toward the east throughout its mountainous area, but as the stream emerges onto the Great Plains its flow gradually diminishes, frequently being dry in western Kansas during the dry summer months. In Kansas the stream maintains its eastward course for a distance

Fig. 4.24. Surface Drainage at Proposed Repository Site.

of about 150 miles before establishing a northeastward course that diverts the stream as far north as southern Barton County and southwestern Rice County. The stream then maintains a southeastern course, flowing past Hutchinson and Wichita before leaving the state along its southern border.

4.4.2 Groundwater

General. — Figure 4.25 is a map of Kansas that shows the general availability of groundwater in the various regions of that state. In general, the greatest quantities of water are found in the gravel- and sand-filled valleys of the larger streams. Less productive areas include the shallower filled river valleys and areas underlain by thick deposits of Tertiary and Quaternary deposits. Moderate supplies of groundwater may also be obtained from deep water-bearing rocks in the extreme southeastern corner of the state. In those areas of the state where Pennsylvanian, Permian, or Cretaceous age bedrocks exist at or near to the surface, generally small supplies of groundwater are available.

In the general region of the Repository, the thick deposits of gravel and coarse sand that fill the large stream valleys are the source beds for the principal supplies of groundwater (Fig. 4.25). Perhaps the most important source bed is found in the Great Bend region of the Arkansas River Valley which lies a few miles to the south of the site. This region is underlain mostly by sand and gravel deposits of Tertiary and Quaternary age that may be as much as 300 ft thick. Overlying sand dunes provide an excellent surface for recharge. Depth of groundwater within the area is generally less than 100 ft. Supplies in excess of 1,000,000 gal per day from these deposits are commonly developed.

The city of Lyons obtains its water supply from several wells in alluvial deposits located about 2-1/2 miles south of the proposed site. The towns of Sterling (about 10 miles south of the site) and Chase (about 10 miles west of the site) also obtain public water supplies from alluvial deposits in the Arkansas River Valley.

Fig. 4.25. Map of Kansas Showing General Availability of Groundwater (after S. W. Lohman et al., in Ground-Water Supplies in Kansas and Available for National Defense Industries, University of Kansas Publications, State Geological Survey of Kansas, Bulletin 41, Lawrence, Kansas, April 1942).

Within the immediate vicinity of the site there are several wells extending to the Cretaceous age sandstones from which water is drawn for domestic or stock uses. The yields from these wells or from deeper wells would be insufficient for industrial, irrigation, or public water supplies.

In general, the rocks below the salt bed contain numerous porous beds that contain salt water and perhaps some oil and/or gas. Fresh water is confined essentially to the uppermost 300 ft of the rock column. The Stone Corral, which lies between about 270 ft and 285 ft, is the deepest known fresh water aquifer at the site. It may yield water at the rate of about 1 to 3 gal per min. The Cretaceous age sandstones (45 ft to 120 ft below the surface) are capable of yielding water at the rate of about 20 gal per min, while the overlying unconsolidated silts (0 to 45 ft below the surface) may yield water at the rate of about 5 gal per min. The average depth to groundwater at the site is about 25 ft.

4.4.3 Hydrological Characteristics of the Rocks in the Vicinity of the Site

Except in the incised valleys of Cow and Little Cow creeks south and west of the Repository site, respectively, where thick deposits of water-bearing gravels, sands, and silts have accumulated, the Pleistocene surface sediments in the immediate vicinity of the site consists mostly of a thin blanket of eolian silts that have a low permeability and may yield little or no water to wells. According to Angino, the loess deposits probably would not yield more than 10 gpm to wells anywhere within the area, while the fluvial deposits in the stream valleys will yield quantities of water to wells in excess of 1000 gpm.⁴ Consequently, there are no known usable wells that penetrate only the loess deposits in the area but several domestic, stock, and even municipal and irrigation wells in the thick valley fill deposits. In general, the depth to groundwater at the site is about 25 ft, rising somewhat in the wet winter months and falling slightly in the dry summer months. The direction of groundwater movement is from northeast to southwest across the site toward the buried valley of Cow Creek and then generally southeastward. (See Fig. 4.14.) Indeed, the depth to groundwater

and the direction of movement as determined recently by Angino⁴ is remarkably similar to that as determined by Fent⁷ some 20 years earlier in a more general study of the geology and groundwater of Rice County.

Cretaceous rocks in the vicinity of the site include the Cheyenne sandstone, the Kiowa shale, and the Dakota formation. However, only the Kiowa shale is present directly beneath the site; the other two pinch out a few miles to the north. In general, the Cheyenne consists mostly of siltstone of low permeability, that yields no water to wells. In contrast, the Dakota formation, which consists of clay, shale, siltstone, and highly permeable sandstones that yield water at the rate of 30 to 70 gpm to several industrial wells in the southwestern part of the county, is a prolific water bearer.⁷ Except for a thin rubble zone at its top which may yield, locally, moderate amounts of water wells, the only water-bearing zones in the Kiowa are the sandstone members. At the site the sandy beds, which may occur at several stratigraphic horizons, vary in thickness from 30 to 50 ft in the southeastern portion of the area to thin beds of alternating sandstone and shale in its western part.⁴ Yields to wells in these areas are reported to be 50 to 100 gpm and 10 to 20 gpm, respectively.⁴

The Harper sandstone at the site of the Repository consists mostly of silty shale and siltstones that are apparently nonwater bearers. Only very small quantities of water have been found in the uppermost weathered zone which is probably the most active water-bearing part of the formation. Some potential for storing and transmitting water through the formation may exist in the unsealed fractures observed in the core of the Harper from Test Hole No. 1. Thus, additional studies have been initiated to define further the nature and extent of the fracturing and to determine the significance of it with regard to the hydrologic regimes of the area.

The deepest freshwater-bearing rocks encountered in borings at the site are those of the Stone Corral formation. This thin sequence of anhydritic, dolomitic, and shaly beds contrasts sharply with the overlying silty beds of the overlying clay shale of the Ninnescah Shale formation and is consequently easily identifiable in subsurface borings at the site as well as surface exposures to the east. The dolomitic and anhydritic beds in the upper half of the formation are vuggy and often fractured and thus provide the principal paths of water movement through it. The aquifer

is probably capable of yielding water only at the rate of a few gallons per minute and hence is not known to supply water to any wells within Rice County.

The Ninnescah shale, the Wellington formation (which includes the Hutchinson salt member), the Nolans limestone and the Odell shale lie successively below the Stone Corral at the site and apparently are all nonwater-bearing rock formations. It is especially significant that no voids, open fractures or permeable zones, and no measurable quantities of water were found through observations of the core in Test Holes 1 and 2 in the salt column and at the interface or contact between the salt and the overlying and underlying rocks.

Hydraulic tests have been conducted in Test Holes 1 and 2 by personnel of the USGS and in four shallower borings at the four corners of the site by the same USGS groups and by personnel of the State Geological Survey of Kansas. Preliminary data from these tests indicate that indeed the sandstone members of the Kiowa shale are the principal fresh-water-bearing aquifers above the salt and that the Stone Corral formation contains and transmits only limited quantities of water. Also it was concluded that the rocks above the salt and below the Stone Corral do not contain significant quantities of water nor do the rocks below the salt to the extent of the penetration of the borings into the Odell shale. Furthermore, it was concluded that the waters in the Kiowa and Stone Corral exist under some artesian pressure which causes their levels to extend somewhat above their stratigraphic positions but still maintaining decreasing potentials with depth. This means that the unrestrained water level or piezometric surface in the Kiowa shale will rise into the lower part of the overlying alluvium but not up to the elevation of the water level of that aquifer. Similarly, the unrestrained water level in the Stone Corral will extend upward into the Harper Sandstone but not up to the hydrostatic level of the Kiowa aquifer.

The direction of the flow of water in the Kiowa is from northeast to southwest across the site or in the same general direction as that in the overlying loess deposits.⁴

Chemical and radiochemical analyses are being performed by the State Geological Survey of Kansas and the State Department of Health on water samples from many of the borings and wells on and near to the site. Analyses

of several samples taken in the immediate vicinity of Lyons are presented in Tables 4.2 and 4.3. In general, the results indicate that the groundwaters in the unconsolidated sediments and the Kiowa formation are hard and high in calcium and bicarbonate.⁴ Dissolved solids range generally from 250 ppm to 750 ppm; however, a few samples taken near salt mine and oil wells (such as at sample locations 19 8W 34 bdd and 20 8W 12 ccb), where salt brines have been discharged into the soil, show considerably higher concentrations. Trace element analyses of samples indicate that, with one exception, these elements are found in concentrations that are within the limit of potable water in the United States.⁴

Preliminary results of the hydraulic tests conducted in Test Holes No. 1 and No. 2 by personnel of the USGS indicate that the rock column in the interval below the Stone Corral formation has low permeability.^{8,9} In Test Hole No. 1 an inflatable packer was set against the side walls of the hole just below the salt at a depth of 802 ft. The isolated interval (802 to 1300 ft) was then charged instantaneously with a quantity of fluid and measurements were then made of the reaction of the water level to this stress. From these measurements the transmissivity of the isolated interval was estimated to be $1 \times 10^{-4} \text{ m}^3 \text{ pd per m}$. By assuming that the contributing interval was that of the 38-ft-thick Herington limestone (1252 to 1290 ft below the land surface), the hydraulic conductivity was estimated to be $2 \times 10^{-5} \text{ m}^3 \text{ pd per m}^2$.⁸ The relative specific capacity of the interval was estimated to be about $1.8 \times 10^{-3} \text{ m}^3 \text{ pd per m of drawdown}$, and the static water level in the hole was estimated to be about 330 ft below land surface.⁸ In Test Hole No. 2 the packer was set at a depth of 296 ft or just below the Stone Corral, and the remaining portion of the hole (to a depth of 1216 ft) was tested as a single hydrologic unit. From the injection test conducted in the isolated interval (296 ft to 1216 ft), the transmissivity was estimated to be $1.8 \times 10^{-4} \text{ m}^3 \text{ pd per m}$, and the hydraulic conductivity was estimated to be $6.4 \times 10^{-7} \text{ m}^3 \text{ pd per m}^2$ (assuming that the thickness of the producing interval is the entire isolated interval). The hydraulic potential for the tested interval was estimated to be 315 ft and the relative capacity estimated to be $2.5 \times 10^{-4} \text{ m}^3 \text{ pd per m of drawdown}$.

Hydraulic tests, similar to those described above, were also made of the Kiowa and Stone Corral aquifers in boreholes located at the four

Table 4.2. Chemical Analyses of Water from Selected Wells and Test Holes
in the Vicinity of the Proposed Repository^a
(Dissolved Constituents and Hardness Given in Milligrams per Liter)

Well Location	Sample Depth (ft)	Geologic Formation	Dissolved Solids Evaporated at 180 °C	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na + K)	Bicarbonate (HCO ₃)	Sulfate (SO ₄)	Chloride (Cl)	Fluoride (F)	Nitrate (NO ₃)	Total	Carbonate	Noncarbonate	Specific Conductance Micromhos at 25 °C	pH
19 SW 26 baa 2	135	Kiowa shale	650	69	22	150	407	82	114	1.0	0.0	262	262	0	1,150	7.5
19 SW 26 baa 3	316	Stone Corral Formation	6,440	724	227	1,115	73	2,428	1,820	1.1	0.9	2,740	60	2,680	8,720	8.0
19 SW 26 ddd	105	Kiowa shale	370	93	4.9	34	315	16	36	0.3	2.9	252	252	0	600	7.8
19 SW 27 aab	95	Kiowa shale	438	81	16	59	278	25	90	0.4	4.9	268	228	40	760	7.2
19 SW 27 abb 2	135	Kiowa shale	1,208	97	39	271	285	286	318	1.1	0	402	234	168	2,050	7.7
19 SW 27 abb 3	316	Stone Corral Formation	5,960	512	161	1,322	56	1,972	1,910	1.2	0	1,939	54	1,885	8,720	8.3
19 SW 27 dcc 2	74	Kiowa shale	540	85	32	68	371	67	71	0.8	10	344	304	40	920	7.4
19 SW 27 dcc 3	284	Stone Corral Formation	5,880	680	249	949	93	2,336	1,610	1.2	0.4	2,720	76	2,544	9,000	7.4
19 SW 27 ddd	85	Kiowa shale	652	147	15	71	273	40	212	0.2	1.5	428	224	204	1,150	7.9
19 SW 27 ddd 2	68	Kiowa shale	---	99	22	72	205	40	193	0.3	0.7	338	168	170	---	8.0
19 SW 34 bdd	85	Kiowa shale	54,940	1,530	137	19,252	400	2,288	30,900	0.1	13	4,380	328	4,052	91,566	7.2
19 SW 34 cda	65	Kiowa shale	3,410	576	44	614	224	99	1,860	0.1	23	1,618	184	1,434	6,340	7.6
20 SW 12 ccb	64	Kiowa shale	1,200	193	30	206	298	93	492	0.1	4.0	605	244	361	2,150	7.3
20 SW 13 ccc	53	Alluvium	1,704	227	33	340	300	103	770	0.1	5.3	702	246	456	2,990	7.7
20 SW 14 c c	32	Alluvium	380	70	6.2	55	224	46	47	0.5	19	200	184	16	620	7.7
20 SW 15 ecc	36	Alluvium	394	65	12	58	239	45	48	0.6	21	212	196	16	630	7.8

^a Analyses performed at the Kansas State Department of Health.

Table 4.3. Trace Element Analyses of Water from Selected Wells and Test Holes in the Vicinity of the Proposed Repository^a
(concentrations in ppm)

Well Location	Depth (ft)	Mn	Fe	Co	Ni	Cu	Zn	Si	Sr	Li	Pb
20-8W-13 ccc	50-55	0.007	0.044	0.022	0.015	0.009	0.068	12.9	1.39	0.020	N.D. ^c
20-8W-15 ccc	30-36	0.007	0.032	0.009	0.006	0.006	0.108	9.2	0.035	0.008	N.D. ^c
19-8W-26 ddd	99-104	0.011	0.033	< 0.001	0.010	0.006	0.047	14.0	0.392	0.012	N.D. ^c
19-8W-27 ddd	90	0.037	0.053	0.012	0.002	0.011	0.025	11.1	0.599	0.017	N.D. ^c
19-8W-34 bdd	79-85	0.049	0.477	< 0.025	0.086	0.027	0.932	N.D. ^{b, c}	5.912	N.D. ^{b, c}	N.D. ^c
19-8W-27 dcc 2	62-74	0.073	0.089	< 0.001	0.008	0.005	0.020	4.41	0.832	0.033	0.01
19-8W-27 dcc 3	266-284	0.272	0.096	0.034	0.081	0.013	0.064	1.39	11.4	0.174	0.04
19-8W-26 baa 3	296-315	0.196	0.140	0.033	0.061	0.016	0.040	1.49	11.2	0.187	0.03
19-8W-26 baa 2	106-126	0.087	0.111	N.D. ^c	0.011	0.006	0.039	3.33	1.09	0.034	< 0.01

^aAnalyses performed at the Kansas Geological Survey.

^bSample unconcentrated due to high chlorine concentrations in ppm.

^cN.D. -- not detected.

corners of the site (NE corner, Test Hole 1S; SE Corner, 2S; NW corner, 3S; and SW corner, 4S). The results of these tests are summarized in Table 4.4. In general, it is observed that both the Kiowa and Stone Corral have significantly higher permeability than the deeper intervals tested in Holes 1 and 2 above. The coefficient of transmissivity, which gives the capacity of the formations to transmit groundwater, varies from $3 \times 10^{-4} \text{ m}^3 \text{ pd per m}$ in the Stone Corral in Test Hole 2S to $1.3 \text{ m}^3 \text{ pd per m}$ in the Kiowa in Test Hole 4S. The variations in the measured values in the Kiowa are probably due to changes in the nature and thickness of the water-bearing sandstone lenses, while the amount and extent of fracturing in the dolomite may account for the variations in hydraulic properties in the Stone Corral formation.

In Fig. 4.26, which is a water-level contour map of the Kiowa formation, it is observed that the general north to south flow within the area is interrupted by an anomalously low water level at the southeast corner of the site. The anomaly may be due simply to the physical isolation of a water-bearing zone in the Kiowa which is a condition that commonly occurs in lenticular sandstone aquifers such as the Kiowa. On the other hand, it is possible that the low water level is due to some local vertical and/or lateral penetrations that accelerate the drainage of the formation. It is planned to bore and test hydraulically several additional holes within the area to determine more precisely the geohydrologic factors that are responsible for the anomaly. Water level measurements in the Stone corral show that the flow gradient for this formation is also generally from the north to the south across the proposed Repository site.

In the rocks deep below the salt, several water-bearing zones are present. To determine the relationships of the potentiometric surfaces of some of the more prolific zones to the rock salt deposit, drill stem tests were made in a recent oil and gas test hole drilled in the southeastern part of the proposed repository area (Barnett et al. No. 1 Wright, approximately CS/2 NW/4 Section 35-19S-8W). These tests showed that fluids in the Florence (1416-1455-ft depth), Lecompton (2565-2604 ft depth), Douglas (2784-2823 ft depth), and the Lansing (3004-3043 ft depth) formations would all stand above the salt in unrestricted bore holes penetrating these zones.

Table 4.4. Hydraulic Test Data for the Kiowa and Stone Corral Aquifers
at the Proposed Repository Site

Hole No.	Interval Tested (Depth in Feet)	Static Water Level (Depth in Feet)	Relative Specific Capacity (m ³ Pd per m of Drawdown)	Transmissivity (m ³ Pd per m)	Hydraulic Conductivity (m ³ Pd per m ²)	Water-bearing Interval (Depth in Feet)
Kiowa Formation						
1-S	101-130	63.0	0.4	0.72	0.15	110-126
2-S	84-125	62.04	0.09	0.075	0.031	87-95
3-S	80-150	44.62	0.18	0.58	0.08	90-127
4-S	60-126	32.19	0.39	1.3	0.36	63-75
Stone Corral						
1-S	263-316	107.6	0.09	0.069	0.012	296-315
2-S	230-267	---	0.0004 ^a	0.0003 ^a	0.00006 ^a	235-253
3-S	217-315	99.68	1.1	0.85	0.28	286-298
4-S	260-300	91.90	0.037	0.02	0.004	266-284

^aEstimated.

Fig. 4.26. Water-Level Contour Map of the Kiowa Formation.
(Numbers refer to the number of feet above sea level.)

4.5 Meteorology

4.5.1 Climatology

Weather history has been evaluated to identify the normal and extreme climatic conditions which must be considered in the design and operation of the Repository. Weather bureau records of 14 stations in Central Kansas (Table 4.5, Fig. 4.27)¹⁰ were examined to determine the average, variance and extremes of climatic conditions in the area, since only precipitation data were collected at Lyons.

Precipitation.¹¹⁻¹⁷ - Data on monthly mean precipitation at Lyons (dotted line, Fig. 4.28) is compared with the average of 11 nearby stations. Summer maxima and winter minima characterize the seasonal rainfall distribution in Central Kansas. The trend at Lyons follows closely the seasonal pattern of the 11-station average, exceeding the 95% confidence interval only during July, August, September, and December. Analysis of variance, which considers year-to-year variation of all stations for 30 years, showed a significant difference between Lyons and the composite 11 stations only in September.

Average annual precipitation at Lyons was 25.9 in., approximately the midpoint between the high (31.0 - Wichita) and the low (Dodge City - 21.0). Grouping the stations according to Duncan's multiple range test ($P < .05$) showed three distinct aggregations reflecting similarities in total rainfall. The most inclusive grouping (Table 4.6) contained ten stations, excluding Wichita and Dodge City. This implies that with regard to rainfall, the weather phenomena at ten of twelve stations does not deviate significantly from regional average conditions so that data from these ten can provisionally be used to infer a climatic regime for Lyons.

Precipitation extremes are evaluated because of their relationship to storm and surface runoff and lowland flooding. Maximum monthly precipitation at Lyons was 14.1 in. (June 1965), although hourly or daily rates for this extreme at Lyons are unknown. Daily maxima in Central Kansas are as high as 8 in. (Table 4.7, Wichita, 1911), but this type of event is highly localized because a given extreme seldom has been registered at more than one station.

Table 4.5. Location and General Characteristics of Weather Stations Used for Climatological Summaries

	County	Latitude (N)	Longitude (W)	Elev. (ft)	References
Concordia WB City	Cloud	39° 34'	97° 40'	1375	11,12,13, 16,19
Dodge City WB AP	Ford	37° 46'	99° 58'	2594	11,12,13, 19,23
Garden City Exp. Stat.	Fenney	37° 59'	100° 49'	2840	13
Geneseo	Rice	38° 31'	98° 09'	1755	11,12,13
Great Bend	Great Bend	38° 22'	98° 46'	1940	11,12,13, 20
Hutchinson Exp. Field ^a	Reno	37° 56'	98° 02'	1570	11,12,13, 22
Kanapolis Dam	Ellsworth	38° 36'	97° 57'	1492	11,12,13
Lyons	Rice	38° 19'	98° 12'	1696	11,12,13, 17
Manhattan Agronomy Farm	Riley	39° 12'	96° 36'	1106	13
McPherson	McPherson	38° 20'	97° 40'	1495	11,12,13
Russell FAA AP	Russell	38° 52'	98° 49'	1864	11,12,13
Salina FAA AP	Salina	38° 49'	97° 34'	1271	11,12,13, 21
Sterling	Rice	38° 13'	98° 12'	1636	11,12,13
Wichita WB AP	Sedgwick	37° 39'	97° 25'	1321	11,12,13, 14,18

^aAir temperature data from Hutchinson KWBW were used when those from experimental field were not available.

BASED ON PERIOD 1931-55

ISOLINES ARE DRAWN THROUGH POINTS OF APPROXIMATELY EQUAL VALUE.

CAUTION SHOULD BE USED IN INTERPOLATING ON THESE MAPS.

KANSAS

Fig. 4.27. Mean Annual Precipitation, Inches.

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Fig. 4.28. Monthly Mean Precipitation for 11 Stations, Including 95% Confidence Intervals, and Monthly Mean Precipitation for Lyons (Average of 30 Year Data).

Table 4.6. Duncan's Grouping (0.05) of Stations According to Annual Total Precipitation^a

Station	Annual Total Precipitation (in.)	Grouping ^b
Wichita	30.95	}
McPherson	29.31	
Hutchinson	29.00	
Salina	28.34	
Concordia	27.24	
Geneseo	27.14	
Russell	26.77	
Lyons	25.94	}
Kanopolis Dam	25.61	
Sterling	25.46	
Great Bend	25.43	
Dodge City	21.02	}

^a Average for 30 years of data.

^b Any two means not included within the same bracket are significantly different at 0.05 level.

Table 4.7. Extremes of Temperature and Precipitation, Including Snowfall, at Four Stations

Station	Highest ^a Temperature (°F)	Lowest ^b Temperature (°F)	Maximum Monthly Precipitation		Maximum Rainfall		Maximum Snowfall	
			Amount (in.)	Date	Rate (in./hr)	Date	Rate (in./24 hr)	Date
Concordia ^c	116	-25			6.46	May 1950	17.2	March 1924
Dodge City ^c	109	-26	12.82	May 1881	6.03	June 1899	17.5	March 1922
Wichita ^c	114	-22	14.43	June 1923	7.99	Sept. 1911		
McPherson ^d	117	-27			4.52	July 1897	20.0	Feb. 1912

^aMaximum temperature for each station occurred in August 1936.

^bMinimum temperature for each station occurred in February 1899.

^cLocal Climatological Data, Annual Summary with Comparative Data, 1969 (U. S. Weather Bureau).

^dClimatology of the United States No. 20-14, 1962.

Frequency of recurrence of different rainfall intensities is given for Rice County (Table 4.8). During the next 25 years one could expect a rainfall event of the magnitude of 3 in./hour or 5.5 in./24 hr intensity. Catastrophic flooding within the confines of the Repository areas would not be expected from these rainfall intensities.

Temperature.¹¹⁻¹⁶ - Ambient temperature data were unavailable from Lyons; therefore, 30-year data from 11 nearby stations were averaged to estimate this parameter for the Repository site. Monthly and annual averages are given in Table 4.9, accompanied by the 95% confidence limit. Monthly means range from a low of 29°F (January) to a high of 80°F (July), averaging 55°F for all stations. Air temperatures are more uniform (annual means range from 56.6°F at Wichita to 53.7°F at Concordia) and exhibited tighter variation than precipitation. Analysis of variance of monthly means showed statistically significant differences among stations for five months, however, and four different groupings of annual means were determined from Duncan's multiple range test (Table 4.10). Sterling and Geneseo, both Rice County stations, were in the same grouping; thus an average of their data would provide the best temperature estimate for Lyons. The annual average of 55.2°F agreed remarkably well with the grand average for 11 stations (55.3°F).

Ambient temperatures greater than 100°F occur an average of 15 days per year in Central Kansas. Material transfer and storage operations will be designed to withstand temperature extremes of both summer and winter seasons. Extremes range from a high of 117°F to a low of -27°F, both of which occurred at McPherson, but not in the same year. That three other stations exhibited all time highs and lows on the same occasion (Table 4.4) is further evidence of general uniformity of climate in the Great Plains.

Wind.¹⁸⁻²³ - Estimates of wind velocity and direction for Lyons can be made from the average of data from surrounding stations because of the consistency and uniformity of prevailing wind over broad expanses of the plains region. Annual average wind velocity and

Table 4.8. Frequency of Specified Amounts of Rainfall During Stated Time Intervals in Rice County^a

Length of Return Period (years)	Total Rainfall (in.) for Various Time Intervals						
	30 min	1 hr	2 hr	3 hr	6 hr	12 hr	24 hr
1	1.1	1.3	1.5	1.6	1.9	2.0	2.3
2	1.6	1.6	1.9	2.0	2.4	2.6	3.0
5	1.7	2.1	2.5	2.7	3.2	3.5	4.0
10	2.0	2.4	2.9	3.1	3.7	4.2	4.6
25	2.3	2.9	3.4	3.6	4.4	4.9	5.5
50	2.7	3.3	3.9	4.2	5.0	5.7	6.2
100	3.0	3.7	4.4	4.7	5.7	6.4	7.0

^aData taken from United States Department of Commerce, Weather Bureau, 1961. Rainfall Frequency Atlas of the U. S. for Duration From 30 Minutes to 24 Hours and Return Period From 1 to 100 Years, Tech. Paper 40 (1961).

Note: This table shows the expected frequency of rainfall events of a specified duration for return periods ranging from 1 to 100 years. For example, in a 24-hr period, 2.3 in. or more of rainfall may be expected once a year; 4.6 in. or more, once in 10 years; and 7.0 in. or more, once in 100 years.

Table 4.9. Monthly Mean Air Temperature of 11 Stations,
Including 95% Confidence Limits^a

Month	Mean Ambient Temperature (°F) ^b	95% Confidence Limits
January	29.4	<u>+0.6</u>
February	34.4	<u>+0.6</u>
March	41.7	<u>+0.7</u>
April	54.7	<u>+0.5</u>
May	64.8	<u>+0.4</u>
June	74.8	<u>+0.4</u>
July	80.2	<u>+0.4</u>
August	78.8	<u>+0.4</u>
September	69.6	<u>+0.4</u>
October	48.8	<u>+0.4</u>
November	43.3	<u>+0.4</u>
December	33.0	<u>+0.5</u>
Annual	55.3	<u>+0.2</u>

^a Data from Climatic Summary of the United States, 11-12
(Suppl. for 1931-1952), 86-12 (Suppl. for 1951-1960), and Annual
Summary of Climatological Data No. 13 (Kansas), Vol. 75 (1961) to
Vol. 83 (1969).

^b Based on 235 and 239 observations per monthly value.

Table 4.10. Duncan's Grouping (0.05) of Stations According to Annual Mean Temperature

Station	Annual Mean Temperature (°F)	Grouping ^a
Wichita	56.6	}
Hutchinson	56.2	
McPherson	56.1	
Great Bend	56.0	
Sterling	55.6	}
Salina	55.1	
Dodge City	55.0	}
Geneseo	54.8	
Kanopolis Dam	54.3	}
Russell	54.0	
Concordia	53.7	}

^aAny two means not included within the same bracket are significantly different at 0.05 level.

variance as a function of direction is illustrated in Fig. 4.29. Maximum velocity is from a southerly direction, the wind path which would disperse radionuclides away from the Lyons population center. Confidence intervals of approximately one mph indicate high directional uniformity among six different areas in Central Kansas. As shown on the wind rose (Fig. 4.30), directional frequency is greatest from a southerly direction and the maximum velocity winds most frequently come from the south. Fair weather winds are generally from the south for 11 months of the year. February is the exception when wind frequency is slightly greater from the north. Slightly more than 60% of the wind velocities occur in the 13-24 mph class (Table 4.11), and maximum wind velocity exceeds 46 mph for only 0.2% of the vernal winds at Dodge City.

Despite the apparent uniformity of the wind regime of Central Kansas, significant differences were observed among stations. Using a model which considers the cyclical character of the wind parameters (Fig. 4.29 and 4.31), analysis of variance and multiple range tests indicated that annual velocities were similar for Dodge City and Great Bend, Hutchinson and Wichita, with Concordia and Salina being in individual categories (Table 4.12). Although annual mean differences were small, it appears that local factors, possibly topography or fetch, influence air movement patterns.

Inversion conditions tend to localize atmospheric dispersion of radioactivity, but this phenomenon will occur only during periods of relatively calm air. The percentage of calm days ranges from 0.1 (Dodge City) to 8.1 (Salina), averaging 2.6 for 6 stations. Low inversion frequency would be expected on the basis of the infrequent occurrence of calm days. Again, on-site observations of this phenomenon will be necessary because analysis of variance and similarity groupings (Table 4.13) indicate that only Concordia and Wichita are alike in this regard.

Fig. 4.29. Average Mean Wind Velocity of 6 Stations at Each Direction, Including 95% Confidence Intervals.

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Fig. 4.30. Percentage Frequency of (1) Wind Direction, Including 95% Confidence Intervals, and (2) Wind Velocity from Prevailing Direction.

Table 4.11. Percentage Frequency of Wind Velocity from Prevailing Direction^a
(Average of Three Stations^b)

Wind Velocity Class (mph)	Frequency (%)
1-3	1.0
4-12	27.8
13-24	61.6
25-31	8.6
32-46	1.2
Over 46 ^c	-
Average wind velocity from prevailing wind direction	16.2

^aSouth.

^bGreat Bend, Wichita, and Dodge City.

^cObserved 0.2% of February and March winds at Dodge City station.

Fig. 4.31. Average Mean Velocity of 6 Stations in Each Month, Including 95% Confidence Intervals.

Table 4.12. Duncan's Grouping (0.05) of Stations According to Wind Velocity

Station	Annual Mean Wind Velocity (mph)	Grouping ^a
Dodge City	13.9	}
Great Bend	13.7	
Hutchinson	12.8	
Wichita	12.6	
Concordia	12.0	
Salina	11.2	

^aAny two means not included within the same bracket are significantly different at 0.05 level.

Table 4.13. Duncan's Grouping (0.05) of Stations According to Percentage Frequency of Calm Days

Station	Mean Percentage of Calm Days	Grouping ^a
Salina	8.1	}
Hutchinson	4.0	
Concordia	1.5	
Wichita	1.2	
Great Bend	0.4	
Dodge City	0.1	

^aAny two means not included within the same bracket are significantly different at 0.05 level.

4.5.2 Atmospheric Dispersion

Estimating atmospheric dispersion of radioactive materials requires an in-depth knowledge of wind conditions. Wind measurements have not been made at the site; therefore, meteorological data from six stations were summarized to characterize the wind regime for Central Kansas and Rice County. Estimates of dispersion were then calculated using a diffusion model and atmospheric data from the Wichita Station.

Average annual downwind air concentrations are calculated by a modified Gaussian plume formula as follows:

$$X(\theta x) = \sum_{i=1}^R \sum_{S} \frac{2.032 F(\theta S)_i Q_0}{\sigma(Sx)_z \bar{u}(\theta S)_i x} \cdot \exp \left[-\frac{h^2}{2\sigma(Sx)_z^2} \right] \quad (1)$$

where

$X(\theta x)$ = average annual concentration along a 22.5° arc at distance x in direction θ (curies/ m^3),

$F(\theta S)_i$ = fraction of time that the wind is in direction θ , for stability S and wind speed group i ,

Q_0 = initial emission rate (curies/sec),

$\sigma(Sx)_z$ = vertical dispersion coefficient at distance x for stability S (m)

$\bar{u}(\theta S)_i$ = average wind speed in direction θ , for stability S and speed group i (m/sec),

h = stack height (m),

R = index denoting wind-speed groups,

S = index denoting stability parameter.

This expression is obtained by integrating the Gaussian plume formula over the crosswind direction and distributing the results uniformly along the entire arc. Since the average wind-speed vector and its frequency of occurrence are used, calculations yield average annual air concentrations. Applications of this technique have been demonstrated previously by Culkowski.²⁴

Equation (1) is modified to include washout and fallout by multiplying by the appropriate correction factors. Corrections for washout and fallout are based on the work of Chamberlain and Slade respectively.^{25,26} These corrections are as follows:

$$Q_{\text{washout}} = \exp \left[- \frac{\Lambda x}{\bar{u}(\theta S)_i} \right], \quad (2)$$

where Λ is the washout coefficient (sec^{-1}); and

$$Q_{\text{fallout}} = \exp \left\{ -(2/\pi)^{1/2} \frac{V_g}{\bar{u}(\theta S)_i} \int_0^x \frac{1}{\sigma(Sx)_z} \exp \left[- \frac{h^2}{2\sigma(Sx)_z^2} \right] dx \right\}, \quad (3)$$

where V_g is the deposition velocity (m/sec). Equation (3) can be evaluated numerically, based on curves of σ_z values given by Hilsmeier and Gifford.²⁷

Information concerning the frequency with which the wind blows in each of the sixteen cardinal directions, together with the joint frequency of eight discrete wind speeds, was collected at McConnell Air Force Base at Wichita, Kansas, over a 20-year period. These data have been reduced to a form appropriate for use in this analysis as shown in Table 4.14.

Since the data as received were not tabulated by atmospheric stability condition, it was assumed that Pasquill stability D condition existed. This condition is considered typical for this locale.²⁸ The calms, which account for approximately 5% of the total number of observations, were omitted from the data.

The rate at which radioactive material is removed by dry deposition from a contaminated plume or cloud depends upon the chemical and physical form of the radionuclide and the surface upon which it deposits. An average deposition velocity of 0.1 cm/sec is reported for inert material (such as ^{90}Sr and ^{137}Cs) on vegetation.²⁹ This value is chosen to reflect the deposition of all radioactive material emitted from the Repository.

Figure 4.32 shows the calculated air concentrations at the ground surface for a 1 part/sec ground-level release from the Repository. The deposition rate, w (parts/m²/sec) is the product of the air concentration

Table 4.14. Joint Frequency Distribution of Wind Speed and Wind Direction^a

Wind Direction	Meters per Second							
	0.894	2.24	3.80	6.04	8.49	10.95	13.63	> 15.20
SSW	0.00310	0.00826	0.02893	0.04236	0.01343	0.00413	0	0
SW	0.00310	0.01136	0.02789	0.02376	0.00620	0.00207	0	0
WSW	0.00310	0.00723	0.01446	0.01343	0.00310	0.00103	0	0
W	0.00413	0.01033	0.01963	0.01550	0.00413	0.00103	0	0
WNW	0.00207	0.00620	0.01136	0.00723	0.00103	0	0	0
NW	0.00207	0.00826	0.01860	0.01653	0.00413	0.00103	0	0
NNW	0.00207	0.00723	0.01860	0.02479	0.01240	0.00413	0	0
N	0.00413	0.01033	0.02893	0.05475	0.02996	0.00930	0.00103	0
NNE	0.00103	0.00620	0.01136	0.01136	0.00413	0.00207	0.00103	0
NE	0.00207	0.00413	0.00826	0.00310	0.00207	0.00103	0	0
ENE	0.00103	0.00207	0.00310	0.00207	0.00103	0	0	0
E	0.00207	0.00413	0.00620	0.00207	0.00103	0	0	0
ESE	0.00103	0.00413	0.00310	0.00310	0.00207	0.00103	0	0
SE	0.00103	0.00620	0.01240	0.01963	0.01240	0.0103	0.00310	0.00103
SSE	0.00207	0.00620	0.1756	0.03822	0.02376	0.01240	0.00207	0
S	0.00310	0.01343	0.03719	0.06818	0.03822	0.1446	0.00207	0

^aT. P. Hamrick, Calculated from data in "Revised Uniform Summary of Surface Weather Observations for Wichita, Kansas/McConnell AFB," January 1948 - April 1967, Data Processing Division, ETAC, USAF, Asheville, N. C. 28801.

Fig. 4.32. Average Annual Air Concentrations at Ground Level in Parts Per Cubic Meter.

and the deposition velocity. The deposition rate is calculated by multiplying the contours of Figure 4.32 (parts/m³) by 10⁻³ (m/sec).

4.5.3 Extreme Weather

Tornadoes. - Tornadoes result from violent storms of the Great Plains region. They occur most frequently in summer, and over a 34-year period the average annual frequency rate has been 2.1 per 10,000 mi² in Kansas.³⁰ According to Thom³¹, the probability of a tornado striking a given square mile is calculated from the following relationship:

$$P = \frac{Z \cdot \bar{t}}{A}$$

where:

P = mean probability of a tornado striking any given square mile area,

Z = mean path of a tornado (for Kansas, length = 10 mi. and width = 0.25 mi.; thus, Z = 2.5 mi²),

$\bar{t}$ = mean number of tornadoes per year = 2.1,

A = 10,000 mi².

The calculated annual probability is 5.25×10^{-4} . Adjusted for increased frequencies in Central Kansas (1.1 times the Kansas average according to Flora)³⁰, the probability (P') becomes 5.8×10^{-4} . The summation of annual probabilities for 25 years, the expected life of the facility, gives a 1.4% probability of a tornado interacting with a given 1 mi² area in Central Kansas. The probability (P'') would be 0.023 for a 1000-acre area. Using the relationship

$$R = 1/P' \text{ or } 1/P''$$

the mean recurrence intervals (R) are 1730 and 1107 years for one square mile and 1000-acre areas, respectively. If the Repository site should experience a tornado (P'' = 0.023), then it is unlikely

to occur again during the limited time of operations. Of course, tornado phenomenology cannot be expected to follow strictly the laws of probability, and actual events may occur at lesser or greater frequency.

Hailstorms.³² - Crop damage from hailstorms in Kansas averages \$10 million per year, and this is ten times the damage from tornadoes. Although hail damage per se to the Repository is not anticipated, the commonality and severity of hailstorms is an indicator of storm violence which can be expected in the Kansas plains region. Over 75% of the hailstorms occur during May, June, and July with nearly all the damage being to the wheat crop.

4.6 Agriculture and Ecology

Soils and climate of Central Kansas strongly favor grassland vegetation. Dryland farming represents a successful adaptation to this type of environment. Reversion to a native grassland would quickly follow abandonment of intensive agriculture, and Kuchler³³ designates the climax vegetation for this area as bluestem-grama prairie.

4.6.1 Soils

The Repository site will be located on uplands comprised of loessal-derived soils which are nearly level or gently sloping. Five different series have been mapped, and their textures range from silty clays to clay loams.³⁴ The soils are well drained and possess a high available water capacity and medium-to-high native fertility. All the soils are well suited for range grasses and dryland agriculture, although crop losses occasionally result from summer drought. Alternatively, water erosion occurs on sloping areas and lower drainage systems experience flooding.

4.6.2 Agricultural Crops

On-site vegetation currently consists of agricultural crops and pasture. Traces of native endemics, cosmopolitan weeds, shrubs and trees occur along fence rows, drainages and roadsides. Small but persistent

prairie communities exist along Santa Fe and Missouri-Pacific railroad right-of-ways. On occasions, prairie grass may be cut for winter hay. Practically all the 1000-acre site supports intensive agriculture for which cropping systems may vary from year to year on a given field because planting decisions depend on rotations, markets, allotments, and other commitments. Average on-site acreage-plantings seem to follow the pattern for Rice County with 73% of land planted to wheat, 18% sorghum, and pasture-soybeans-hay comprising the balance (Table 4.15). Other grains, such as corn, oats, barley, and rye would account for only a small fraction of total crop production. Midsummer 1970 on-site field observations agree with these county-wide production data. Future crops in surrounding areas probably would follow the same pattern except for possible future increase in sorghum production.

4.6.3 Livestock

Approximately 14,000 cattle and 3,900 hogs are located in a 200 mi² area around Lyons. Small numbers of sheep, lambs, and chickens are also raised in this area (Table 4.16). The possible presence of 530 milk cows in this vicinity, according to pro rata calculations, may require periodic monitoring of milk samples because the grass-cow-milk-man pathway is a principal mode of critical radionuclide ingestion by man. Rural situations where total milk intake is from local sources may require special attention. Otherwise, monitoring of milk from the Wichita milkshed collections probably would be continued according to planned Public Health Department schedules and would satisfy requirements for identifying incipient nuclide accumulation in milk products.

4.6.4 Permanent Vegetation

Kansas ecologists (Gery Tamasek and Gary Huellet, Ft. Hays State College; Lloyd Hulbert, Kansas State University) strongly recommend that native prairie should be established on the Repository site. Specific advantages of native vegetation include enhanced ecosystem stability, reduced erosion, minimal dispersal of radioactive materials, economical

Table 4.15. Proportional Crop Production for 200-Square-Mile Area Surrounding Lyons, 1968

Crop	Harvested Acreage	%	Yield Rate ^{a, b} (kg/ha) ^d	Total Production (ton) ^c
Wheat	49,306	73.2	1,934	34,803
Sorghum	12,077	17.9		
grain	(11,080)	(16.5)	2,176	8,802
silage	(637)	(0.9)	24,453	6,325
Corn	679	1.0		
grain	(277)	(0.4)	5,271	533
silage	(360)	(0.5)	24,700	3,606
Oats	116	0.2	1,074	46
Barley	75	0.1	2,100	57
Rye	158	0.2	1,128	65
Hay	4,820	7.2	4,940	9,626
alfalfa	(3,740)	(5.6)	5,434	8,239
wild	(609)	(0.9)	2,717	666
Seeds (alfalfa, red clover, sweet clover)	507	0.5		21
Soybeans	94	0.1	1,445	27
Pasture land (1964 census)	32,660			

^aWeight conversion factor: 1 kg/ha = 0.028 bu/acre at 32 lbs; = 0.019 bu/acre at 48 lbs; = 0.016 bu/acre at 56 lbs; and = 0.015 bu/acre at 60 lbs.

^bGrain weight per bushel: wheat 60 lbs; barley 48 lbs; oats 32 lbs; rye, corn, sorghum, and soybeans 56 lbs.

^cTon = 2000 lbs avoirdupois.

^dHectare (ha) = 10,000 m².

Note: Production data summarized from ref. 35.

Table 4.16. Livestock^a on Farms in Rice County and Proportional
Number for 200-Square-Mile Area (Jan. 1968)

	Milk Cows	Other Cattle	All Cattle	Hogs	All Sheep and Lambs	Chickens
Rice County	1,900	49,100	51,000	14,000	3,000	11,000
Proportional	530	13,700	14,230	3,900	830	3,050

^aLivestock data summarized from ref. 35.

long-term maintenance, control of management influences, and educational-cultural benefits. Of course, revegetation with native flora would change the physiognomy, biotic equilibria and microenvironments. Thus, the projected native ecosystem, at least 3-10 years hence, would exhibit a character greatly different from the present, intensively managed agro-ecosystem.

Reseeding will result in a 90% native grass community within 3 years. Native forbs would become established during the next 10 years as the vegetation succeeds to the complete aspect of native prairie. The inherent stability of such a community should be extremely valuable for assessing real or alleged impacts of the Repository operation on the environment. The terminal species composition of the reseeded grassland will include many of those which were reported growing along the Santa Fe and Missouri-Pacific railroad right-of-ways. These areas could also serve as a seed source for exotic prairie species which normally would not be present in commercial seed.

4.6.5 Wildlife

In the 1970 Ecological Surveys more than 900 animal taxa were identified as being associated with either local agroecosystems, aquatic environments or projected grassland ecosystems. Understandably, the inventory is incomplete, but it suggests the most representative flora and fauna peculiar to a native terrestrial ecosystem. The more conspicuous animals would be herbivorous birds (bob white, pheasant, dove, meadowlark), carnivorous birds (hawk, owl, kingbird, sparrow), herbivorous mammals (rabbit, mouse, vole, ground squirrel, prairie-dog [introduced]), and insects (beetles and wasps). Introduction of a large animal grazer, i.e., buffalo, would be a stabilizing factor in the surface grassland ecosystem.

4.6.6 Site Management

Reversion to a native grassland community will simplify management because of the natural interactions among soil-grass-consumer-decomposer components. A managed herd of large grazers would remove excess vegetation,

thereby striking a balance between grass growth and harvest. Occasional hay cutting, harvest or burning management may be necessary during developmental phases of the operation.

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5. IMPROVEMENTS TO LAND (Reference Figs 5.1 and 5.2)

5.1 Site Clearing, Grading and Landscaping

5.1.1 Site Clearing

A minimum of site clearing will be required. Areas designated for buildings, roads, railroads, other structures and structural or nonstructural fills will be stripped of trees and stumps, brush and topsoil. Areas not affected by construction activity are to be left in their natural state.

5.1.2 Grading

There will be a minimum of site grading required because of the relatively low relief in the site area. Areas requiring structural fill to bring them to grade will be cleared and stripped, the subgrade compacted, and the fill material placed and compacted. Non-structural fill areas will be cleared and fill material will be spread in thin lifts. Compaction will be accomplished by the passage of the fill-placing and spreading equipment. Grading for site drainage will be on the basis of overland sheet flow collected in open ditches and drainage swales. The drainage ditches and swales will carry the collected storm water discharge to the nearest natural drainage channel. Culverts will be provided to pass storm drainage under roads and railroads. Efforts will be directed toward minimizing erosion during construction.

5.1.3 Landscaping

Landscaping will be limited to the restoration of ground cover in those areas disturbed during the construction operation. The ground cover used will consist of local grasses to provide adequate protection against erosion. Adequate topsoil, fertilizer, and mulch will be applied to assure good ground coverage.

Fig. 5.2. Repository Plot and Utility Plan.

5.2 Roads and Parking

Road access to the site will be by the county road system. It is assumed that any required upgrading and maintenance of these roads will be the responsibility of the applicable county and state agency.

5.2.1 Primary Road Network

The primary road network begins at the intersection with the existing east-west county road north of the Repository surface facilities. Acceleration and deceleration lanes will be provided on the county road at this intersection. This road will serve the High-Level Facility, the Alpha-Operations Facility, the warehouse, and the main Repository parking lot.

Primary roads will have two 12-ft-wide lanes with 6-ft-wide shoulders. Pending design analysis based on field and laboratory soil tests, the primary road section has been assumed to be 1-1/2 in. of asphaltic concrete over 8 in. of compacted aggregate subbase. This pavement section will be founded on not less than 6 in. of compacted subgrade made from suitable native material. The shoulders will consist of 6 in. of compacted aggregate base course material on compacted subgrade with a single bituminous surface treatment. Drainage slopes of 2% for the traveled way and 5% for the shoulders will be used.

5.2.2 Secondary Road Network

Secondary roads will serve the upcast ventilation shaft and the magazine.

Secondary roads will be a single 12-ft-wide lane with 4-ft-wide shoulders. Pending design analysis based on field and laboratory soil tests, the secondary road section has been assumed to be a double bituminous surface treatment on 8 in. of compacted aggregate base course material, founded on 6 in. of compacted native material. Shoulders will have 6 in. of aggregate base material on compacted subgrade.

Drainage slopes of 2% and 5% will be provided for the traveled way and shoulders respectively.

5.2.3 Parking

A central parking lot, with space for 150 vehicles, will be provided adjacent to the High-Level and Alpha-Operations Facilities for the Repository staff, visitors, and shift personnel. In addition, a 6-car lot will be provided at the main gate for visitors, and space for two maintenance vehicles will be provided at the upcast ventilation shaft. Access aprons will be provided at the alpha-M & M shaft, at the maintenance shop and warehouse, and at each of the hoist houses. All parking lots and aprons will be of the same structural section as the secondary roads.

Drainage of parking lots and aprons will be by sheet flow to surface drainage ditches or swales.

Sidewalks will be provided between the parking lot and the Alpha-Operations, High-Level and warehouse buildings. The sidewalks will be concrete 4 in. thick, 4 ft wide. They will be founded on 2 in. of compacted granular material on compacted subgrade.

5.3 Fencing

A 7-ft-high chain link fence topped with three strands of barbed wire on brackets, angled outward, 1 ft high, for a total height of 8 ft will be provided around the Repository buildings area. Fencing design will be in accordance with the requirements of AEC Manual Appendix 2401, Part II, C.3.a. The visitors' parking lot adjacent to the main entrance will be located outside this fenced area. Similar perimeter fences will also be provided at the upcast ventilation shaft, magazine and substation. Swing-type vehicular gates will be provided in the Repository perimeter fence at the main road entrance and the railroad entrance. They will also be provided in the localized fencing enclosing the ventilation shaft, magazine and substation.

The fencing at the existing Carey Salt surface works is assumed to be adequate and will not require modifications. It has also been assumed that the fencing system now in use around the various farms outside the developed area of the Repository will remain when the land is

acquired by the government. All fencing will be grounded in accordance with OR Appendix 630¹. Fence installations which cross "power corridors" will be further grounded in accordance with that same document.

Man barriers will be provided at points where the perimeter fence crosses the surface drainage system ditches.

5.4 Relocation of Existing Private Utilities

Of the several private utilities that cross the Repository site, only the 6-inch diameter Northern Natural Gas Company line is within the 500-ft safety clearance limit established by the criteria (Sect. 3.5.4); therefore a portion of this line will be relocated to provide a minimum of 500 ft clearance from all inhabited structures. Construction of the relocated line will be similar to that used for the existing line.

5.5 Sealing of Abandoned Wells

At least one active and a number of abandoned oil wells penetrate the salt deposit at the Repository site and the one-mile buffer zone. In addition, there are presently two exploratory core holes that penetrate the salt deposit. It is necessary that all these penetrations of the salt deposit be investigated and plugged so that the salt bed will be protected from intrusion of oil, water, and gas from both above and below. The procedures for sealing these penetrations and testing the seals will be developed based on a detailed evaluation of each hole. The seal may consist of multiple barriers using different materials at different levels so that the plug will be stable and compatible with the surrounding material at all elevations.

6. ALPHA-OPERATIONS FACILITY

The Alpha-Operations Facility will receive alpha waste packaged in burial units delivered to the Repository by special rail cars. Facilities and equipment will be provided to: (1) inspect the burial units to assure integrity and an acceptable level of radioactivity; (2) transport them by surface, mine shaft, and underground vehicles; and (3) bury them efficiently in a safe manner for permanent storage in the existing salt mine.

Engineering and economic studies indicate that efficient waste handling can best be achieved in an integrated facility consisting of an alpha waste receiving building, mine operations building, Repository administration building, hoist house, and a mine fresh air supply fan house. The arrangement of the facility structures, waste handling systems, and supporting operations has been predicated on providing the most economical method of handling and storing alpha waste, while maintaining high standards of operational safety and reliability. A further consideration provides for ease of expansion in later years to accommodate possible increases in the delivery rate of waste to the Repository.

The buildings and components of the Alpha-Operations Facility are described in Sect. 6.1. The two major systems in the Alpha-Operations Facility are described in detail with particular attention given to safety considerations. These systems include the Alpha Receiving, Handling, and Burial System (Sect. 6.2) and the Alpha Facility Ventilation and Confinement System (Sect. 6.3).

6.1 Alpha Facility Components

6.1.1 Alpha Waste Receiving Building and Support Structures (See Fig. 6.1)

Facility Description. - The alpha waste receiving building will be designed in accordance with criteria set forth in AEC Appendix 630¹ and other criteria specified herein. The container unloading and storage area will provide a staging area for directing the flow of cargo containers between the rail cars and the confinement

Fig. 6.1. Alpha Waste Receiving Building.

zone of the building. The building will contain the necessary equipment and facilities to inspect and transport the waste to the alpha-M & M shaft for lowering into the mine.

Except for the weather-protected container unloading and storage area, all areas for alpha waste handling will be in a confined structure. The building provides two entries for waste and two unloading and decontamination rooms to allow continuity of burial unit flow through a single transfer room to the alpha-M & M (man and materials) shaft (see Sect. 6.1.5). The alpha-M & M shaft will be located in an isolated waste loading compartment adjacent to the transfer room. This compartment will be opened to load a burial unit on the alpha cage for lowering to the mine. Support facilities for the receiving building operations will be located adjacent to the operating areas.

Functional descriptions of rooms and areas within the alpha waste receiving building are as follows:

1. Container Unloading and Storage Area. - The container unloading and storage area will be a weather-protected concrete working pad, sized for unloading two containers from an ATMX rail car, dolly transport of the containers through air locks into the unloading and decontamination rooms, and adequate laydown space for storage of rail car covers and six empty cargo containers. A 25-ton overhead bridge crane with a 5-ton auxiliary hook will be provided for all rail car loading and unloading operations. The structure providing the weather protection for the unloading and storage area will extend the full length of the concrete working pad and over the ATMX rail car unloading station. It will be an uninsulated, structural steel framed enclosure with galvanized corrugated metal roofing and siding over the full length of the crane runway. The height of the structure will be dictated by the crane rail elevation as established by clearance requirements. Weather doors will be provided at both the rail car entrance and exit to allow direct pass-through of cars on the rail siding.

2. Air Locks. - Separate air lock entries will be provided to maintain the confinement integrity of the two unloading and decontamination rooms. Gasket-sealed overhead doors will be provided with electrical interlocks to prevent both air lock doors from being opened simultaneously. Door openings will be designed to accommodate passage of an 8-ft by 8-ft by 20-ft cargo container on a rail-mounted, motorized transfer car.
3. Unloading and Decontamination Rooms. - Two unloading and decontamination rooms will serve as the check points for alpha shipments and provide unloading docks for removal of burial units from the cargo containers using lift-trucks. Each room will be sized to provide space for the transfer car at the face of an unloading dock. Sufficient space will be provided on each dock to allow room for maneuvering a lift-truck, and for interim storage of the contents of a cargo container. Motorized overhead doors with gasketed seals will be provided to minimize floor area requirements. Safety guard rails will be provided at the face of the dock.
4. Transfer Room. - The transfer room will provide maneuvering space for the lift-trucks to move the burial units through a room for weighing and nondestructive assay, and then into the alpha cage for lowering to mine level. The floor elevation of this area will be approximately 2 ft 6 in. above the surrounding natural grade which will preclude flood water from entering the mine shaft should a severe rainfall and flood occur.
5. Nondestructive Assay Room. - The nondestructive assay (NDA) room will be used for the dual function of weighing each burial unit and determining its fissile material content. The walls will be 8-in.-thick concrete to provide shielding from the radiation source associated with the nondestructive assay equipment. Access will be through a sliding door, designed to prevent radiation streaming when the door is in the closed position.

6. Waste Loading Compartment. - The waste loading compartment will isolate the alpha-M & M shaft from the transfer room except for intermittent periods when the door to the transfer room is opened to allow passage of a burial unit into the alpha cage. The compartment will be sized to provide working room around the shaft for maintenance and access to the head frame. The door will be designed to allow removal of the alpha cage for maintenance, decontamination, or for changeout of the hoist cable.

The alpha cage must be at floor elevation and the partial closure must be in place around it before the door from the transfer room is opened. This is necessary to circumvent the escape of radioactivity into the shaft.

7. Head Frame and Cable Enclosure. - The alpha-M & M shaft head frame will be a circular 18-ft-diam reinforced concrete silo-type tower. It will be mounted directly over the alpha and man and materials compartments of the shaft and will constitute an above-grade extension of the mine shaft. A sheave house will be located at the top of the head frame and be separated from the body of the head frame by a concrete slab, with sleeve penetrations for the hoist cables. The sheave house will be divided into separate compartments by a concrete dividing wall. Both the alpha head frame and sheave compartment will be confined areas. An air-tight enclosure will be installed around the alpha cage cables and will be maintained at a negative pressure. However, the pressure in the alpha hoist house and cable enclosure will be slightly greater than the pressure in the transfer room so that a small quantity of air will flow from the hoist house, through the cable enclosure into the transfer room.
8. Hoist House. - The hoist house will be divided into two separate units: one unit will be confined to enclose the alpha hoist machinery; the other will be unconfined and

will house the man and materials hoist machinery. The building will not be tornado resistant.

9. Exhaust Fan-Filter Room. - This room will contain exhaust fans and filters for cleanup of the alpha waste receiving building ventilation. The exhaust air will pass through a duct to the stack which will be attached to the outside of the mine shaft head frame and extend approximately 10 ft above the top of the head frame roof.
10. Alpha Waste Receiving Building Support Area. - A facilities support area will be provided adjacent to the confined areas of the building and will contain: a counting room, a personnel check station, a change room, a maintenance and battery charge room, and the shift foreman's office. Access from this area into the confined areas of the facility will be through air locks.

Confined Areas. - The confined areas of the building are those areas where alpha burial units will be transferred from the cargo containers to the mine, and all areas surrounding the alpha hoist cable. These areas will be maintained at a negative static air pressure with respect to the outside atmosphere to ensure an inflow of air.

Confinement will generally be provided by the following means:

1. Selection of construction materials for minimum air leakage.
2. Sealing all structural connections and joints where leakage could occur.
3. Use of air locks and gasket-sealed doors.
4. Ventilation control.

Confined areas will in all cases be separated from the outside atmosphere by air locks. The confined areas will include the following:

1. Unloading and decontamination areas.
2. Transfer room
3. Nondestructive assay room.

4. Waste loading compartment and head frame.
5. Exhaust fan-filter room.
6. Alpha hoist cable enclosure.
7. Hoist house (alpha hoist portion).

The following sets of doors will be interlocked to prevent both doors being opened at the same time:

1. Cargo doors at both ends of container air locks; and
2. Cargo doors at both ends of air lock separating the transfer room and mine materials unloading dock.

Design Classification. - All structures, systems and equipment within the Repository will be classified by the three design category groupings described in Sect. 3.5.1. This classification is applied to identify plant features for purposes of public safety and operational reliability during postulated accident conditions. Categories for structures in the Alpha-Operations Facility are given in Table 6.1.

6.1.2 Mine Operations Building

Facility Description. - The architectural and structural design of the mine operations building will be in accordance with the criteria specified in AEC Appendix 630¹, and other criteria specified herein. Surface activities relating to mine personnel, equipment and materials will be centered in the mine operations building to avoid disruption of waste handling in the alpha waste receiving building.

The mine operations building will be contiguous to the alpha waste receiving building and will provide for: change room and shower facilities for mine personnel; offices for mine supervisors; a personnel check station; dispensary; miners' lanterns storage and repair shop; and a materials and equipment receiving and storage room with direct access to the alpha-M & M shaft. Access between this building and the alpha waste receiving building is provided through an air lock.

Table 6.1. Alpha-Operations Facility Design Categories

Structure	Design Categories
a. Container unloading and storage area	III
b. Container air locks	I
c. Unloading and decontamination rooms	I
d. Transfer room	I
e. Waste Loading compartment and head frame	I
f. Nondestructive assay room	I
g. Alpha waste receiving building support area	III
h. Hoist house - alpha portion	II
i. Hoist house - M & M portion	III
j. Exhaust fan-filter room	I
k. Mine air supply fan house	III
l. Alpha cable enclosure	II

An open unloading dock and staging area will be provided between the alpha-M & M shaft and the receiving and storage room in the mine operations building. This open area will serve as the connecting corridor between the mine operations building and the shaft.

A full basement will be provided under the mine operations building to house the mechanical equipment serving the Alpha-Operations Facility and for the Repository main switchgear, standby power generators, and central control and monitoring station. None of the main floor areas of the mine operations building or the basement mechanical and electrical equipment rooms will be confined.

Structural Considerations. - The mechanical and electrical equipment rooms will be located below grade and will form the foundation for the above-grade portion of the mine operations building.

Tornado resistance will be provided by non-exposure of the basement walls to the direct wind loading and by blowout panels in the basement roof slab. The below-grade portion of the structure will assume the same seismic acceleration as the surrounding ground. Since this basement area houses the central control and monitoring station and the equipment in this area is vital to plant operation and maintenance of confinement in other areas, Category I classification will be given to this equipment and the applicable seismic loading will be used for such design. The structural design of the above-grade portion will follow requirements for Category III structures.

6.1.3 Repository Administration Building

The Repository administration building will house all central administrative activities involved in the operation of the Repository. Office space will be provided for Repository management, engineering, accounting, personnel, safety, and payroll personnel and for files and records.

The Repository administration building will be connected to the mine operations building by an eight-foot wide enclosed passageway. The Repository administration building will be located approximately 100 ft from the alpha-M & M shaft to provide adequate distance for shaft excavation and other facility construction.

6.1.4 Mine Air Supply Fan House

The mine air supply fan house will be a below-grade structure to house the ventilation equipment supplying the mine with fresh air. The fan discharge will be routed through a 6-ft diam underground duct to the alpha-M & M shaft air intake compartment. A fresh air intake duct will project above the roof of the fan house. The fan house will not be a confined area and will be Category III construction.

6.1.5 Alpha-M & M Shaft (Reference Fig. 6.2)

Facility Description. - The alpha-M & M shaft will be designed to fulfill the following functions:

1. Lower sealed burial units containing alpha waste into the alpha mine for burial, at a design rate of 1 million ft³ of alpha waste per year on a three-shift, five-day-per-week basis.
2. Provide access for men and materials in and out of both the alpha and high level portions of the mine. In addition, provisions are to be made in the design for the future installation of salt hoisting capability.
3. Serve as the main passage of fresh air into the entire mine.

To perform the functions listed above, the shaft will be subdivided into three main compartments (for alpha waste, man and materials, and air supply) and two auxiliary compartments (for counterweight and manway). The alpha-M & M shaft will be an 18 ft ID concrete lined shaft with concrete divider walls for the three main compartments. The shaft liner will extend 60 ft below the alpha station to allow the installation of a salt and spill pocket at a later date. A sump will be installed at the bottom of the shaft for leakage collection and disposal. The shaft lining and supports will be Category I.

The alpha waste compartment must be isolated from other compartments by an airtight concrete divider wall over the entire length of the shaft to preclude any possibility of the spread of alpha contamination in the unlikely event that the alpha waste compartment becomes contaminated. The alpha waste compartment will be large enough to accommodate a cage with the following dimensions:

Length	6 ft-6 in.
Width	6 ft-6 in.
Height	8 ft-0 in.

The cage will hold one alpha waste burial unit with dimensions of

Fig. 6.2. Alpha and M & M Shaft, Underground Stations and Cage.

4-ft by 6-ft by 6-ft-high. The capacity of the hoist in the alpha waste compartment hoist will be 20,000 lb.

The man and materials (M & M) compartment will be large enough to accommodate a cage 6 ft-6 in. by 10 ft-6 in. by 10 ft-0 in. high, with a capacity for 26 men. The compartment will be isolated from the alpha waste compartment by a solid concrete wall. The man and materials compartment will be large enough to permit the lowering and raising of large pieces of equipment either in assembled or partly disassembled form, with a weight limit on individual pieces of 14,000 lb. The lifting capacity of the man and materials compartment hoist will be 24,000 lb and provisions will be included in the design for the future installation of salt hoisting capability in this compartment.

The air supply compartment will have a minimum cross sectional area of 30 ft². The total air flow through this compartment will be approximately 62,000 cfm but the compartment is sized for an ultimate capacity of 100,000 cfm. The air supply compartment will be completely isolated from all other shaft compartments by divider walls to avoid any possibility of radioactive contamination or recirculation of fresh air.

Two auxiliary compartments will be provided adjacent to the M & M compartment. One compartment will include a manway, which will be an emergency exit for all mine personnel, together with space for utilities. The other auxiliary compartment will include a counterweight to permit balanced hoisting in the M & M compartment. Neither the manway nor the counterweight compartment will be airtight with respect to the M & M compartment.

Mine Level Stations. - The alpha-M & M shaft is provided with two mine-level stations: an alpha station and an M & M station. The alpha station will be located at the existing mine level, approximately 1023 ft below grade level. Its purpose will be to provide space for transfer of alpha burial units from the alpha cage to the transporter, using a battery-powered lift truck. The walls, floor, and roof of the alpha station will be built of reinforced

concrete and this structure will be tied into the shaft concrete. The station will be isolated from the main entry by a double door air lock, constructed of concrete frames and hinged metal doors.

Men and materials entering or leaving the mine will utilize the M & M station. This station will be above the alpha station and on the opposite side of the shaft. The M & M station will be completely isolated from the alpha compartment. The construction of the M & M station will be similar to the alpha station except that it will be larger in order to facilitate handling of materials and to provide space for future installation of salt hoisting capability. The shaft will be separated from the station by a steel door for personnel safety. This station will be separated from the mine by a double-door airlock located approximately 50 ft from the edge of the shaft. The air lock will be of fire-proof construction and will also serve as a refuge for mine personnel in case of fire or other emergency conditions.

6.1.6 Alpha Mine

Facility Description. - The underground alpha storage operations will be conducted under the following guidelines:

1. All storage operations will occur in fresh ventilation air. The patterns of the operation will be a retreat system whereby the first burial units will be placed closest to the upcast ventilation shaft. To avoid the possibility of personnel being exposed to alpha contamination from the storage operation, no storage will occur in areas ventilated by air that has passed or circulated through a previously filled area.
2. Sealed burial units will be lowered in the airtight cage to the alpha station. The burial units will be removed from the cage by a battery-powered forklift truck, transferred through an air lock and placed on an electric trolley-powered transporter. The transporter will be able to carry one or two burial units per trip to the storage area.

3. Burial units will be off-loaded from the transporter by an electric-powered lift truck. They may then be carefully rotated by special handling forks of this lifting unit and stacked in the storage rooms, either upright or with their longest dimension laid horizontally, as efficient utilization of available room height demands.
4. After a row of burial units has been stacked in the storage room a backfilling machine will throw salt into the remaining empty space above and around the row to complete the storage sequence. The machine will be loaded with finely ground salt by an electrically-powered, elevating-discharge shuttle car.
5. Closure of each alpha burial room will be maintained by a pair of panels installed as baffles to retain the crushed salt backfill. The interior panel will extend two-thirds of the distance from the ceiling to the floor and the external baffle will extend two-thirds of the distance from the floor to the ceiling; thus lengthening the flow path for the escape of alpha particulates from the burial room.

Mining Equipment. - Electric power will be used extensively for underground equipment to minimize the required ventilation air volume, and thus the capacity of the fans and filters and the size of the upcast vent shaft. All mobile mining equipment except one load-haul-dump (LHD) unit, required for initial mine development work, and one maintenance vehicle (mobile crane) will be electric powered. Haulage vehicles, except for the one LHD unit will be powered either by batteries or from a 500-V dc two-conductor trolley system. Five-hundred-foot cable reel extension feeders extending from the trolley conductors will be used as needed. All other mobile equipment will be powered either from storage batteries or a 480-V ac three-phase power feeder system.

The 150-hp diesel-powered LHD unit will be used during initial mine development, principally for loading and haulage of

salt debris in early cleanup work before dc electric power feeders are installed for operation of other machines. Since this unit will have little or no function after the initial development period, it does not affect the mine ventilation system design.

A 90 hp, 7-ton capacity diesel-powered mobile crane (provided for emergency use only) will have no significant effect upon ventilation requirements because it will be normally inoperative. During occasional uses of this machine, air volumes in excess of requirements for personnel, circulated primarily for dust and temperature control, will be more than sufficient for dissipation of the engine exhaust fumes.

Portable ventilation fans and ducting will be used to exhaust salt dust from the working face locations of the continuous miner to the return portion of the mine ventilation circuit. For effective dust evacuation, the exhaust tube inlet must be as close to the cutting head of the miner as possible.

Mining Operation. - During the initial development of the high level mine, it is intended to erect and use a belt conveyor behind a continuous miner. The use of the conveyor will become necessary to provide adequate transport capacity for the salt tonnage output of the miner as the haul range increases into the high level mine. Shuttle cars will be used to move the material from the discharge end of the conveyor system to disposal areas and to transfer salt to the system when the miner is operating off the course of the belt.

Transfer of salt from the discharge end of the belt conveyor to shuttle cars requires surge capacity for the material received in steady flow and hauled away in batch quantities. In addition, when the Repository becomes operational, sized fractions of the material must be hauled from this location for use as backfill salt for alpha burial units and to fill the holes over the high level cans. This backfill salt will be screened from the run-of-mine material to produce maximum particle sizes of less than one inch. Oversize material and all salt quantities in excess of

the backfilling requirements will be stored in designated areas. A backfilling machine will be required for daily use, since each row of stacked alpha waste burial units placed in an alpha burial room must be covered before the next row is put in place. This sequence is essential because the slinger mechanism of the backfilling machine will not be able to throw the backfill salt further than the width of one or two burial units.

Burial Unit Handling Equipment. - The following units will be provided for handling and depositing the alpha waste burial units:

1. One hard-tired, battery-operated lift truck, for handling operations at the alpha station. Capacity = 10,000 lb @ 24 in. load center.
2. One balloon-tired, electrically-operated lift truck, for operations in the alpha waste burial rooms. This unit will be equipped with cable reel extension and rotating forks with load clamping attachment. Capacity = 10,000 lb @ 36 in. load center.
3. One alpha burial unit transporter for moving the alpha burial units from the alpha station to the alpha burial rooms. It will consist of a 4-wheel mine tractor with flat cargo deck, equipped with trolley poles (2 sets) for take-off from 500 volt dc, double conductor power source in both forward and reverse motion. Payload = 20,000 lb.

6.1.7 Upcast Vent Shaft and Central Filter Station

Upcast Vent Shaft. - The 6-ft-ID, concrete-lined upcast vent shaft will conduct all mine exhaust air to the surface. Exhaust air streams from the alpha mine and the high level mine will join at the base of this shaft. At the top of the shaft, the mine exhaust air will flow to the mine exhaust fans through exhaust filters which are housed in the central filter station.

Central Filter Station and Stack. - The central filter station complex, operating in conjunction with the mine air supply system will provide confinement for both the alpha and high-level mines. Fan and damper controls associated with the supply and exhaust systems will maintain both mines at a negative pressure. This arrangement will provide assurance that all mine air that may have come in contact with burial areas will be filtered under controlled conditions prior to discharge.

The central filter station will be a confined, below-grade concrete structure to house the mine exhaust filters and frame, and the stack monitors. It will be designed in accordance with Category I requirements. Gasketed covers at grade will permit access to the upcast vent shaft, filter banks and fans. A 5-ft-ID exhaust stack, extending 10 ft above grade, will be mounted on top of the stack monitor room.

6.2 Alpha Receiving, Handling, and Burial System (Reference Fig. 6.3)

6.2.1 Functions and Design Requirements

Functions. - The functions of the alpha receiving, handling, and burial system will be:

1. Receive ATMX rail cars containing palletized burial units consisting of metal boxes or drums of alpha waste contained within cargo containers.
2. Monitor the rail cars, cargo containers, and burial units for radioactive contamination, and decontaminate these items as required. Unload the cargo containers from the rail cars.
3. Remove the burial units from their cargo containers, transport them to the NDA monitors, and place them individually in the alpha cage of the alpha-M & M shaft.
4. Lower the burial units to mine level, move them to a burial room, stack them in such a manner as to make minimum use of the room, record burial location, and, as the room is filled, backfill with crushed salt.

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Fig. 6.3. Alpha Receiving, Handling and Burial System.

5. Monitor empty cargo containers and rail cars and prepare them for return to shipper.

Basic Criteria and Design Requirements (See Sect. 3 for Basic Criteria)

Concept-Related Design Requirements

1. The alpha waste receiving building will be designed to house surface level components required for receiving and handling palletized burial units containing alpha waste.
2. Air lock entry to and confinement of the receiving building will be provided to prevent spread of contamination to the environment in the event of an accidental release of radioactivity.
3. A weather-protected structure will be provided as part of the alpha waste receiving building for unloading rail cars. This area will be serviced by a 25-ton capacity overhead bridge crane used to remove and replace rail car hatch covers and to carry cargo containers between the rail cars and the transfer cars.
4. Instrumentation will be provided for monitoring the interior of the rail cars, the interior and exterior of the cargo containers, and the exterior of the palletized burial units for transferable contamination.
5. A nondestructive assay room will be provided in which the burial units will be weighed and in which nondestructible assay can be performed to detect potentially unsafe units.
6. Surface level handling equipment will be provided to:
(1) move the cargo containers through the air locks and into the building; (2) unload palletized burial units from the cargo containers; (3) decontaminate if required and (4) move them to the NDA room and thence to the alpha cage of the alpha-M & M shaft.
7. An alpha waste shaft compartment, shaft cage, surface-level hoist, and hoist house will be provided for lowering alpha waste to mine level.

8. A mine-level alpha station and a lift truck will be provided to receive the burial units and transfer them to the transporter.
9. A transporter and a lift truck will be provided to move the burial units to the burial rooms and to stack them in the mine.
10. Equipment will be provided to backfill the burial rooms and their access entries with crushed salt.

Applicable Documents

1. Atomic Energy Commission General Design Criteria, Appendix 6301, and appropriate Codes and Standards referenced therein.
2. AEC Manual Chapter 0550, Operational Safety Standards.

6.2.2 Physical Description

Summary Description. - The Alpha-Operations Facility will receive ATMX rail cars carrying alpha wastes packaged in palletized burial units within cargo containers. One rail car will transport two cargo containers, each containing four burial units. The rail car will be positioned inside a weather-protected area for unloading and storing the containers. After a survey for free alpha contamination, the rail car hatch covers will be removed, and full cargo containers unloaded and placed on transfer cars. The transfer cars will then be moved through air locks to the unloading and decontamination rooms. During this period, two empty cargo containers will be loaded in the rail car, the hatch covers replaced, and the rail car moved out of the building.

In the unloading and decontamination rooms, the burial units will be removed from the cargo containers, decontaminated if necessary, and moved individually to the nondestructive assay room. After weighing and assaying they will be transferred to the alpha cage of the alpha-M & M shaft and lowered to the mine-level alpha station. From there they will be loaded on a transporter and hauled to a burial room. Burial units will be stacked in rows

in the room and the rows backfilled with crushed salt before the next row of burial units is put in place.

Major System Components

1. Container Unloading and Storage Area. - A weather-protected concrete pad designed for: (1) unloading two containers from an ATMX rail car; (2) transport of the containers to the unloading rooms by dolly and (3) storage space for empty cargo containers. A 25-ton bridge crane with a 5-ton auxiliary hook will be provided for rail car loading and unloading operations.
2. Unloading and Decontamination Rooms. - A confined area where the alpha contamination levels inside the containers will be checked, followed by removal of the burial units from the containers using lift trucks.
3. Transfer and Nondestructive Assay Rooms. - Confined areas where the burial units will be maneuvered, using lift trucks, through a weigh and fissile material content assay and then loaded into the alpha cage for lowering to the mine level.
4. Alpha Waste Compartment and Shaft. - An airtight compartment separated from the other compartments in the alpha-M & M shaft by a concrete divider wall along the entire length of the shaft. The alpha cage, which will ride in this compartment, will be sealed from the alpha waste compartment by closures whenever it is at the surface or mine level in order to prevent the spread of contamination. The alpha cage will be of airtight construction, accommodate one burial unit, and be lifted by a 10-ton mine hoist.
5. Alpha Station. - A station for unloading burial units from the alpha cage by lift truck. It will be isolated from the alpha mine by an air lock.
6. Alpha Transporter. - An electrically-powered haulage unit for transporting the burial units to the burial rooms.

7. Alpha Burial Rooms. - Burial rooms mined in the bedded rock salt will be used to store up to 1 million ft³ of alpha waste per year. The storage operations will be accomplished in fresh ventilation air and no storage will occur in areas ventilated by air that has circulated through a previously filled area. Burial units will be removed from the transporter and stacked in the storage room by an electric lift truck. After each row has been stacked, a backfilling machine will fill the empty spaces with crushed salt. When a room is filled with burial units and crushed salt, the room entrance will be filled with crushed salt and a closure installed (see Sect. 6.1.6 for description of closure).

6.2.3 Primary Safety Considerations

Consideration has been given to the following possible hazardous situations that could result in the spread of contamination in the alpha facility or the release of greater than the normal amounts of alpha particulates to the environment.

1. An ATMX rail car arrives at the Repository and the initial alpha survey indicates abnormally high concentrations of alpha contamination within the interior of the rail car.
2. A cargo container is dropped during car unloading operations in the container unloading area.
3. A cargo container has been moved into an unloading and decontamination room. An air sample indicates abnormally high concentrations of air-borne activity within the container.
4. The outside of a cargo container is surveyed for penetrating radiation. A source greater than that permissible is determined to be within the container.
5. Nondestructive assay indicates a concentration in a burial unit of fissile material above the acceptable level.
6. An accident occurs while handling the burial unit either at surface level within the alpha waste receiving building or at mine level and the accident results in a break in the burial unit seal.

7. The alpha cage, lowering a burial unit, breaks loose and (1) is stopped by the safety dogs; or (2) is not stopped by the safety dogs.
8. Fire occurs in the alpha wastes packaged in a burial unit while it is being inspected or transported to the alpha mine.
9. Fire breaks out in the alpha wastes stored in a burial room.
10. A tornado watch is received for the Repository vicinity.
11. A failure occurs in the alpha ventilation system.
12. Potentially explosive chemicals or oxidants are discovered in an alpha burial unit.
13. Stack monitors indicate that the levels of alpha release from the Repository are above normal.
14. The arrival of ATMX cars at the Repository exceeds its capacity over a short period of time.

In addition to the above, possible interactions between the alpha and high level mines must be examined to determine if hazardous situations could occur.

6.2.4 Safety Precautions (in the same sequence as Sect. 6.2.3)

1. Excessive free alpha contamination within the ATMX car would be an unlikely occurrence as the particulates must first escape from the sealed drums and then leak from the approved cargo container into the ATMX car. Decisions as to the disposition of the car will be made by the agencies concerned.
2. Possible release of radioactive material could result from dropping a cargo container in the container unloading and storage area of the alpha waste receiving building. Since this area does not have the confinement features of the remainder of the facility in which alpha waste will be handled, procedural safeguards will be relied upon to minimize the spread of any radioactive material that maybe released from a ruptured cargo container. These procedures will include sealing the cargo container inside a plastic tent. Immediate procedures would be followed by a careful assessment of the situation and appropriate remedial measures would be undertaken.

3. The presence of air-borne activity within the cargo container has been anticipated in the design of the facility. Doors and air locks will be provided to prevent the spread of particulates through the facility or to the environment after the contaminated cargo container is opened. Ventilation flows will be from areas of low contamination potential to areas of successively higher contamination potential. Operating personnel will be outfitted with equipment to prevent the inhalation or ingestion of alpha particulates during decontamination of the container and its contents.
4. If an above-limits source of penetrating radiation is detected, decisions as to the disposition of the cargo container will be made by the agencies concerned. The method or manner of disposal will be largely governed by the strength of the source.
5. Decisions as to the disposition of waste burial units containing fissile material will be made by the agencies concerned.
6. The handling of the burial units both at the surface and in the mine will be performed by trained operators under controlled conditions. Furthermore, the burial units must meet the packaging criteria specified in Section 3.2, which require resistance to a fall during handling. These combine to minimize the probability of a release of radioactivity from the burial units. In the event of a leak, however, there will be no release to the environment since the handling is all performed within confined areas, and only local decontamination within the confined areas will be required.
7. The cable supporting the alpha cage will be inspected and replaced periodically in accordance with mining regulations. Safety dogs will be installed on the alpha cage as an additional safety precaution.
 - a. If the rope breaks and the cage is stopped by the safety dogs, any alpha particulates escaping from the burial unit will be confined to the cage, since

the cage is sealed. The cage can then be removed from the shaft for decontamination. Thus, the shaft should not become contaminated.

- b. If the cage is not stopped by the safety dogs, the decision as to the extent of shaft cleanup subsequently required will be made by operating personnel. The shaft, head frame and hoist house are confined areas and thus radioactivity will not be released to the environment. These areas will be amenable to decontamination.
8. The fire protection system, which will include heat actuated detectors to activate the sprinkler system, will be designed for this contingency. Contamination released to the ventilation system by the fire will be removed by the filters. Hand extinguishers will also be available for use on small fires.
9. Heat sensitive detectors in the alpha mine ventilation system will be installed to warn of fires in the alpha burial areas. Administrative procedures will be set up for locating and extinguishing any such fires.
10. Adequate space will be provided in the alpha waste receiving building airlock (Design category I) for the two 8-ft by 8-ft by 20-ft containers from an ATMX rail car. Therefore, tornado-proof storage for the contents of the two cargo containers will be provided. The remainder of the alpha wastes being processed in the alpha facility will be protected because the confined areas are designed for tornadoes.
11. See Sect. 6.4, Alpha Facility Ventilation and Confinement System.
12. Alpha wastes containing potentially explosive chemicals, pyrophoric chemicals, oxidants (other than air), and sealed inner containers filled with gas under pressure will not be accepted at the Repository (see Sect. 3.2.2, Alpha Waste Packaging Criteria). A container will be repackaged before burial or returned to the shipper if it is found to contain these materials.

13. If the monitors on either of the alpha facility stacks indicate higher than normal releases of alpha activity, the following procedures will be implemented:
 - a. An immediate check will be made to determine if the emergency procedures should be implemented (see Sect. 13.3.3, Emergency Procedures).
 - b. The source of the abnormal release will be determined.
 - c. The source of a possible breakdown in the confinement system, such as filter failure will be investigated.
 - d. Appropriate corrective actions will be determined by management.
14. Decisions as to the storage of ATMX cars awaiting processing at the Repository will be made by the agencies concerned.

6.2.5 Maintenance Principles

The maintenance program for the alpha receiving, handling, and burial system will be considered in two aspects:

1. Preventive Maintenance (PM) - PM will be based on: (1) the scheduling of equipment inspection, cleaning, and lubrication; (2) a written report of deficiencies in the equipment; (3) the repair and reinspection of these deficiencies; and, (4) the subsequent recording of the repairs into permanent equipment history records. Preventive maintenance inspection procedures will normally be limited to inspecting, adjusting, tightening, cleaning, lubricating, and the routine replacement of parts. Vendor data and operating manuals will provide the basis for establishing this program.
2. Repair - Repair will be considered as that part of the program beyond the scope of preventive maintenance. PM will be a function of the Repository while repair may or may not be a function depending on the complexity of the required repair, the capabilities of Repository maintenance personnel, and the availability of equipment needed to effect the repair.

6.3 Alpha Facility Ventilation and Confinement System (Reference Fig. 6.4 and 6.5)

6.3.1 Functions and Design Requirements

Functions. - The alpha facility ventilation and confinement system will provide all rooms and spaces with a proper working environment for personnel and equipment, and effectively confine any airborne contamination within the facility.

Basic Criteria and Design Requirements (see Sect. 3 for Basic Criteria)

Concept-Related Design Requirements. - Specific design requirements for the system include:

1. All confinement structures will be designed to prevent dispersal of radioactivity to the environment. All potentially contaminated structures will be maintained at a negative pressure relative to the atmosphere during normal and emergency operations.
2. Air flows within the facility will be from areas of least contamination potential to areas of increasing contamination potential.
3. The alpha facility will have a once-through ventilation system with no recirculation of central exhaust air.
4. Fresh makeup air to all confinement zones will be filtered. All exhaust air from potentially contaminated rooms will be filtered.
5. All confinement zone ventilation systems except the alpha hoist house will be backed-up by standby systems which will be activated automatically during emergencies such as a fan breakdown, filter failure, or power outage.
6. All confinement systems will be designed to maintain their integrity in the event of fire. Category I systems will be designed to maintain integrity in the event of fire, earthquake, and tornado.

Fig. 6.4. Alpha Waste Receiving Building Ventilation and Confinement System.

Fig. 6.5. Underground Ventilation Flow Diagram.

Applicable Documents. - The design of the ventilation and confinement system will conform to the applicable sections of the following documents:

1. ASHRAE Guide and Handbook of Fundamentals, latest edition.
2. ORNL-NSIC-65 Filter Handbook (design of HEPA filter installations).

6.3.2 Major System Components

Air Supply Systems

1. Alpha Waste Receiving Building Supply - Capacity: 7900 cfm of filtered* air.
2. Mine Air Supply - Capacity: 20,000 cfm of air to alpha mine via the supply air compartment of the alpha-M & M shaft.
3. Alpha Hoist House Supply - Capacity: 1000 cfm of filtered* air.

Air Exhaust Systems

1. Alpha Facilities Support Rooms - Capacity: 1350 cfm of filtered* exhaust.
2. Confinement Area Exhaust - Capacity: 6700 cfm of filtered** exhaust including a standby filter and fan plus a stack which will exhaust air approximately 87 ft above ground level.
3. Alpha Hoist House - Capacity: 1000 cfm of filtered** exhaust.
4. Alpha Mine Cleanup Area - A mobile filter-fan unit⁺ for exhausting approximately 15,000 cfm to alpha waste burial area.
5. Alpha Waste Burial Area - A mobile filter-fan unit⁺⁺ for exhausting 20,000 cfm to the upcast vent shaft and central filter station.

*Filters - 30% NBS, 90% NBS, HEPA.

**Filters - 30% NBS, 90% NBS, 2 - HEPA in series.

⁺Filters - 7% NBS, 30% NBS, 90% NBS.

⁺⁺Filters - 7% NBS, 30% NBS, 90% NBS, HEPA.

6. Upcast Vent Shaft and Central Filter Station (for ventilation air from both the alpha and high level mines) - Three filter-fan units^{**} connected in parallel. Two trains will handle a normal 60,000 cfm of air, and the third is standby unit. Air will be exhausted to stack (10 ft above ground level).

6.3.3 Confinement Control

1. Negative pressures will be maintained in potentially contaminated areas as indicated in Fig. 6.4.
2. All confinement structure connections and joints will be sealed where leakage could occur. Seal closures will be provided to isolate the alpha cage from the alpha shaft during normal loading and unloading operations.
3. Entries through confinement zones will be through air locks.
4. Duct backflow preventers will be installed to preclude the accidental flow of air from a confined to a nonconfined room or to the atmosphere.
5. A tornado damper will be installed between the central filter station and its stack.
6. The alpha mine cleanup and burial areas will be confined by temporary closures to direct the flow of ventilation air to the active working areas. Exhaust air will pass through a mobile filter-fan unit. Alpha cleanup or mining operations will always be carried out upstream of the burial operations.
7. Motorized control dampers and backflow preventers will automatically control confinement zone ventilation flows and negative pressures.

6.3.4 Primary Safety Considerations

1. The activity levels in all potentially contaminated exhaust systems must be minimized, monitored, and recorded.

^{**}Filters - 30% NBS, 90% NBS, 2 - HEPA in series.

2. Contamination from the system must be released in a manner that assures dilution of the radioactivity to concentrations at ground level below the allowable limits specified in Sect. 4.
3. Provisions must be made to prevent the spread of contamination within the system to prevent excessive exposure to personnel.
4. In the event of an accident, release of contamination from the facility must be held to less than the limits specified in the Safety Criteria (Sect. 5).
5. Provisions must be made to prevent the excessive release of contamination from the alpha wastes during long term storage in the alpha mine.
6. Provisions must be made to protect all filtering systems on potentially contaminated streams from failure due to shock, vibration, or fire. Standby filter-fan facilities must be provided in case of power outage, fan breakdown, or filter failure.
7. Provisions must be made for detecting and extinguishing fires in alpha wastes stored in the alpha burial rooms.
8. Provisions must be made for the protection of personnel working in the Alpha Facility during emergencies.

6.3.5 Safety Precautions (in the same sequence as Sect. 6.3.4)

1. Activity released by the Alpha Facility will be reduced to the lowest practical value by:
 - a. Containment of alpha activity in sealed containers or burial units during all handling operations.
 - b. High efficiency filtration of all potentially contaminated exhaust streams before release to the stacks.
2. The radioactivity released from the Alpha Facility stack will be monitored and recorded continuously and will conform to the limits specified in Sect. 3.4., Radiological Safety Criteria. Adequate dilution of the activity from the stacks will be assured. The average annual concentration at the Repository

site boundary is estimated to be about 8.6×10^{-6} Ci/m³ per Ci/sec average release rate at the stack (see Sect. 1.2).

3. Contamination confinement within the system will be provided as follows:
 - a. Air flows will be from areas of least contamination potential to areas of increasing contamination-potential.
 - b. Duct backflow preventers will preclude the accidental backflow in the ducts to lower contamination potential areas.
 - c. Areas where the cargo containers are opened, such as the unloading and decontamination rooms, will have the highest negative pressure (-0.60 in. H₂O) to insure that air leakage will be into the rooms.
 - d. In the alpha mine, cleanup and mining operations will always be conducted upstream of the burial operations. A minimum air velocity of 30 fpm will be maintained in the alpha mine working area tunnels and room.
4. Accidental release of contamination in the alpha facility will be contained by the confinement structures and the high efficiency filters. In the event of power failure, ventilation exhaust fans serving all confinement zones will automatically be switched to standby power systems. Supply fans will not operate. In the event of excessive discharge of contaminated air from a stack, the ventilation exhaust fans to that stack will be shutdown.
5. Backfilling of the alpha wastes in the burial rooms with crushed salt and providing room closures will prevent the escape of excessive amounts of contamination during long-term storage. Filtration of the ventilation air will reduce the concentration of contaminants before discharge to the environment.
6. Exhaust filtering systems will be designed for protection against reasonable vibration and shock loads. A sensitive fire detection and sprinkler system will be installed to prevent the spread of fires to the filtration systems.

7. Sensitive detectors in the alpha mine ventilation system will be installed to warn of fires in the alpha burial areas. Administrative procedures will be set up for locating and extinguishing possible alpha mine fires.
8. Personnel protection equipment such as face masks, protective clothing, and special equipment to insure clean breathing air will be provided for emergencies.

6.3.6 Maintenance Principles

Maintenance procedures and schedules will be set up and maintained for periodic lubrication, checking belt tension, and for checking for signs of equipment wear and damage. All filter banks will have differential pressure gages connected to the upstream and downstream side. Filters will be changed when the differential pressures rise to greater than acceptable levels. HEPA filters will be tested in place. Dampers will be provided to isolate contaminated filters from the operating system, so that they may be replaced. Potentially contaminated filters will be sealed in plastic bags, placed in drums, and buried in the mine.

7. HIGH-LEVEL FACILITY

The High-Level Facility will provide the structures and equipment necessary to receive and handle cans of high-level waste shipped to the Repository in shielded shipping casks. The cans will be cooled within the casks, unloaded individually in hot cell facilities, lowered to mine level through the high-level shaft, and then transported and buried in the salt bed using a shielded transporter. The components of the High-Level Facility will include the high-level waste receiving building, the adjoining hoist house, and the exhaust fan-filter house at surface level. Below surface level, the facility will include the high-level shaft, the mine-level receiving station, and the high-level mine with its complement of equipment to develop mine space, and transport and bury the high-level waste cans. The process waste system used to concentrate, solidify, and package any radioactive liquid waste originating at the Repository will also be located within the High-Level Facility.

The buildings and components of the High-Level Facility are described in Sect. 7.1. Three major systems in the High-Level Facility are described in detail with particular attention given to safety considerations. These systems include the High-Level Receiving, Handling, and Burial System (Sect. 7.2), the High-Level Facility Ventilation and Confinement System (Sect. 7.3), and the Process Waste System (Sect. 7.4).

7.1 High-Level Facility Components

7.1.1 High-Level Waste Receiving Building (Figs. 7.1 and 7.2)

Only the minimum facilities necessary to handle clean, undamaged high-level cans will be provided as a part of the initial construction of the high-level waste receiving building. The building includes provisions for the addition of future facilities that may become necessary. Building space will be provided for the future installation of equipment for the recanning of defective high-level waste cans in a shielded recan cell. In addition, space will be provided for an additional cask cooling station to handle the increased high-level waste can rates expected in future years.

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Fig. 7.1. High-Level Waste Receiving Building - Plan.

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Fig. 7.2. High-Level Waste Receiving Building - Elevation.

Facility Description. — The basic architectural design guidelines will be the same as those used for the alpha waste receiving building described in Sect. 6.1. Differences between the handling of high-level waste cans and alpha waste burial units are due primarily to the presence of penetrating radiation in the high-level wastes; thus, all handling operations must be conducted remotely behind massive shielding. In addition, the waste cans themselves represent significant heat sources.

The high-level waste receiving building will receive shipping casks on rail cars which will pass through the rail car airlock into the cask unloading area. The cask unloading area will be a confined high bay crane runway for above-grade handling of the shipping casks. A 100-ton capacity bridge crane with a 15-ton auxiliary hook will be provided for cask handling.

After unloading, the cask interiors will be sampled for contamination and then cooled and/or decontaminated as required. The cooling and, if necessary, decontamination of the cans within the cask will be performed at the cask cooling station. Floor space will be provided for future installation of a second cask cooling station. A biparting hatch leading to a below-grade transfer gallery will be provided in the floor of the cask unloading area. The hatch will be motorized and will travel on rails embedded in the floor slab. The overhead crane will be used to move the cask through the cask unloading area and lower it into the transfer gallery. The transfer gallery extends under the shielded transfer cell where cans of high-level waste will be unloaded from the cask. In the transfer gallery, the cask will be placed on the motor-driven hydraulic lift table, and the cask access plug bolts will be removed. The cask will then be moved to a position beneath the transfer cell port and elevated to form a seal against the underside of the cell. With the aid of the 15-ton in-cell crane, the transfer cell port cover and the cask lid will be removed, and the shipping cask basket, containing the high-level cans, will be lifted for observation of the cans.

Individual cans will be transferred from the basket to the high-level cage using the 4-ton crane in the transfer cell. The cage transfer car, which positions the cage at this point, will be moved out over the shaft and the cage containing the high-level waste can will be lowered down through the cage transfer car to the mine-level receiving station.

An operating gallery will be provided adjacent to the transfer cell. This room will be the primary observation and control point for operations within the transfer cell. Two viewing windows and two pairs of manipulator sleeves will be provided in the transfer cell shielding wall.

A support facilities area, which will be provided adjacent to the cask unloading area and the operating gallery, will include a counting room, personnel check station, change room, chemistry laboratory, shift foreman's office, and a maintenance and storage room. Access from this area to the confined portion of the building will be through air locks.

In the basement, adjacent to the transfer gallery, space will be provided for the mechanical equipment room, waste concentration room, decontamination equipment room, and waste casting room. Equipment access to the mechanical equipment room will be provided through an exterior hatch adjacent to the change room. A second hatch in the first floor maintenance and storage room will provide equipment access to the waste casting room.

The hoist house and exhaust fan-filter house will be in separate structures adjacent to the high-level waste receiving building.

Confinement Zones. - The entire operating portion of the facility will be a confinement zone. Included are:

1. Cask unloading area
2. Transfer gallery
3. Transfer cell
4. Recan gallery (structure only provided with initial construction)

5. Recan cell (structure only provided with initial construction)
6. Operating gallery
7. Sheave house
8. Hoist cable enclosure
9. Hoist house
10. Exhaust fan-filter house
11. Mechanical equipment room
12. Waste casting room
13. Decontamination equipment room
14. Waste concentration room

Confinement will be provided by the following means:

1. Selection of construction materials for minimum air leakage.
2. Provision for sealing all structural connections and joints where leakage could occur.
3. Use of air locks and gasket-sealed doors.
4. Automatic control of the ventilation system.

Confinement areas will, in all cases, be separated from the environment and nonconfinement areas by an air lock. An interlock will be provided to prevent both doors of the rail car air lock being opened at the same time.

Applicable Codes and Documents

General Design Standards

1. General Design Criteria - AEC Manual Appendix 6301
2. Uniform Building Code, International Conference of Building Officials
3. American Standard Building Code, Requirements for Minimum Design Loads in Buildings and Other Structures, ANSI A-58.1

Seismic Design

1. Uniform Building Code
2. Nuclear Reactors and Earthquakes, TID 7024

Wind Design

1. Wind Forces on Structures, ASCE Paper No. 3269
2. Tornado Considerations for Nuclear Power Plant Structures,
P. L. Doan, Nuclear Safety, July-August, 1970
3. Uniform Building Code

Reinforced Concrete

1. Building Code Requirements for Reinforced Concrete,
American Concrete Institute

Structural Steel

1. Specification for the Design, Fabrication, and Erection
of Structural Steel for Buildings, American Institute of
Steel Construction
2. Code for Welding in Building Construction, American Welding
Society (AWS)

Open Web Joists

1. The Steel Joist Institute Standard Specification for Open-
Web Steel Joist Construction

Concrete Block Construction

1. Uniform Building Code
2. Crack Control in Concrete Masonry Unit Construction -
Publication 1198, National Academy of Science - National
Research Council
3. American Standard Building Code Requirements for Masonry,
National Bureau of Standards.

Design Classification. - All structures, systems, and equipment within the Repository will be classified by the category groupings as described in Sect. 3.5.1. This classification is applied to identify plant features for purposes of public safety and operational reliability during postulated accident conditions. Categories for structures in the High-Level Facility are given in Table 7.1.

Table 7.1. High-Level Waste Facility Design Categories

Structure	Design Categories
a. Cask unloading area	II
b. Transfer cell	I
c. Recan cell	I
d. Sheave house	II
e. Transfer gallery and recan gallery	I
f. Mechanical equipment room	I
g. Decontamination, waste concentration, and waste casting rooms	I
h. Operating gallery	I
i. Support facilities area	III
j. Rail car air lock	II
k. Rail car holding area	II
l. Hoist house	II
m. Exhaust fan-filter house	I
n. Hoist cable enclosure	II

7.1.2 High-Level Shaft (Figs. 7.2 and 7.3)

The single purpose of the high-level shaft will be to provide access for transporting the waste cans from the high-level waste receiving building to the high-level mine. The top of the shaft will form an integral part of the high-level waste receiving building. At mine level, the shaft will terminate in a shielded receiving station from which the cans will be transferred into a shielded transporter for conveyance to the burial rooms. The loading and unloading of the waste cans into and from the specially-constructed cage used in the high-level shaft will be by remote control, since the cans require shielding at all times.

The high-level shaft head frame, an integral part of the high-level waste receiving building, will be designed to provide radioactive confinement and biological shielding. The shaft will be concrete-lined to provide both durability and readily decontaminable surface. Twin hoisting cables will be utilized to support the cage to ensure that the load will not be dropped in the event of a cable break.

Shaft. - The high-level shaft will be a 4-ft-ID concrete-lined shaft with a built-in concrete and steel guide.

High-Level Hoist. - The high-level hoist will have a speed of 500 fpm and a rope pull of 10,000 lb. Two independently-operated disc brakes will be installed which will activate automatically upon power failure, overspeed or overtravel. In addition, an independent emergency brake will be installed.

Mine Shaft Cage. - The high-level shaft cage will be of a special design to suit the specific requirement for handling different diameter high-level waste cans. The cage will have a circular cross section with a flat bottom and an outside diameter of 36 in. High tensile steel will be used throughout. The cage will have no doors, since loading and unloading of the waste cans will be performed from the top.

Provisions will be made for easily removable liners inside the cage to accommodate waste cans of varying sizes. The purpose of the liners will be to hold the waste cans firmly in position while the cage is being lowered.

Fig. 7.3. Mine-Level Receiving Station.

No provision will be made for safety wedges on the cage since the dual cable installation will provide a higher level of safety than if a single cable with safety wedges were provided. A comprehensive program for cable inspection and maintenance must be conducted throughout the operation of the facility.

The cross head will be of the self-compensating type to maintain equal rope tension; it will be attached to the cage by swivel joints. These joints will allow the cage to be moved sideways for loading and unloading without kinking the hoisting cables. The crosshead will be attached to the hoisting ropes by two closed, swaged, drop-forged steel sockets which will allow additional freedom of sidewise movement of the cage. The guide assembly on the cage will consist of spring-loaded guide wheels, which can be replaced remotely within the transfer cell.

7.1.3 High-Level Mine (Fig. 7.4)

Mine Development. - The plan developed for the high-level mine provides for the burial of the high-level waste cans in accordance with projected rates of shipment to the Repository through the year 2000. Heating effects have been taken into account in the design of the mine shafts and main entries. These effects and an attempt to minimize the amount of initial development led to the mining development sequence shown in Fig. 7.4.

Mine Design

1. Ventilation. Project criteria require that all work by personnel must be accomplished in a fresh ventilating air stream, and that any air having passed a potentially contaminated area must be exhausted through a separate system, isolated from any further contact with personnel. The system utilizes the mine-level entries (corridors) as supply air conduits and exhausts air to the upcast ventilation shaft through mined tunnels located 20 to 40 ft above the roof level of the main mine entries. Bored 30-in.-diam holes will connect the main mine entries to the exhaust air tunnels. This system has the following advantages:

Fig. 7.4. Mine Development Plan.

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- a. It effectively precludes the possibility of potentially contaminated exhaust air mixing with the fresh air of the mine.
- b. It allows the use of a single entry system at mine level, reducing the amount of salt mined.
- c. It is the least costly to construct and maintain.

Upon completion of the development mining steps, an air exhaust connection will be bored through the panel entry room to the overhead exhaust tunnel at the junction with the first operating waste burial room; the system will then be ready for operation.

2. Mine Opening Stability. A vital factor governing mine opening stability is the opening size. The master plan for the high-level mine will be based on driving openings with cross-sections as small as possible, consistent with clearance requirements for the mining methods, mining equipment and efficient space utilization. Therefore, widths of new openings for the mine will not exceed 34 ft. Based upon past history, good mining practice and accepted rock mechanics design, this will ensure the required stability of the openings. Additional considerations concerning opening stability are:
 - a. Continuous mining machines will be employed for driving all entries, thus eliminating any requirement for the use of any explosives in the high-level mine. This will eliminate the shattering effect induced by the explosive shock and the attendant weakening of walls and ceilings.
 - b. Cross sections of all openings will be rectangular. Although the most stable section would be circular, clearance requirements for other equipment, particularly the high-level waste transporter, make the rectangular configuration mandatory.

- c. Roof height will be as required for passage of equipment (approximately 16 ft for vertical burial concept).
 - d. Widths of supporting pillars will be no less than the adjoining opening widths.
 - e. Pillar height-to-width ratio will not exceed 1.
3. Heating Effects. Thermal emissions from the high-level waste will heat the surrounding salt and adjacent formations. This affects the design of the mine shafts and main entries. Differential expansion of strata should accompany movement of a thermal front through the formations. This could include such adverse effects on the shafts as wall cracks and misalignments. The most practical preventive measure involves placing the heat sources as far as possible from the shaft locations. Thus, as shown on Fig. 7.4, the sequence of high-level can storage operations will begin on one property boundary line in a panel with an access entry near the high-level shaft, work generally away from the shaft locations, and finally return to the shaft pillar areas during the final phase of mine burial operations. This sequence was developed to minimize the amount of initial development required, as well as to keep burial operations away from the shaft area until the final phase of mine utilization.

Calculations, based on test results, indicate that a thermal barrier will be necessary between the storage area and the main access entry. This barrier will be approximately 100 ft of solid salt and will suppress the heat buildup to acceptable levels in the main entry. An additional feature of the development sequence is that burial is not required on both sides of any portion of the main entry until that portion of the main entry is no longer required for operation.

A 20-ft barrier pillar between storage panels was chosen as a good compromise between heating effects and space utilization. This should result in a warm but not an excessively hot condition in the last 80 ft of a room approaching a previously-used adjacent storage area. The ventilation system is designed to limit the air temperature in such rooms to reasonable comfort levels.

Receiving Station (Fig. 7.3). - The mine-level receiving station will be the lower terminus of the high-level mine shaft. It will provide a shielded enclosure for transfer of the high-level waste cans from the mine shaft cage into the transporter. The receiving station will include a viewing gallery and a machinery room. The station will be constructed of concrete and steel of thicknesses commensurate with shielding and structural requirements.

1. Station Transfer Car. A transfer car will be provided in the mine-level receiving station to shift the cage from a position beneath the shaft to a position below the transporter. This remotely-controlled transfer car will be actuated by a double-roller chain drive that will be powered by a drive motor located in the machinery room. The transfer car will be supported on rails set at an angle to allow the shaft hoist cables to become slack during the transfer operation.
2. Port Door. A hydraulically-operated, remotely-actuated shielding door will be provided in the receiving station at the transporter loading point. The port door will provide gamma attenuation equivalent to 6 ft of ordinary concrete.
3. Shielding Window. A shielding window will be provided in the viewing gallery to permit visual verification of the connection of the transporter connector to the high-level waste can. The window will provide gamma shielding equivalent to 6 ft of ordinary concrete.

4. Manipulators. A single-purpose manipulator will be provided to inhibit any tendency of the transporter connector to swing and to provide assistance in making the connection to the waste can, if required. The manipulator will be sectionalized for ease of installation and removal.

Mining Equipment. — The complement of mining equipment required for the initial development of the high-level mine and for the initial period of operation has been described in Sect. 6.1.6. The initial development of the alpha and high-level mines will be performed as one integrated operation, and many items of equipment will be used in both the alpha and high-level mines.

Can Transport and Burial Equipment. — The existing Project Salt Vault (PSV) transporter, with necessary modifications, will be utilized for initial burial operations. After this initial period, new transporters designed for this specific application will be utilized.

The transporter will receive the high-level waste can at the high-level mine receiving station. After departing from the receiving station with a waste can, the transporter will charge the salt hopper at a loading point in the exit portion of the station loop. The charging apparatus will consist of a small storage pocket below mine floor level (filled periodically by a shuttle car), a bucket elevator, and a pouring chute. The transporter will then proceed to deposit the waste can in a previously prepared burial hole and backfill the hole to floor level with salt from its hopper.

7.2 High-Level Receiving, Handling, and Burial System (Fig. 7.5)

7.2.1 Functions and Design Requirements

Functions. — The functions of the high-level receiving, handling, and burial system will be:

1. Receive high-level waste cans contained in shielded shipping casks on railroad cars

Fig. 7.5. High-Level Receiving, Handling, and Burial System.

2. Monitor the surface of the cask for transferable contamination and the interior of the cask for airborne radioactivity.
3. Cool the high-level waste cans to a temperature compatible with the handling equipment encountered in subsequent operations and decontaminate waste cans as required.
4. Remove the waste cans from the shipping casks, inspect the cans, and lower the cans to the receiving station at mine level.
5. Transport the waste cans from the mine-level receiving station to burial locations in the mine, place the cans in burial holes in the floor of the mine, and backfill the holes with crushed salt.

Basic Criteria (See Sect. 3.)

Applicable Documents

1. Atomic Energy Commission General Design Criteria, Appendix 6301, and appropriate codes and standards referenced therein.
2. AEC Manual Chapter 0550, Operation Safety Standards.

7.2.2 Physical Description

Summary Description. -- The High-Level Facility will include a waste receiving building for receiving shipping casks containing high-level waste cans. This building will provide an enclosed area serviced by a 100-ton capacity overhead bridge crane. The crane will remove the cask from a railroad car, rotate it to the vertical position, and place it on the cask cooling station. The cask atmosphere will be sampled and the high-level waste cans in the cask will then be cooled by moist steam to a temperature compatible with the subsequent handling equipment. The building will provide the handling equipment and shielded enclosures to remove the cask lid and transfer the waste cans from the cask to the mine shaft cage, remotely.

The facility will include a mine shaft, cage, and hoisting equipment to transfer the waste cans from the surface to a shielded receiving station at mine level. The shielded receiving station will be equipped with the machinery and devices necessary to transfer the cans from the mine shaft cage to a position beneath the transporter. All operations will be remotely controlled and monitored.

The existing diesel-powered PSV transporter will be modified to permit its use during the early years of Repository operation. The modifications will include increasing the length of the cask cavity and the addition of shielding, a blower and filter, a diesel exhaust scrubber, and a salt hopper. The transporter will connect to the can in the mine shaft cage, raise the can into the transporter shield, carry the can to a burial hole, lower the can into the hole, and backfill the hole with crushed salt. The operations will be remotely controlled and monitored where required.

Major System Components

1. Cask Unloading Area. Shipping casks on rail cars will be brought into the cask unloading area in the high-level waste receiving building. Casks will be transferred, using the 100-ton capacity bridge crane, to the cask cooling station. Cask sampling, cooling and decontamination (if required) will be performed at the cask cooling station. The crane will then transfer the cask to the below-grade transfer gallery where it will be positioned under and sealed to the shielded transfer cell.
2. Transfer Cell. A remote 15-ton hoist in the cask transfer cell will remove the cask lid and a remote 4-ton crane will transfer the cans from the cask to the high-level mine shaft cage.
3. High-Level Mine Shaft and Cage. The high-level mine shaft cage will be used to lower the high-level waste cans down the mine shaft to the mine-level receiving station.

4. Mine-Level Receiving Station. At the mine-level receiving station the waste can will be moved remotely from the mine shaft cage to the mine transporter. The receiving station will be a shielded enclosure equipped with manipulators and a viewing window.
5. PSV Transporter. A diesel-powered transporter developed during Project Salt Vault will be used initially for transporting the high-level waste cans from the mine level receiving station to the burial rooms.
6. High-Level Mine. Burial of the high-level waste cans will be accomplished in a previously prepared burial hole followed by backfilling the hole to floor level with crushed salt. The top of the can will be approximately 8 ft below the floor of the mine and at least 4 ft from the walls of the burial room. After a burial room is filled with waste cans, it will be filled with crushed salt and the entry closed. Heat released from the buried wastes will increase the normal flow properties of the salt which will eventually seal the mined openings and consolidate the crushed salt used to backfill the rooms.

7.2.3 Primary Safety Considerations

Safety considerations in this section will be limited to the high-level receiving, handling and burial system. Specifically, the operations considered will be those whose failure might expose operating personnel to unacceptable radiation levels, affect the public or environment, or require the temporary cessation of Repository operations.

Many hazards associated with high-level receiving, handling and burial relate directly to the failure of a piece of equipment to function properly. Others may be due to the failure of administrative procedures, the failure of the waste containers, or acts of nature. Any of the failures outlined below would result in the temporary cessation of Repository operations for the period of time required to make the necessary repairs or corrections.

1. A rail car hits and jams an air lock door.
2. The 100-ton overhead crane fails to operate.
3. The crane drops a cask due to a failure of the crane or in the rigging between the crane hook and the cask.
4. The cask cooling piping or hoses break or leak at the cask cooling station.
5. The lift table in the cask transfer gallery fails to operate.
6. The 15-ton transfer cell hoist fails to operate properly.
7. The 4-ton transfer cell hoist, trolley, or bridge becomes inoperative when transferring a high-level waste can from the shipping cask basket to the mine shaft cage.
8. The cask lid storage rack traversing drive malfunctions during the withdrawal cycle after the rack has accepted the port cover and cask lid.
9. The actuating mechanism for the surface-level cage transfer car fails with the cage transfer car midway between the shaft access port and a position over the mine shaft.
10. A mine shaft cage hoisting cable or cable connection breaks.
11. The actuating mechanism for the mine-level station transfer car malfunctions.
12. The transporter hoist used to lift a waste can into the transporter fails.
13. The transporter hoist fails with the transporter positioned over a burial hole and with a waste can partly lowered out of the transporter.
14. The positioning mechanism for the salt chute on the transporter fails to operate, or the salt discharge valve fails to open after a waste can has been lowered into a burial hole and the connector released.
15. The rail car or the interior or the exterior of the high-level waste cask is found to be grossly contaminated.
16. Activity is released from the cask to the cask cooling system.
17. Activity is released from the waste cans during handling due to ruptured or contaminated cans.

18. Delay in the transit of a waste can from the cask to final burial occurs which might result in excessive can temperatures due to the internal heat generation.
19. The high-level-facility ventilation and confinement system fails.
20. Abnormal release of activity from the stacks is indicated by the stack monitors.
21. A tornado watch is indicated for the vicinity of the Federal Repository.
22. Hydrogen from radiolysis and corrosion accumulates in the sealed burial rooms such that its concentration in air is above the lower explosive limits.
23. The release of very small quantities of radioactive gases such as ^3H , ^{85}Kr , ^{222}Rn , and ^{220}Rn into the high-level mine exhaust system is detected. (See Sect. 11.2.1.)

7.2.4 Safety Precautions (in the same sequences as Sect. 7.2.3)

1. Guard rails will be provided to limit derailment; rail stops will be installed to insure that the car will not hit a closed door; and a slow speed car puller will be used for car movement.
2. A rigorous program of crane inspection, maintenance, and testing will be initiated to insure availability of the crane during normal working periods.
3. The program mentioned in (2) above will be followed for all of the rigging used for cask handling. Connections to the neutron shield and to the cask interior will be sufficiently recessed to preclude damage. The cask must meet DOT requirements to insure that the integrity of the neutron shield and the cask lid will not be breached under any credible drop. The operating procedures will explicitly limit the cask lift height to that which is absolutely necessary for clearance.
4. All lines and hoses will be inspected and tested at periodic intervals. Personnel access to the cask unloading area will be limited during cooling or decontamination operations. Line shut-off controls will be provided at a remote or protected location.

5. A preventive maintenance program will be enforced and suspect components will be replaced.
6. All transfer cell equipment will be designed for the load, temperature, and radiation levels anticipated within the cell, and extensive testing will be performed to assure a high degree of failure-free operation and long operating life.

Assuming, as the worst case, that the residual activity within the cell will be sufficient to prevent personnel entry into the cell and that the 15-ton transfer cell hoist will be:

- a. Unable to remove the cask lid.

In this case the hatch cover in the top of the cell will be removed and the hoist moved from the bridge into the area above the cell to permit repair or replacement of the hoist. Temporary hoisting equipment and a protective enclosure above the cell will be required for use in performing these operations.

- b. Unable to lift the cask lid high enough to provide clearance for the storage rack and the hoist unable to respond to normal "lowering" control.

For this case, a bypass circuit will be provided to bleed the hydraulic fluid from under the pressurized side of the crane hoist piston to allow the cask lid to descend at a controlled rate of speed. The procedure outlined in (a) will then be followed.

- c. Operable but the hoist bridge drive will not respond.

For this case, the bridge will be designed to be "free-wheeling" and capable of being coupled to, and moved by, the transfer cell crane bridge. Thus the shipping cask basket will be emptied, the cask lid and port cover replaced, and the hoist bridge drive unit removed as outlined in (a) above.

7. Safety features to be incorporated in the design of the 4-ton transfer cell crane will include:

- a. Hoists. The trolley will support two hoists. Each hoist will carry enough cable and have sufficient drum storage capacity to complete the unloading of a cask should the other hoist fail.
 - b. Trolley. Two drive mechanisms will be provided, each of which will be capable of traversing the trolley independently of the other.
 - c. Bridge. The bridge will be designed to be "free-wheeling" and capable of being coupled to, and moved by, the transfer cell hoist bridge.
 - d. General. After transferring the high-level waste cans to the mine shaft cage, the crane trolley and hoists and the bridge drive mechanism may be removed from the cell as described in (6) above.
8. Two drive mechanisms will be provided for the cask lid storage rack. Each will be capable of traversing the rack and will be located so as to be accessible for repair by the manipulators.
 9. The hydraulic pump reservoir and control valves for the cage transfer car will be located in the operating gallery. If a faulty component cannot be repaired or replaced immediately, the piping leading to the side of the piston holding the mechanism in an extended position will be opened to allow the weight of the waste can to position the car over the shaft.
 10. The cage will be suspended from two hoisting cables to ensure that the load will not be dropped in the event a support cable or its attachment breaks. Each cable will be capable of supporting the loaded cage with a minimum safety factor of 6.0.
 11. The mine-level station transfer car will be positioned by two roller chains. Each chain will be capable of positioning the car. Roller guides will prevent car derailment if one chain fails. To facilitate servicing the drive machinery, the chain drive machinery will be located in a room shielded from the cage transfer car.

12. The transporter hoist will be mounted outside the shielding on the transporter. When the transporter is in position to receive a waste can, the transporter shield will be lowered into a recess to complete the shielding configuration. This will permit personnel access to repair the hoist, even though the lower transporter shield door and the receiving station port door are open.
13. Two alternatives are presented for this failure mode. Both these and other alternatives will be studied during detail design, and the most acceptable method will be employed.
 - a. As part of the permanent installation, a remotely-controlled guillotine could be provided to cut the hoist cable where it enters the transporter shield. The hole could then be backfilled.
 - b. Because the hoist will be hydraulically operated, separate remotely-controlled circuitry could be provided to dump the hydraulic fluid, allowing the hoist to "free-wheel" and lower the waste can to the bottom of the burial hole. The hole could then be backfilled and the cable cut.

In both of these approaches the connector would be considered to be expendable.
14. In analyzing this failure mode it has been assumed that if the connector were relowered it would not reconnect to the waste can; therefore, the can could not be drawn back into the transporter. Precautionary measures for dealing with this hazard involve both design and operating procedure. Possible design approaches include a vibrator on the salt chute, a screw conveyor and other feed devices.
15. The rail car unloading area is located in a confined building which will prevent the release of contamination from this area to the environment. In addition, the car and cask will be surveyed and the air in the cask will be sampled before the cask is cooled or opened. If necessary, the cask will be decontaminated prior to removal of its cover.

16. The condensed steam from the cask cooling system will be monitored and if it is found to be contaminated, it will be diverted to the process waste system. Decontamination facilities for the cask cooling system will also be available.
17. Two lines of containment for the high-level wastes will be maintained at all times. The waste can will be the first line of containment. However, if the can should fail, containment will still be assured by the confinement of the high-level facility (see Sect. 7.3.4, High-Level Facility Ventilation and Confinement System).
18. Double containment will prevent the escape of contamination from the can to the environment. The transfer equipment will be designed so that heat removal by natural convection and/or radiation will maintain the can temperatures below the maximum permissible limits.
19. See Sect. 7.3, High-Level Facility Ventilation and Confinement System.
20. If the monitors on either the high-level facility exhaust stack or the central filter station stack indicate higher-than-normal releases of activity, an emergency procedure will be implemented to determine the following:
 - a. An immediate check to determine if the emergency procedure should be implemented (see Sect. 13.3.3, Emergency Procedures).
 - b. The source of the abnormal release.
 - c. The source of a possible breakdown in the confinement system such as filter failure.
 - d. Appropriate corrective actions to be determined by management.
21. All structures in which the high-level waste cans will be handled external to the shipping cask are classified as Design Category I and designed for tornado resistance.
22. Provisions will be made to prevent possible hydrogen-oxygen explosions in the sealed burial rooms. They may include one or more of the following procedures:

- a. Incipient ventilation of the sealed burial rooms to remove accumulated hydrogen.
 - b. Blanketing the rooms with an inert gas, such as nitrogen, prior to sealing. This would remove the oxygen from the rooms prior to closure.
 - c. Installation of catalysts to effect recombination of the hydrogen generated by the stored wastes and waste cans.
 - d. Installation of a chemical such as lime near the waste cans to react with the moisture and thus prevent corrosion of the waste cans.
23. The concentrations of radioactive gases in the high-level mine exhaust system will be maintained below the maximum permissible limits by maintaining an adequate volume of ventilation air in the High-Level Facility. (See Sect. 10.)

7.2.5 Maintenance Principles

The maintenance program for the high-level receiving, handling, and burial system will involve two aspects:

Preventive Maintenance (PM). — PM will include (1) the scheduling of equipment inspection, cleaning, and lubrication, (2) written reports of deficiencies in the equipment, (3) the repair and reinspection of these deficiencies, and (4) the subsequent recording of the repairs into permanent equipment history records. Preventive maintenance inspection procedures will normally be limited to inspecting, adjusting, tightening, cleaning, lubricating, and routine replacement of parts. Vendor data and operating manuals will provide the basis for establishing the program.

Repair. — Repair will be considered as that part of the program beyond the scope of preventive maintenance. PM will be a function of the Repository while repair may or may not be, depending on the complexity of the requirement for repair, the capabilities of Repository maintenance personnel, and the availability of equipment to effect the repair.

7.3 High-Level Facility Ventilation and Confinement System (Ref. - Fig. 7.6)

7.3.1 Functions and Design Requirements

Functions. - The high-level facility ventilation and confinement system will provide all rooms and spaces within the facility with a proper working environment for personnel and equipment, and effectively confine airborne contamination within designated areas of the facility.

Criteria. - (See Sect. 3.)

Concept - Related Design Requirements. - Specific design requirements for the system include:

1. All confinement structures will be designed to prevent dispersal of radioactivity to the environment. All potentially contaminated structures will be maintained at a negative pressure relative to the atmosphere during normal and emergency operations.
2. Air flows within the facility will be from areas of least contamination potential to areas of increasing contamination potential.
3. Fresh makeup air to all confinement zones will be filtered. All exhaust air from potentially contaminated rooms will be filtered.
4. All exhaust-air handling equipment will include multiple-bank filtering sections. Each filter section will filter the ventilation air through 30% NBS and 90% NBS and HEPA filters in series. All ventilation exhaust air to the high-level exhaust stack will pass through the 30% and 90% NBS filters and two banks of HEPA filters in series.
5. All confinement zone ventilation systems except the high-level hoist house, will be backed up by standby systems during emergencies such as fan breakdown, filter failure, or power outage.
6. All confinement systems will be designed to maintain their integrity in the event of fire. Category I systems will be designed to maintain their integrity in the event of fire, earthquake, and tornado.

Fig. 7.6. High-Level Facility Ventilation and Confinement System.

Applicable Documents. - The design of the ventilation and confinement system will conform to the applicable sections of the following documents:

1. ASHRAE Guide and Handbook of Fundamentals, latest edition
2. ORNL - NSIC - 65 Filter Handbook (Design of HEPA filter installations)

7.3.2 Major System Components

The following systems will provide for the distribution, control, filtering, and exhaust of ventilation air in confinement zones of the High-Level Facility:

Waste Receiving Building

1. High-Level Waste Receiving Building Supply System. A filter-air conditioner unit in the maintenance and storage room will supply approximately 10,000 cfm of conditioned ventilation air to the operating gallery and the cask unloading area.
2. Cask Unloading Area Recirculation System. A filter-air conditioner unit in the cask unloading area will combine approximately 1150 cfm from the operating gallery and 4850 cfm of recirculation air from the cask unloading area for a total discharge of 6000 cfm to the cask unloading area.
3. High-Level Cell Supply System. Dual filter-fan units in the fan-filter house (one operating and one on standby) will remove approximately 2350 cfm of cask unloading area air (at -0.1 in. H_2O), filter it and recirculate 280 cfm to the transfer cell and 2100 cfm to the transfer gallery. Heat produced within the transfer cell will be removed by two fan-coil recirculating air units, one operating and one standby, to maintain a proper temperature for can handling operations in the cell. A pressure of approximately -1.50 in. H_2O will be maintained in the transfer cell and approximately -1.00 in. H_2O in the transfer gallery by the ventilation supply and exhaust control dampers.

4. Cask Unloading Area Exhaust System. Dual filter-fan units in the exhaust fan-filter house (one operating and one on standby) will remove approximately 7620 cfm of cask unloading area air (at $-.10$ in. H_2O) and 400 cfm from the exhaust fan-filter house, filter it, and exhaust it to the atmosphere through the exhaust stack.
5. High-Level Cell Exhaust System. Dual filter-fan units in the exhaust fan-filter house (one operating and one standby) will remove approximately 280 cfm from the transfer cell (at -1.5 in. H_2O) and 2100 cfm from the transfer gallery (at -1.0 in. H_2O) and exhaust the total volume to the atmosphere through the high-level facility exhaust stack.
6. High-Level Fan-Filter House Supply System. A filter-heating coil-fan unit in the exhaust fan-filter house will supply approximately 400 cfm of outside ventilation air to that building.

Waste Concentration Area

1. Waste Concentration Area Supply System. A filter-cooling coil-fan unit in the decontamination equipment room will supply approximately 2200 cfm of tempered ventilation air (1000 cfm from maintenance and storage room and 1200 cfm of recirculated air) to the waste concentration, waste casting and decontamination equipment rooms.
2. Waste Concentration Area Exhaust System. A filter-fan unit in the decontamination equipment room will exhaust approximately 1000 cfm of ventilation air (at $-.10$ in. H_2O) to the high-level facility stack.

Hoist House

1. High-Level Hoist House Supply System. A filter-air conditioner unit in the hoist house will supply approximately 3500 cfm of conditioned ventilation air to the hoist house (1000 cfm outside air and 2500 cfm recirculated air).
2. High-Level Hoist House Exhaust System. A filter-fan unit in the hoist house will exhaust approximately 1000 cfm of ventilation air from the hoist house (at -0.25 in. H_2O) to the atmosphere.

High-Level Shaft. - The high-level shaft is an extension of the transfer cell confinement system. There will normally be no ventilation provided for the shaft; however, any inleakage to the system through the mine-level station will flow up the shaft and be discharged through the transfer cell exhaust system.

High-Level Mine. - Approximately 40,000 cfm of fresh air will be supplied to the high-level mine via the air supply compartment in the alpha-M&M shaft. About 50% of this air will be used for areas being mined and the remainder will be used in the burial operation. A room being mined will be ventilated by drawing air from a mine entry using a filter-fan unit mounted on a low bed trailer. If not needed for other mine ventilation purposes, the exhaust may be directed into the upper exhaust tunnel (which is located above the mining entries and is used exclusively to carry exhaust air to the upcast vent shaft).

In the burial rooms, the ventilation will be similar to that used in the mining rooms except that the filter-fan units will include a HEPA filter in addition to the 30% and 90% NBS filters. The fan will discharge to the upper level tunnel through flexible ducts or holes drilled upward from mine level. The waste burial sequence designates that burial work will be carried out in such a manner that personnel and machinery in the areas being mined will not be exposed to the exhaust air from the burial operations.

7.3.3 Confinement Control

1. All normally occupied confinement zones (except the cask unloading area) will be ventilated with 6 to 10 air changes per hour. The ventilation rate for the cask unloading area will be less than 6 air changes per hour due to its large volume (as compared with its floor area), low personnel occupancy, and the low hazard potential presented by cask handling. The ventilation air supplied to the cask unloading area will provide over 5 air changes per hour in that portion of the room that lies below a level 25 feet from the working floor. The entire volume of the cask unloading area will be ventilated with 3-1/4 changes per hour.

2. The exhaust air from the cask unloading area will be returned to the exhaust fan-filter house. Part of it will be refiltered and used to ventilate the transfer cell and transfer gallery, and the balance discharged through HEPA filters to the stack and atmosphere.
3. Negative pressures with respect to the atmosphere will be maintained in all confinement zones. Noncontaminated air will be supplied to areas of least contamination potential and exhausted from areas of highest contamination potential.
4. Duct backflow preventers will be installed to preclude the accidental flow of air to the atmosphere and a tornado damper will be installed upstream of both exhaust stacks.
5. Ventilation air for the high-level mine will either flow from uncontaminated areas that are being mined through the burial areas or be divided into two streams, one directed through the mining operations and the other through the burial operations.
6. Two lines of containment for the high-level wastes will be maintained at all times. The solidified waste can will be the first line of containment. The second line will be either the shielded (alpha-tight) shipping cask, an air-locked confinement area in the building, or any portion of the high-level mine.
7. Most of the equipment in the basement mechanical room is critical in maintaining high-level facility confinement integrity. Therefore, all outside air to the basement will enter through confinement control dampers and ducts to the boilers and air handling units and the entire basement will be treated as a confined area.

7.3.4 Primary Safety Considerations

1. The activity levels in all potentially contaminated exhaust systems must be minimized, monitored, and recorded.
2. Contamination from the facility must be released in a manner that assures dilution of the radioactivity to concentrations at ground level below the allowable limits specified in Sect. 3.

3. Provisions must be made to protect plant personnel from excessive radiation exposure and from the spread of contamination present in the high-level waste.
4. In the event of an accident, release of contamination from the facility must be held to less than the limits specified in the Safety Criteria (Sect. 3).
5. Provisions must be made to prevent the excessive release of contamination to the environment from the high-level wastes after burial.
6. Provisions must be made to protect all filtering systems on radioactive streams from failure due to shock, vibration, or fire. Standby filter-fan facilities must be provided in case of power outage, fan breakdown, or filter failure.
7. Provisions must be made for the protection of personnel working in the High-Level Facility during emergencies.
8. Provisions must be made to monitor and protect personnel from noxious gases in the mine exhaust system.

7.3.5 Safety Precautions (In the same sequence as Sect. 7.3.5)

1. Activity released by the High-Level Facility will be reduced to the lowest practical value by:
 - a. Two lines of containment for the high-level wastes during all handling and burial operations.
 - b. Two banks of high efficiency (HEPA) filtration for all exhaust streams from confined rooms before release to the atmosphere.
2. The radioactivity released from the stacks will be monitored and recorded continuously and will conform to the limits specified in Sect. 3.4.1, Radiological Safety Criteria. Adequate dilution of the activity from the stacks will be assured. The average annual concentration at the Repository site boundary is estimated to be about 8.6×10^{-6} Ci/m³ per Ci/sec average release rate at the stack.
3. Contamination confinement within the system will be provided as follows:

- a. Air flows will be from areas of least contamination potential to areas of increasing contamination potential.
 - b. Duct backflow preventers will preclude the accident backflow in the ducts to lower contamination potential areas.
 - c. Areas having the highest contamination potential, such as the transfer gallery and transfer cell, will have the lowest pressures.
 - d. In the high-level mine, mining operations will always be conducted upstream of the burial operations. A minimum air velocity of 30 fpm will be maintained in the mine working areas.
4. Accidental release of contamination in the High-Level Facility will be contained by the confinement structures and the high efficiency filters. In the event of power failure, ventilation exhaust fans serving all confinement zones will automatically be switched to standby power systems. Supply fans will not operate.
 5. Backfilling of the burial holes, rooms, corridors, and shafts with crushed salt will prevent the escape of excessive amounts of contamination during long-term storage. Filtration of the ventilation air will reduce the concentration of contaminants before discharge to the environment.
 6. Exhaust filtering systems will be designed for protection against reasonable vibration and shock loads. A sensitive fire detection and sprinkler system will be installed to prevent the spread of fires to the filtration systems.
 7. Personnel protection equipment such as face masks, protective clothing, and special equipment to ensure clean breathing air will be provided for emergency conditions.
 8. The levels of noxious gases in the high-level mine exhaust such as hydrogen, hydrogen chloride, carbon monoxide and carbon dioxide (from diesel exhaust) will be monitored. Personnel will not be exposed to this exhaust except during inspection and maintenance, and protective clothing and masks will be used.

7.3.6 Maintenance Principles

Maintenance procedures and schedules will be maintained for periodic lubrication, and for checking belt tension, signs of wear, and equipment damage.

All filter banks will have differential pressure gages connected to the upstream and downstream side. Filters will be changed when the filter resistance restricts flow to below acceptable levels. HEPA filters will be tested in place.

7.4 Process Waste System (Ref. Fig. 7.7)

7.4.1 Function and Design Requirements

Function. - The process waste system will decontaminate any radioactive liquid waste generated in the operation of the Repository to as far as practicable below the limits set forth in AEC Manual Chapter 0524 and reduce the residue to forms suitable for disposal in the Repository.

Basic Criteria (See Sect. 3.0.)

Concept-Related Requirements

1. The process waste system will be installed in an area designed for Category I-tornado and seismic resistance.
(See Sect. 3.5.1)
2. Equipment will be arranged to permit the addition of unit shielding if required.

Applicable Documents and Standards

1. AEC Manual Chapter 0524 Standards for Radiation Protection.

7.4.2 Physical Description

Summary Description. - The process waste system will collect and routinely process all potentially contaminated solutions emanating from process-oriented functions. Nonprocess, potentially contaminated

wastes discharges, will be routed to a collection tank; they will be monitored and will be processed if contaminated.

The process waste system will be located in the high-level waste receiving building. All floor drains from potentially contaminated areas, including the drains from the chemistry laboratory, the cask cooling and decontamination area, and the mine shaft sump will discharge into a confined collection sump. The waste will be pumped from this sump into a 2500-gallon process waste collection tank. The potentially contaminated process waste generated in the alpha waste receiving building will be generated during decontamination operations. Small in volume, these solutions will be collected in 55-gal drums, transported to the high-level waste receiving building by truck, and transferred to the process waste system through a liquid transfer station.

The solutions to be processed will be neutralized and successively evaporated, condensed, and passed through a cation-anion column. The system will be designed to process (in a 24-hr period) the waste generated during one cask-cooling operation. Instrumentation and sampling points will be provided for process control. In the event of incomplete decontamination, installed recycle lines will permit solutions to be returned for additional processing.

Nonprocess wastes which may become contaminated and require processing include effluents from change room showers, hand and janitor sinks, and the fire water system. A 10,000-gallon collection tank will be provided at both the High-Level Facility and Alpha-Operations Facility into which these wastes will be discharged via the controlled rain collection and floor, fire, and sink drain systems, respectively. The contents of the tanks will be sampled at regular intervals and, if contaminated, will be transferred to the 2500-gallon process waste tank for processing. If free of contamination the contents will be evaporated to the atmosphere by the evaporator located at the High-Level Facility.

The evaporator concentrate, containing the bulk of the radioactive contaminants, will be blended with dry cement and solidified in 55-gal drums. The drums will be taken by truck to the alpha waste receiving building and lowered to mine level for burial. The equipment for processing the evaporator concentrate into a solidified form will be developed during Title I design.

Major System Components

1. Holdup Tanks. Two 10,000-gallon holdup tanks, one for the alpha facility and the other for the High-Level Facility, will be provided for potentially contaminated wastes. After sampling, the wastes will be evaporated to the atmosphere if they are not contaminated. Contaminated wastes will be evaporated and the decontaminated condensate recycled as process waste or evaporated to the atmosphere.
2. Process Waste Collection Tank. A 2500-gallon stainless steel tank located in a concrete enclosure which will serve as the feed tank for the evaporator.
3. Batch Waste Evaporator. A 500-gallon stainless steel batch evaporator will be designed for a 850 lb/hr boilup rate and include demisting and condensing facilities. A heater will be provided to remove entrained water vapor and a filter will be provided to remove particulates from the off-gases before discharge to the chemical laboratory exhaust.
4. Condensate Equipment. A 1000-gallon stainless steel tank will be provided for condensate collection followed by cation-anion exchange columns for the removal of residual contamination. The ion exchange columns will use replaceable cartridges which, after removal, will be packaged and buried in the mine.
5. Waste Casting Equipment. Evaporator concentrates will be cast in concrete prior to final storage in the alpha mine.

7.4.3 Primary Safety Considerations

The process waste system will be operated independently of the alpha and high-level facilities. Therefore, malfunctions in this system will have no immediate effects upon the other operations. Possible hazards or abnormal operating conditions are listed below.

1. Fissionable or explosive materials in the process waste system feed.
2. Abnormal operation of the evaporator including foamovers, excessive entrainment or boiling to dryness.
3. The appearance of contamination in the condensate leaving the demineralizers.
4. Excessive contamination or moisture in the evaporator off-gases.
5. Excessive volumes of contaminated waste to be evaporated.
6. Power or steam failure.
7. High levels of radiation in the process waste feed to the evaporator.

7.4.4 Safety Precautions (In the same sequence as Sect. 7.4.3.)

1. Administrative control will insure that fissionable or explosive materials are not allowed in the process waste system.
2. The evaporator will have appropriate instrumentation to control the boilup and feed rates, pressure, temperatures, liquid level and solution density. In addition, radiation monitors will be used to continuously check the decontamination of the feed and if excessive contamination of the condensate occurs, it will be returned to the evaporator for additional processing. Low pressure steam will be used to heat the evaporator which will limit the temperatures in the evaporator.
3. Radiation monitors will be installed to check the contamination levels in the demineralizer effluent. If it exceeds the permissible limits, the ion-exchange resin will be replaced and the effluent will be recycled through ion exchange or both evaporation and ion exchange.

4. A heater will be installed in the off-gas line to evaporate moisture entrained in the evaporator off-gas. In addition, the off-gas will be filtered by an HEPA filter before discharge to the chemical laboratory exhaust.
5. Administrative control will restrict the volumes of process waste such that the capacity of the system to process these wastes will not be exceeded.
6. The process waste system will be designed to fail safe on power failure. A negative pressure ($-.10$ in. H_2O) will be maintained in the waste concentration area during power failure by the exhaust system, which will be connected to the standby power system.
7. The batch waste evaporator and the waste casting equipment will be installed in shielded areas and operated remotely. If access to these areas is required, shadow shields will be installed to protect the operating personnel.

8. SUPPORT FACILITIES

8.1 Warehouse

The warehouse building will be designed to serve the initial needs of the Repository for warehouse space and a maintenance shop. Codes and documents applicable to the construction of support facilities are as follows:

1. General Design Standards
 - a. General Design Criteria - AEC Manual Appendix 6301
 - b. Uniform Building Code, International Conference of Building Officials
 - c. American Standard Building Code, Requirements for Minimum Design Loads in Buildings and Other Structures, National Bureau of Standards
2. Seismic Design - Uniform Building Code
3. Wind Design - Uniform Building Code
 - Wind Forces on Structures, ASCE Paper 3269
4. Reinforced Concrete - Building Code Requirements for Reinforced Concrete, American Concrete Institute
5. Concrete Block Construction - Uniform Building Code
6. Crack Control in Concrete Masonry Construction - Publication 1198, National Academy of Sciences - National Research Council
7. The Steel Joist Institute Standard Specification for Open-Web Steel Joist Construction
8. Specification for the Design, Fabrication, and Erection of Structural Steel for Buildings, American Institute of Steel Construction

The building will be approximately 161 ft long by 85 ft wide with a floor area of approximately 14,000 ft². It will have a nominal height of 12 ft. The building will feature open floor areas for working and storage space.

8.2 Underground Maintenance

8.2.1 General

Facilities for underground maintenance work will consist of the necessary work space, tools and machines to permit the replacement of mobile equipment components, and the change or relocation of electrical circuit components required to keep mine equipment in operating order. Major component repair functions, such as pneumatic tire repairs, will be performed in a Repository shop at the surface or in commercial repair and machine shops outside the Repository.

8.2.2 Maintenance Shop

Shop floor space required for mechanical and electrical maintenance work will consist of a mine room approximately 100 ft long and nominally 30 ft wide in the vicinity of the alpha-M & M shaft. An adjacent 50-ft-long area will be utilized for installation of a lubrication pit for mine mobile equipment. Underground maintenance supply stores will also be kept in an adjacent, conveniently accessible 50-ft-long room.

Simple shop fixtures and equipment will be provided, including two 20-ft by 3-1/2-ft work benches, equipped with heavy-duty vises, and electrical and compressed air power outlets for power tools.

8.3 Magazine

Small quantities of commercial dynamite will be stored on the site. Dynamite is considered as a Class 7 explosive, the same as TNT. For this reason, the Army Safety Manual, AMCR 385-100, will be used for the design and location of the magazine on the site.

The maximum amount of explosive that will be allowed in the magazine at any one time will be 1000 lbs. Separation distances between surrounding facility buildings and parking lots will be in accordance with AMCR 385-100, which specifies these distances in relation to explosive weight.

The building will be approximately ten feet square. It will consist of concrete block walls of conventional construction with a frangible blow-out type roof. For missile protection of all facility structures and parking areas, an earth-mound barricade will surround the building except at the entrance side. The barricade will extend above the height of the magazine. A locked steel door will be provided for access. No facility buildings will be exposed to this entrance. No lighting or heating will be provided. Dynamite will be handled in accordance with the applicable codes listed in Sect. 3.4.3. The entire installation will be surrounded by a chain link fence with padlocked gate as described in Sect. 5.3.

8.4 Gate House

The gate house will be located at the entrance to the Repository facility. It will be the main information and check point for all employees, visitors, and automotive traffic entering and leaving the Repository. It will be provided with all of the alarms and communication systems necessary for safeguarding and controlling access to the facility. All windows and doors will be glazed with laminated safety glass and have protective grilles. Toilet facilities will be provided for the convenience of the guards and visitors.

8.5 Fallout Shelter

Space will be provided at mine level near the base of the man and material shaft for a suitable fallout shelter.

9. UTILITIES AND SAFETY SYSTEMS

9.1 Water System

The Repository domestic and fire protection water systems will be combined in a common supply and distribution system. Existing municipal potable water mains, if available, will be the source of supply for all Repository water. Check valves will be provided in the connecting lines to preclude backflow of water into the municipal system from the Repository system should a low pressure condition occur in the municipal system. If an adequate municipal system is not available, a water system based upon the supply from wells drilled at the Repository site will be used. Necessary storage and treatment facilities will also be included.

9.1.1 Domestic Water

The Repository domestic water system will be comprised of an 8-in.-diam. pipe loop with separate laterals to each of the major facilities. Laterals will be provided to the following facilities and buildings:

1. Alpha-Operations Facility
2. Repository Administration Building
3. High-Level Facility
4. Warehouse

Cast iron pipe with 5 ft of earth cover for freeze protection will be used for the domestic supply and distribution system.

9.1.2 Fire Protection Water System

Function and Design Requirements

Function. The fire protection water system will provide a water supply for sprinkler systems, hose racks, and fire hydrants. The fire protection supply system, including the storage tank, will be common with the domestic water system.

Basic Design Requirements

1. Hydrants will be 500 gpm capacity, dry-barrel type with two 2-1/2-in. outlets. A single steamer outlet will be provided. Steamer outlet size will conform to local fire department requirements.
2. Hydrants will be placed no farther than 500 ft apart and not farther than 250 ft from the building served.
3. Residual pressure at hydrants will be 60 psig with flow of 500 gpm.
4. Hydrant laterals will be not less than 6-in. diameter.
5. Each lateral will be provided with an isolation valve.
6. Hydrants located in areas that may make them susceptible to damage from vehicular traffic will be protected by suitable guard posts.
7. Sprinkler laterals will be not less than 6-in. diameter. Post indicator valves will be provided as required.
8. The minimum residual pressure at the highest sprinkler will be 15 psig.
9. An on-site storage tank of sufficient size for a 1-hr fire flow will be provided.
10. Portable fire extinguishers will be provided as required throughout the Repository.

Design Choices. - Three methods of supply for the fire protection system were examined:

1. Gravity flow from a large elevated storage tank.
2. Use of the municipal water system without booster pump or storage.
3. Use of the municipal water system with ground level storage and a booster pump.

The required 15 psi residual pressure at the highest sprinkler head would have required an excessively high-gravity flow tank, and the municipal system may not be of sufficiently high pressure to meet the fire protection needs. Hence, a ground level storage tank and booster pump, capable of meeting the fire protection demands, will be provided.

The system will include the following mechanical equipment:

1. Dual fire booster pumps, complete with automatic controllers, will be provided at the storage tank. These pumps will be connected in parallel with the storage tank. Automatic alternators will be provided to distribute operational use and maintain one standby unit on the standby power system.
2. A gas-fired hot water system will be provided to protect the fire protection storage tank from freezing and heat the pump house. An exterior diesel fuel storage tank will be provided as a standby fuel source.

Applicable Documents. - The applicable documents for the domestic water fire protection systems are listed below:

1. Chapter 0550, "Standards for Health, Safety and Fire Protection," AEC Manual.
2. Chapter 0552, "Industrial Fire Protection," AEC Manual.
3. "National Fire Codes," National Fire Protection Association.
4. "Manual of Recommended Water Sanitation Practice," U.S. Health Service Publication 525.
5. Practices recommended by the American Water Works Association.

9.1.3 Physical Description

A "looped" system will be provided around the main plant area. The looped system will be common to both the domestic and fire water systems. Separate laterals will be provided for the fire hydrants and sprinkler systems. A 60,000-gallon ground-level storage tank with heater and booster pump will be provided to meet the 1-hr fire demand. Water level in the tank will be controlled by a level sensor connected to an automatic valve in the fill line.

During periods of high fire water demand, an electric motor-driven booster pump will increase pressure in the system. This pump will be a standard fire pump conforming to the National Fire Codes and capable of

providing 1500 gpm at a pressure of 100 psig; it will be activated by a pressure-actuated switch. A standby pump and motor will be connected to the standby power system.

9.1.4 Primary Safety Considerations

1. Fire protection must be available at all times, and the system must be designed for power failures.
2. The system must be protected during freezing weather.
3. The system must be capable of providing fire protection in the event of an earthquake or design basis tornado.
4. Loss of feed to the cask cooling steam boiler (if not operating on recycle condensate) could shut down the cask cooling and process waste systems.
5. Potentially contaminated condensate from the cask cooling system must be isolated from the potable water system.

9.1.5 Safety Precautions (in the same sequence as Sect. 9.1.4)

1. On failure of the normal power supply, standby power to operate either of the booster pumps will be supplied from a diesel generator. The system will be tested weekly by a fire pump controller which will check the fire pump operation automatically in accordance with National Fire Code paragraph 931. Annual tests will also be performed with the pumps at full design capacity in accordance with National Fire Code paragraph 932.
2. A gas-fired heater system will be provided to protect the fire protection water tank from freezing. Supply piping will be buried with 5 ft of earth cover for freeze protection.
3. The electric-motor-driven pumps and the water storage tank will be vulnerable to acts of nature. Therefore, in the event of failure due to an earthquake or tornado, tank trucks from the nearest municipality will be brought in for use in the fire protection water system. Check valves will be used to isolate the water tank from the pumps in order to prevent leakage from the system in case of a break at the water tank.

4. Operation of the cask cooling system could be suspended for short periods of time without detrimental effects on the overall operation or loss of containment in the high-level waste facility. Interlocks on the cask cooling steam boiler will shut it down if feed water pressure is lost.
5. Check valves and approved air breaks will be installed to prevent potentially contaminated condensate from leaking back into the water system if a break should occur. In addition, alarms will be installed on the cask cooling system to warn of contamination in the cask cooling system. Procedures will then be implemented to decontaminate the system.

9.2 Electrical Power Systems

9.2.1 Functions and Design Requirements

Functions. - The normal and the standby electrical power systems will provide the Repository with a reliable, economical and safe supply of normal electrical power obtained from commercial sources and provide standby power for essential demands when the normal power is interrupted.

Basic Design Requirements. - The following are the design requirements of the system:

1. The safety requirements include protection of personnel from contact with live components and protection for electric equipment.
2. To obtain the required reliability, the design must provide isolation of faults with minimum disturbance to the rest of the system, and on-site generation of standby power.
3. The electrical system must provide a reliable supply of power to the in-plant users.
4. Voltage regulation of not more than $\pm 5\%$ will be provided to extend the life and operation of the electrical equipment.

5. There must be accessibility to the power system and its components for inspection and maintenance.
6. Normal power will be obtained from a commercial utility, and standby power will be provided from a separate source within the Repository.
7. All loads on the standby distribution system must restart automatically following loss of normal power and upon availability of the standby power.
8. When the normal source of power again becomes available after a power outage, the return to the normal mode of operation must require deliberate operator action to switch the standby line back to the normal power.
9. The standby power system must be reliable and capable of supplying all load demands essential to safety and maintaining confinement conditions upon interruption of normal power.

Applicable Codes and Documents. - The latest issue of the following codes and standards will be used as a reference and adhered to where applicable.

1. National Electrical Safety Code
2. National Electrical Code (NFPA No. 70, ANSI C1)
3. Institute of Electrical and Electronics Engineers - Standards
4. American National Standards Institute - Standards
5. Illuminating Engineering Society Lighting Handbook
6. Insulated Power Cable Engineers Association - Standards
7. Underwriters Laboratory, Inc. - Standards
8. Factor Insurance Association - Recommended Good Practice for Transformer & Switchgear Installation
9. General Design Criteria AEC Appendix 6301
10. National Electrical Manufacturers Association - Standards

9.2.2 Physical Description

Summary Description. - The electrical power systems for the Repository will consist of:

1. Normal or commercial power supply received from the utility distribution system at 4.16 kV for utilization as the facility prime distribution voltage.
2. On-site standby power generation matching the primary distribution voltage of 4.16 kV. The source of standby power will be two 750-kW diesel generators, either of which can supply the total standby power load demand, exclusive of the M & M hoist.
3. A third 750-kW diesel generator unit for standby operation of the M & M hoist.
4. A dc battery supply maintained in a fully-charged condition and utilized to supply loads requiring uninterruptible power such as alarm systems.

The distribution voltages will be (a) 4.16 kV to power centers and motors rated 150 hp and larger; (b) 480 volts to all motors rated less than 150 hp and greater than 1/3 hp and to lighting transformers for use on 480/277 lighting; (c) 480/120-208 volts for incandescent and fluorescent lighting; (d) 500 volts dc for mine traction machinery supplied by industrial rectifiers; (e) 120 volts dc for the nominal battery supply voltage.

Major System Components

1. Power Line. The incoming 34.5 kV overhead power line, furnished by the electric utility, will be the source of normal power to the Repository. The line will be terminated at the facility substation.
2. Facility Substation. A substation will be provided by the electric utility to step the voltage down from the utility distribution voltage of 34.5 kV to a facility utilization voltage of 4.16 kV.
3. High Voltage Switchgear. One assembly of government excess switchgear, with 7.2 kV oil circuit breakers, will serve the 4.16 kV loads of the facility. This switchgear assembly will be located in a basement room of the mine operations building.

4. Underground Distribution. All electrical wiring between the utility substation and the facility, as well as between surface facility buildings, will be in underground ducts. The underground duct banks will consist of rigid steel conduit or nonmetallic conduit encased in red-colored concrete. Manhole(s) will be provided to facilitate cable installation. Power will be supplied to the mine by exposed insulated 4.16 kV cables installed in the utility compartment of the alpha-M & M shaft.
5. Standby Power Generation. Three standby power generating units will be provided to supply those loads necessary to maintain the facility in a safe shutdown condition during normal power outage or sustained undervoltage. The units will be government excess equipment suitable for standby duty.

The generators will each be rated for 750 kW at an 0.8 power factor and will have a three-phase output voltage of 4.16 kV. They will be equipped with suitable voltage regulating and adjusting equipment to permit the starting and operation of the standby system loads. Government excess switchgear will be modified to start the standby power units automatically and to isolate the designated loads for operation on this source of power. The generators will be supplied with at least the following accessory equipment:

- a. Direct-driven exciter
- b. High-speed voltage regulator
- c. Exciter field rheostat
- d. AC voltmeter with transfer switch
- e. AC ammeter with transfer switch
- f. Frequency meter

The standby generating units will have local controls but will be arranged to start automatically upon loss of the normal source of power or excessive undervoltage conditions.

To prevent a possibility of the "reflected fault," i.e., the loss of the power from one load group to another, the M & M hoist will be supplied from an independent bus section of the 4.16 kV switchgear.

6. Facility Power Distribution. For power distribution, high voltage cable in underground ducts and exposed on racks will be used to distribute 4.16 kV power from the switchgear to power centers and other 4.16 kV loads. A combination of wire in conduit and cable in trays will be used for distributing low voltage power within surface buildings of the Repository. Power cables will be isolated from control cables. Design of cable installations will include means for preventing propagation of fires in multicable applications. Trolley conductors, supplied with 500 V dc power, will be used for shuttle cars and the alpha transporter in the mine.
7. System Battery. A 120-volt battery will be provided to supply power for emergency lighting and all instrumentation and control systems requiring noninterruptible or failure-free power. Two battery chargers will be provided. These chargers will operate from the normal standby bus.
8. Lighting. Emergency lighting will be provided to permit safe movement of personnel in the building during complete power outages. These lights will normally operate from the dc battery power system and will provide nominal illumination upon loss of all other sources of power. In the mine shaft, station areas and shops, illumination during power outage will be provided by portable continuously-charged dc lights located for maximum lighting effect.

Lighting levels within the Repository buildings will be as recommended by the I.E.S. Handbook. Supplemental lighting will be provided in areas where high lighting intensity is required.

No perimeter fence lighting will be provided except at the main entrance gate. The illumination level at the gate will be approximately 5 foot-candles. Lighting level at the 150-car parking lot will be approximately 2 foot-candles.

9. Grounding System. Grid-type ground systems will be installed for the Repository. These grids will consist of a loop of stranded annealed copper wire at least 4/0 AWG completely encircling a building or area, together with a number of cross connections between two points on the loop. Copper-clad steel ground rods at least 10 ft long will be driven at each corner of the ground loop and at enough intermediate points to obtain a resistance from each grid to earth of not more than 5 ohms as measured by the "fall of potential" method.

9.2.3 Primary Safety Considerations

High voltage electrical distribution systems with their connected components are always a source of potential hazards. Interruption or loss of normal (commercial) power could result from an in-plant incident, from abnormal weather, or from an off-site condition affecting the utility service.

The loss of normal power would present a potentially hazardous condition since re-establishment of operation of certain plant operating equipment is essential to maintaining the Repository confinement integrity (see Sect. 6.3 and Sect. 7.3).

9.2.4 Safety Precautions

Strict adherence to the protective measures and safe practices of the established codes and standards, as listed in Sect. 9.2.1, will provide adequate safeguards for the operating personnel and the plant electrical systems.

As a safeguard against loss of normal power, three diesel generators will be provided for the standby power system. One of the diesel

generators will be sufficient to supply all standby power requirements except the M & M hoist. Two of the units will serve the common standby system, with the second unit starting if the first fails to operate. The third unit will be used to provide standby power for the M & M hoist. When normal power fails, the standby feeders and buses will be automatically isolated from the normal power system by the opening of the 4.16 kV tie-breakers, so that only the standby distribution system will receive power from the diesel generators. All equipment essential to maintaining integrity of confinement zones and safe shut-down conditions for the Repository will be served by the standby power system.

9.2.5 Maintenance Principles

Preventive maintenance will be exercised through periodic inspection, cleaning, and routine maintenance of items of equipment. All components of the system will be inspected at regular intervals. In the event of a fault in the bus or of a loss of service, the parts of the system affected will be inspected as soon as the fault is cleared and service restored. All adverse effects arising from the fault will be corrected before the affected equipment is used.

9.3 Sanitary Waste Disposal System

A sanitary waste system will be provided to collect and dispose of all the sanitary wastes generated in the above-ground portion of the Repository facilities. Sanitary wastes that are generated underground will be collected in self-contained chemical toilets which will be serviced by a contractor for disposal off-site. Wastes from potentially contaminated sources are not discharged into the sanitary waste system.

Gravity flow collector mains will serve the Alpha-Operations Facility, High-Level Facility, gate house and warehouse. The mains will terminate in a collector manhole. Lift stations will be used to pump the sewage into a municipal sewage system, if available, or a Repository sewage system if it is necessary to provide a separate facility.

9.4 Fuel Gas

9.4.1 Functions and Design Requirements

Functions. - To provide fuel for space and unit heaters, domestic water heaters, boilers, and the fire protection water storage freeze prevention system.

Design Requirements

Basic Design Requirements

1. Total Demand: 23,400 cfh of natural gas
2. Pressure Required: Approximately 1/4 psig
3. Cover for Underground Lines: 3 ft minimum

Applicable Documents

American National Standards Institute, "Gas Transmission and Distribution Piping Systems," ANSI B31.8

9.4.2 Physical Description

The Repository will obtain natural gas fuel from existing supply lines located in the vicinity of the site. The gas will flow through a pressure reducing valve, a connecting supply line and meter, and then to the Repository distribution system. The distribution system will convey the gas to the various buildings at 15 psig. The gas pressure will be reduced further at the buildings as required to meet operating requirements.

9.4.3 Primary Safety Considerations

1. Leakages in the gas supply system
2. Corrosion of underground distribution piping
3. Overpressuring of the supply system
4. Mechanical damage to the piping
5. Failure of the gas supply to the Repository

9.4.4 Safety Precautions (in the same sequence as Sect. 9.4.3)

1. To prevent leakages, all piping system components, joints and materials will be designed, installed, and tested in accordance with the requirements of ANSI B31.8.

2. An investigation will be made of the corrosive nature of the soil, and a suitable corrosion allowance will be added to the pipe wall thickness in accordance with ANSI B31.8. Coating will be provided; in addition, cathodic protection will be provided, if required.
3. Relief valves will be provided as required to prevent over pressuring.
4. To prevent mechanical damage, guard posts will be provided around all above-ground parts of the system. Also, isolation valves, identified by marker posts, will be provided so that the system components can be isolated for repair, maintenance, or modification.
5. A backup fuel oil supply system will be installed to provide for failure of the gas supply to the Repository.

9.4.5 Maintenance Principles

1. An operating and maintenance plan will be prepared that will conform to ANSI B31.8, Sect. 850, 851, and 852.
2. The pipelines will be patrolled and inspected periodically for indication of leaks and other factors affecting the safety and operation of the line.
3. A leakage survey will be made at least once a year.
4. An inspection for corrosion will be made once a year in accordance with ANSI B31.8, Sect. 851.2.
5. A record of all maintenance and inspection work will be kept.

9.5 Communications System

A telephone and intercommunication system will be designed and installed in accordance with the applicable portions of the latest issue of the AEC Appendix 6301. The communication system will be based on a combined telephone-intercommunication system and will include dial-type telephones served from the nearest commercial telephone exchange through a multiple-conductor telephone cable.

Speakers, amplifiers, and the necessary relay equipment located in telephone closets will be provided to enable any telephone at the Repository to page within the facility by dialing a special number. Page-call return will be made from any telephone within the facility by dialing a designated code. This will automatically connect the telephones for a two-party conversation.

To prevent acoustic coupling, the speaker adjacent to any hand set station will be silenced automatically when that hand set is removed from its cradle. Speakers adjacent to hand set stations will not be silenced, however, to page-call when those hand sets are in use on the party-line circuit.

For emergency backup service, a two-way short-wave radio communication system will be supplied to allow voice communication between strategic points in the Repository and with outside emergency organizations.

9.5.1 Fire Alarm System

The fire alarm system will be part of the communication system. Fire alarms will be initiated in three ways:

1. By manual operation of coded fire alarm pull boxes located at strategic points throughout the Repository.
2. By signal from heat-actuated detectors located in the confined areas or in the burial rooms of the alpha mine.
3. By a discharge in the sprinkler system.

When a fire alarm is initiated by any of these sources, the following alarms will be given:

1. Coded signals will be transmitted over the paging system which will identify the location of the alarm. These signals will take priority over all other calls on the page system.
2. Fire alarm signals will be transmitted automatically to the nearest municipal Fire Department.
3. Annunciator panels, located in the guard gate house and at the central control monitoring station, will be lighted to show the location of the fire alarm.

9.6 Railroad Spurs

A standard-gage railroad spur will provide service to the Alpha-Operations and High-Level Facilities. Sidings and working track will provide space for the handling of 12 cars at the Alpha-Operations and 10 cars at the High-Level Facility.

The track structural section will consist of 18 in. of ballast on a compacted subgrade, 7 in. x 9 in. x 8 ft-6 in. timber ties, and 90-lb. A.R.A. rail. Bumping posts will be provided at exterior dead-end track locations.

The railroad installation will conform to AEC General Design Criteria Appendix 6301, AREA standards, and the standards of the local operating railroad for the proposed rail car loads.

In-plant rail car movements will be handled by a combination highway and railtrack switching vehicle. The unit will be provided with a snow plow attachment for use in clearing the plant track and roads.

9.7 Site and Regional Monitoring and Surveillance

The conceptual design is based on the double confinement philosophy used in other radioactive handling and processing facilities. Containers, cars, or casks will enter receiving buildings through air locks. Ventilation air from all areas of potential contamination will be filtered before release and operations will be carried out at negative pressures relative to the atmosphere. Site and regional monitoring systems will be provided to assure that the confinement systems are functioning properly and to maintain long-term records of the activity levels at the site and in the region surrounding the Repository.

9.7.1 Site Monitoring

Site monitoring includes operational monitoring and perimeter monitoring. All site monitoring will be a part of the Repository operation and will be the responsibility of the operating contractor.

Multiple samplers and instrumentation will be provided to continuously monitor, indicate, and record the level of radioactivity in effluents discharged from confinement areas. The system will include in-stack samplers, alpha and beta-gamma monitors, and gas-flow measuring equipment. These instruments will provide data on the quality of air being discharged to the environment from the processing buildings and the mine.

Perimeter air and fallout monitors will be installed at a number of points near the site boundaries. Locations will be based on prevailing wind patterns and the relation of the facilities to the perimeter.

Surface storm water drainage will be monitored at appropriate locations where the drainage leaves the site. A continuous recirculating sampler and monitor-alarm system will be installed in manholes at these locations.

9.7.2 Regional Monitoring

Radiation monitoring of the region outside the Repository perimeter will be performed by members of the Repository staff, appropriate agencies of the State of Kansas, and other qualified agencies. These agencies will provide a continuing evaluation of the effect of Repository operation in the region. The program will be initiated well in advance of startup to provide necessary baseline data and will continue after Repository operation commences. Monitoring will include measurements of surface contamination (fallout plates), measurement of off-site radiation dosage, and periodic tests of ground and surface water and vegetation. Wind rose plots will be used to select optimum locations for the monitoring stations.

10. IMPACT OF PROPOSED OPERATIONS

10.1 Thermal Effects

After the waste is buried in the mine, the heat from radioactive decay is dissipated in the salt and surrounding formations and eventually flows to the surface of the earth, where it is transferred to the atmosphere. A consequence of the subsurface heat release is an increase in the temperature of the mined area and its environs. The temperatures gradually increase and then finally decrease since the heat generation rate in the waste is continuously decreasing. Eventually the temperatures will return to normal; however, thousands of years are required.

Factors which influence the allowable heat release rate include: (1) thermal instability of the waste; (2) structural integrity of the mine during operation; (3) structural integrity of the overlying formations; (4) temperature rise in freshwater aquifers; (5) heating of the earth's surface; (6) temperature increases beyond the boundaries of the mine; and (7) release and migration of brine contained in small cavities in the salt.

Thermal design considerations are confined primarily to the high-level portion of the Repository. Power densities in the alpha waste, even with the tentatively proposed maximum compaction factor of 10, are about a factor of 10^5 smaller than those for the high-level solidified waste and constitute no significant thermal problems. The high-level waste, on the other hand, does constitute a thermal problem in the sense that the high-level portion of the Repository must be carefully designed to achieve adequate safety without excessive cost. Variables at the disposal of the designer are room, pillar, and waste-container dimensions; waste package array and spacing within the room; initial thermal power per waste package; and the age of the waste at the time of burial.

Criteria associated specifically with the thermal analysis place limits on temperatures in the solidified waste, in the geologic formations, in freshwater aquifers and at the earth's surface. The maximum permissible temperature of the waste is presently specified as the maximum temperature that existed during the waste solidification process.

It appears that these temperatures will range between 1100 and 2000°F, a specific value depending upon the solidification process used. Maximum permissible temperatures for the salt are based on feedback from the rock mechanics analysis. Tentative values, which will be modified as the iterative process continues, are as follows:

- a. The volume of salt above 482°F that surrounds the waste container and that is confined within a unit cell outlined by horizontal planes at the ends of the container and by the usual vertical planes of symmetry shall constitute less than 1% of the unit cell volume.
- b. The volume of salt above 382°F in the above unit cell shall be less than 25% of the unit cell volume.

Other limiting temperatures are: earth's surface temperature rise, $\leq 1^\circ\text{F}$; temperature rise in the geologic formation at the edge of the Repository buffer zone, $\leq 1^\circ\text{F}$; and stagnant aquifer temperature rise at a depth of 300 ft below the earth's surface, $\leq 50^\circ\text{F}$.

Thermal analysis of the Repository is being conducted by both analytical and experimental means. The analytical approach includes solution of the differential heat conduction equation by numerical techniques for one-, two-, and three-dimensional problems.¹ The experimental program has involved temperature measurements in the salt surrounding electrically heated waste containers at the Lyons site and the determination of material thermal properties. Material samples for the latter measurements were extracted from cores drilled at the proposed site.

10.1.1 Waste Loading Surface Densities

Results from the thermal analysis indicate that compliance with the present salt-formation and waste-temperature criteria results in a design that more than satisfies the remaining thermal criteria. Based upon the more restrictive criteria, the maximum permissible high-level waste loading for 10-yr-old waste is about 6 metric tons of waste nuclides per gross acre. For 1-year-old waste, the limiting value is less by a factor of at least two, the value of the factor depending upon the spacing between waste packages and the type of waste.

10.1.2 Temperature Distributions for a Typical Burial Scheme

A typical burial scheme for the proposed site is shown in Fig. 10.1, and temperature increases above the original ambient, corresponding to the locations indicated alphabetically, are shown in Fig. 10.2 for a 10-year-old calcined waste. Each waste package contains 165 kg of high-level waste nuclides and evolves 4.34 kw of thermal power at the time of its burial. For this case, the "25%" temperature criterion in the salt was limiting. As indicated in Fig. 10.2, the waste-temperature increase reaches a maximum of 900°F in about 6 years, while the surface of the container experiences a maximum temperature rise of 550°F, and this is achieved in about 15 years. The maximum temperature rise in the stagnant aquifer is 38°F (500 years), and at the earth's surface the maximum temperature rise is only 0.26°F (500 years). The maximum temperature rise at the base of the pillar is 300°F (50 years), and the permissible 1°F temperature rise for "mineral rights" occurs 2500 ft out from the edge of the mined area at a depth of 2000 ft (location j in Fig. 10.1). The corresponding time for the latter temperature rise is 6000 years. It is also of interest to note that the maximum heat flux, resulting from the waste heat, at the earth's surface is about 0.2 Btu/hr·ft², which is 12 times the geothermal heat flux and about 500 times less than the average solar heat flux.

10.1.3 Formation Stability

The temperature increases in the geologic formations alter the mechanical and physical properties of the various materials in the formation and thus affect formation stability. Thermal expansion (reduced density) and increased flow rate of the salt (reduced creep strength) are two major effects, and both are included in the analysis of room closure rate and strains in the overlying protective shale bed. Limiting temperatures in the salt have been established on the bases of such analyses.

Heating of water-bearing shale could present a special formation-stability-related problem because of increased pore pressure, due to expansion of the trapped water, and because of possible chemical changes.

Fig. 10.1. Typical Burial Scheme for High-Level Waste.

Fig. 10.2. Temperature Rise vs Time after Burial for 10-year-old Calcined Waste, 15-ft Room, 25-ft Pillar, Single Row of 6-in.-diam Containers on 30-ft Pitch. (Each container has 165 kg of waste nuclides and evolves 4.34 kW of thermal power at the time of its burial.)

Pore pressure presumably could result in local fracturing or at least contribute to failure (of the shale) otherwise induced by external loads. Recent experimental data, however, show no microscopically observable mineralogical changes and no reduction in uniaxial compressive strength of typical shale over a temperature range of 75°F to 300°F. As indicated in Fig. 10.2 (curve g), the expected maximum temperature at the base of the overlying shale bed is only 210°F (the initial ambient at this elevation is 70°F).

10.1.4 Brine Migration and Salt Decrepitation

Brine-filled cavities, ranging in size from a few millimeters and smaller, occupy about 0.5% of the salt volume at the proposed site. Thermal expansion of the brine can result in local fracturing (decrepitation) of the salt, particularly at a free surface. The incipient decrepitation temperature for a free surface is about 480°F, and for bulk salt under hydrostatic pressure it presumably is higher. A consequence of decrepitation is a sudden release of the brine and in some cases a reduction in the effective thermal conductivity of the salt. The area of concern in the mine is that adjacent to the waste package. Free surfaces will exist in this area until the crushed salt backfill is reconstituted, becoming an integral part of the surrounding salt bed, and is subjected to the hydrostatic overbearing pressures. Based upon results from the Project Salt Vault experiments, it is expected that because of the rapid reconsolidation of the crushed salt backfill (which will raise the incipient decrepitation temperature of the salt and restore favorable hydrostatic conditions), variations in thermal conductivity will not constitute a problem.

When the brine cavities are subjected to a temperature gradient, they will move either up or down the gradient. A cavity containing only brine will move up the gradient in the direction of the heat source, while a cavity containing some gas can move down the gradient. Gas may already exist in a brine cavity, and additional gas can be generated by radiolytic decomposition of the liquid brine. The concern over the migration is the deposition of brine around the waste packages, and the

transport of activity away from the waste packages. It suffices to say here that neither of these mechanisms appears to constitute a serious problem. Further details associated with the brine are discussed in Sect. 10.2.

10.1.5 Movement of Waste Packages After Burial

There are several mechanisms that may tend to displace the waste packages from their original positions in the salt, and these mechanisms are related to the deposition of decay energy in the mine. One of the mechanisms is associated with room closure, which would take place even in the absence of increased temperatures, but which is certainly accelerated at elevated temperatures. The specific mechanisms for moving the waste is the plastic flow of salt from beneath the room up into the room. The waste package would be carried along, but once the room has closed through deformation and reconsolidation of the salt, the motion will stop. The estimated maximum vertical displacement is 2 ft, which does not constitute a problem.

Buoyant and other external forces can also cause the waste packages to move. Salt immediately around the packages will be at a high enough temperature to behave as a viscous fluid, and a conservatively estimated value for the viscosity is 2×10^{20} lb·sec/ft². For these conditions the least dense solidified waste would have an upward velocity well under 10^{-10} in/year. The most dense waste will have a downward velocity of the same order of magnitude. Such a displacement rate is negligible even over 10^6 years.

External forces considerably in excess of the buoyant force might result from generation of steam and gas pressure at the ends of the containers. Prior to the time that the backfill above the waste package constitutes a tight seal, and provided that an impervious, sliding seal is developed around the sides of the container, steam and gas pressure at the bottom of the package (derived from the brine) could push the package upward. Laboratory experiments indicate that refluxing of the brine along the sides and above the container can produce a rather tight seal near the upper end of the container. However, the Salt Vault

experiments revealed no tendency for containers to move, and at the conclusion of the experiment the backfill directly above the cans was essentially reconstituted. It is tentatively concluded that a combination of frictional force buildup along the sides of the container and leakage around the outside of the container prevented detectable movement of the waste package.

10.2 Radiation and Chemical Effects in Mine

10.2.1 Radiation and Thermal Chemistry

The radiation and chemical effects of concern are those due to the presence of small amounts of water close to the waste containers. The water is dispersed in the form of small brine-filled cavities throughout the salt, and it also occurs in the shale which is one of the major impurities of bedded salt. The brine cavities, which range in size up to a few millimeters on a side, occupy from 1/4 to 1/2 percent of the salt volume at the proposed site. When these cavities are subjected to a temperature gradient, they will move either up or down the gradient. A cavity containing only brine will move up the gradient in the direction of the heat source, while a cavity containing some gas can move down the gradient. Under certain conditions, particularly when a free salt surface exists, thermal expansion of the brine can result in fracturing of the salt and a sudden release of the cavity contents.

Shale can release water upon heating, and presumably this water can enter the waste container burial hole where shale layers intersect the hole. It is also possible that this water will migrate from the shale through the salt toward the heat source. However, there is no evidence to date to indicate that the transport of water from the shale to the heat source is significant, and in any event, this effect will be minimized by burying the wastes only in regions of relatively pure salt.

Brine, vapors, and precipitated salts in the vicinity of the waste packages will be exposed to intense gamma radiation and to high temperature. Thus, they will be subjected to radiation decomposition and thermally-induced changes in composition.

Identity, Sources, and Formation Rates of Radiation and

Thermal-Reaction Products. - Predicted radiation and thermal-reaction products, their origin and their formation rates are summarized in Table 10.1. The products include H_2 , HCl , HNO_3 , O_2 , ClO_2 , Cl_2 , Br_2 , chlorates, and bromates. Hydrogen gas can be produced by radiolysis of the brine and by corrosion of the waste containers. Radiolysis of the encapsulated brine results from direct absorption of gamma rays and from dissolution of trapped electrons and holes in the $NaCl$ crystal lattice. The latter are dissolved along with the salt as the brine migrates. The concentration of H_2 within the brine will be limited to 1 mole/liter or less by reverse migration and by radiation-induced back reactions. The expected maximum H_2 production rate by radiolysis is about 4 moles/year, and this rate would prevail for only the first year after burial.

Hydrogen production from corrosion will be no greater than 400 moles per year (for a 5-kW package), which corresponds to 7 liters of brine per year and an average corrosion rate of 50 mpy. At the end of the first year, the rates will be down by a factor of 3.5. For a 2-kW package, the brine flow rate would be less than 1 liter/year at all times, and the corrosion rates would be correspondingly lower. Estimated brine flow-rates as a function of time are shown in Figs. 10.3 and 10.4 for 2- and 5-kW packages, respectively.

Because of the high temperature of the waste container surface, liquid water will not be in contact with the container surface. The high corrosion rates are assumed to exist because of the presence of HCl and Cl_2 in the water vapor. The HCl is produced by hydrolysis of $MgCl_2$, which is present in the encapsulated brine at a concentration of 2-3 moles/liter, and by the reaction of Cl_2 with H_2 .

HNO_3 , the oxidized species O_2 , Cl_2 , Br_2 , ClO_2 , and chlorates and bromates are formed by radiolysis of the brine solutions and moist gases around a waste package. Oxygen will be the principal oxidized radiolytic species within the encapsulated brine,

Table 10.1. Summary of Conclusions Regarding Identities of Species Appearing Around a Waste Can and Maximum Rate of Appearance

Species	Source	Max. Rate of Appearance (moles/year)	Max. Period After Burial (years)	Balancing Oxidized Species	Remarks
H ₂	Radiolysis product within encapsulated brine	4	<1	O ₂ , chlorates, bromates	Comparable rates for 2- and 5-kW cans.
H ₂	Radiolysis of solution around can	0.8 followed by a decrease to 0.3	0.1 0.5	O ₂ , Cl ₂ , Br ₂ , ClO ₂ , ClO ₃ , BrO ₃	For 2-kW cans. Insignificant radiolysis with 5-kW cans because of rapid heatup.
H ₂	Corrosion of can (50 mils/year)	400	<1		Assumed brine inflow rate of 7 liters/year, with all H ₂ O reacting with can.
HCl	Hydrolysis of MgCl ₂	20	<1		Assumed brine inflow rate of 7 liters/year, 3 M MgCl ₂ within brine, and 50% hydrolysis of MgCl ₂ .
HNO ₃	Radiolysis of moist mixtures of N ₂ and O ₂	0.50	<0.1		Likely that all N ₂ will have been expelled at <0.1 year after burial.
O ₂ and other oxidized species	Radiolysis				To balance radiolytic H ₂ .

10-10

Fig. 10.3. Cumulative Brine Inflow vs Time After Burial.
(Two kilowatts of 10-year-old fission products.)

Fig. 10.4. Total Cumulative Brine Inflow vs Time After Burial, Midplane, $h = 10$ ft. (Five kilowatts of 10-year-old fission products.)

although some chlorate and bromate will also be present. The sodium and magnesium chlorates and sodium bromate within the open spaces around a waste package will decompose thermally to halides and oxygen. Magnesium bromate will decompose thermally to oxide, oxygen, and bromine. The chlorine will react with H_2 to form HCl , and ClO_2 will decompose thermally or by reaction with reducible species including the metal container.

Formation of Explosive Gas Mixtures with Hydrogen Gas. - Prior to the time that a tight seal is formed in the hole above a waste package, hydrogen will diffuse out of the hole into the room above. As long as the room is ventilated, H_2 concentrations in the room and hole will be well below explosive limits. If there were no ventilation in or diffusion from the room, the hydrogen concentration at the end of the first year would be only 3 vol %. In practice, a room might be backfilled as burial takes place. This will reduce the void space in the room by a factor of 3 and thus will increase the H_2 concentration accordingly.

In an actual case, the diffusion of H_2 out of a room into a ventilated corridor will be appreciable. For steady-state conditions, it is predicted that the H_2 concentration at the rear of a 500-ft-long backfilled room will be about 8 vol %, and at 120 ft from the front of the room it will be 4 vol %. At container level the corresponding concentration would be no greater than 12%. The lower explosive limit for H_2 in a large container is about 4 vol %, but in the backfill it is expected to be considerably higher, probably in excess of 12 vol %. Thus, it appears that a flame would not propagate through the backfill, but an explosion could take place in the relatively large void space (1 to 2 ft in height) between the top of the backfill and the ceiling of the room. The time required to reach steady-state conditions has not as yet been calculated, but it is expected to be several years. This may provide enough time for ceiling-sag and floor-heave to eliminate the void space above the backfill before explosive concentrations are reached, particularly if care is

taken to fill the room to the greatest practicable extent. If this remedial action is not adequate, the void space might be ventilated or the corrosion rate of the waste containers reduced substantially. Two ways of doing the latter are to reduce the power surface density in the mine (thus reducing the temperatures and temperature gradients and, consequently, the brine flow rate) or surround the container with a protective material such as calcium oxide, which will react with the water and HCl before they contact the container.

If the hole above the waste container becomes tightly plugged, explosive H_2 concentrations can exist in void spaces beneath the plug. Oxygen for combustion can be provided by the radiolytic decomposition of the water and by trapped air. Such explosions would not have any deleterious effects provided that the rooms are backfilled with salt. If backfilling progresses promptly, explosive mixtures will not be achieved in a hole before that hole is well covered with backfill.

Introduction of Noxious Gases, Other Than Radioactive Species, into Working Areas. - All inhabited working areas in the mine will be ventilated at such a rate that concentrations of HCl, Br_2 , and HNO_3 will be well below permissible values. Without ventilation the HCl tolerance concentration of 5 ppm could be reached in about one day. Considerably longer times would be required to attain the tolerance levels of Br_2 and HNO_3 .

Effects of HCl and Other Active Species on Transport of Fission-Product Activity. - It is possible, but not probable, that volatile oxychlorides will be formed, and their presence can contribute to the transport of the oxidized fission products. Investigations regarding this phenomenon are in progress (see Sect. 10.2.2).

Effects of Explosive Reactions of Chlorates, Perchlorates, and ClO_2 . - Chlorates and perchlorates are explosive when they are in contact with oxidizable materials. The explosive force which could be developed from these materials on a yearly basis is estimated to be equivalent to 0.4 lb of TNT, assuming the maximum possible net formation-rates of the reactive materials and an abundance of reducing species. However, decomposition of the chlorates and perchlorates and an unavailability of reducing species will limit the explosive force potential at any particular time to well below that, which is considered acceptable provided several feet of backfill cover the tops of the holes.

ClO_2 is not expected to contribute to the explosive potential because it decomposes so rapidly that significant concentrations should not accumulate.

Effects of HCl and Cl_2 on the Corrosion of the Waste Container. -

It is expected that the corrosion rate of stainless steel and carbon steel will be appreciable when these materials are in contact with high-temperature water vapor containing HCl and/or Cl_2 . The maximum rate of reaction between the vapor and metal would be proportional to the flowrate of the brine, and the corresponding maximum corrosion rate in the case of a typical 5-kW package would be about 50 mpy for the first year, and substantially less in following years. At these rates a container with a 0.25-in. wall thickness would be completely converted to oxide within 16 years after burial.

10.2.2 Isotope Migration

Three general modes of transport exist for the dispersal of radioactivity subsequent to the emplacement of the radioactive waste containers within the salt formation. These transport mechanisms include: (1) gas phase transport, (2) solid state bulk (or volume) and grain boundary diffusion, and (3) migration along free surfaces. In order for two of these mechanisms to become operative, however, if only in a potential

sense, the waste container must itself be breached. This can occur in one of two ways, either through a direct loss in structural integrity, as by corrosive action, or through the solid state diffusion mechanisms. A most conservative estimate of the extent of isotope transport is had if the waste containment is not regarded as itself a barrier to migration but rather as an additional component having the potential to interact chemically with its salt and waste environ. Even when viewed on this basis, the research performed thus far suggests that isotope migration within the formation will not compromise the capability of the salt to maintain the isolation of the radioactive waste from the biological environment over the required period of time.

Save for the possibility of combustion of an alpha waste, which conceivably can result in an enhanced dispersal of radioactivity via an aerosol mechanism (here regarded as a special type of gas phase transport), the alpha facility offers no circumstances for additional transport mechanisms over those encountered in the high-level facility. Moreover, because the causes for migration (higher temperatures, higher concentrations of water and radiolysis products) are intensified in degree in the high-level facility, conservative estimates of transport within the high-level facility are necessarily conservative with respect to transport within the alpha facility as well.

Small amounts of gaseous radioactive species, such as tritium, krypton, xenon, and possible iodine, will accumulate within the high-level waste containers prior to their emplacement within the mine. Studies which have been performed concerning the gas transport characteristics of crushed salt beds indicate that the crushed salt backfill will not provide significant holdup for the radioactive gaseous components. In the most favorable instance investigated, as an example, the extent to which the crushed salt bed retarded gas transport was only about a factor of eight less than the rate of transport in free space. It is thus imperative either to ensure the integrity of the waste container until backfilling of an entire room has been completed, or to provide guarantees that exposures resulting from early containment breaches are well within acceptable limits.

Although it is most unlikely that the solidified waste-waste container-salt system can result in the formation of volatile radioactive species, the likelihood of such a possibility is enhanced because of the brine-filled cavities which are interspersed throughout the salt formation. In addition to increasing the number of possible interactions involved because of the many chemical species which are contained within these tiny cavities, significantly greater degrees of freedom are introduced because of radiolytically induced reactions which will occur as the cavities traverse the radiation fields. To perform a systematic study of the problem in the laboratory is prohibitive; instead, it is desirable to limit the study to those chemical components which can reasonably be expected to be present in sizeable amounts, and to supplement this work with carefully controlled in situ experiments with actual waste in purposely-breached containers. Accordingly, since water is a main component of the brine-filled cavities, and many of the calcined species are most likely to be in oxide form, studies of the oxide-water vapor interaction have been performed. As a result of this work, the oxide-water vapor interaction has been discounted as a mechanism for the formation and subsequent transport of volatile radioactive species.

Of course, if the bedded salt, and the reconsolidated backfill salt as well, is completely impermeable to gases, the formation of gaseous species (including aerosols) and their transport through the repository would be limited in significance to only that relatively brief period over which reconsolidation of the crushed salt backfill around the containers occurred. In a similar manner, migration along free surfaces would likewise be limited in duration to the reconsolidation period. Unfortunately, little has been done toward a determination of the permeability characteristics of bedded salt, though the work which has been performed supports its assumed impermeability. Additional work is desired, however, and will be performed even prior to the demonstrational aspects of the Repository's operation.

Studies which have been conducted categorically discount solid-state bulk diffusion as a mechanism for significant dispersal of radioactivity through the bedded salt formation, although some possibility exists for

enhanced transport by the bulk diffusion process in those areas in which significant irradiation of the salt occurs. If the possibility of introducing radiation-induced space charges within the sodium chloride is regarded as unimportant in its effect on solid-state diffusion, it then appears most unlikely that any of the radioactive species of interest, particularly plutonium, can traverse the solid significantly more rapidly than sodium ions themselves. Along this line of reasoning, measurements of sodium self-diffusion in salt indicate that migration via solid-state diffusion would disperse the radioactive waste species to distances less than one meter over a million-year period under the anticipated temperature conditions of the Repository.

Grain boundary transport can be regarded as a special type of migration along free surfaces, and for this reason studies of diffusion along grain boundaries have been bypassed in favor of surface diffusion investigations, particularly since neither transport mechanism has received much attention previously, and the latter appears to be more readily studied. The work performed thus far in this regard, though not definitive, nonetheless suggests the two transport mechanisms to be inconsequential with respect to isotope migration. Specifically, the measurements made to date of the surface diffusion of lanthanum oxide (which is being used to simulate the behavior of plutonium dioxide) on salt surfaces result in an estimate of radioactive waste migration amounting to less than ten meters over a million-year period.

10.2.3 Stored Energy

Radiation damage in solids is comprised of displaced atoms and other lattice disorder. Some or all of the energy associated with this disorder is released when the solid is heated to sufficiently high temperatures subsequent to irradiation. In some cases, all of the energy can be released with a relatively low initiating temperature. In these cases, the initial energy release heats the solid sufficiently to trigger additional energy releases at successively higher transition temperatures.

It is important to know the possible effects of annealing of the radiation damage which may accumulate in the materials which will be in

the radiation thermal environments of the waste cans. The materials in question are glasses or ceramics which contain the radioactive wastes, and the rocksalt which is adjacent to the waste can; the metal containers will store negligible amounts of radiation energy.

Experimental and theoretical information is available from which rough estimates can be made of the maximum densities of stored energy in the Repository materials and of the effects of time and temperature on annealing of the stored energy. Also, we have an estimate of the thermal and mechanical effects on the Repository of instantaneous release of 200 cal per g from the wastes within a burial can and the simultaneous release of 20 cal per g from the salt lying within a radius of 1.1 ft from the center of the can.

Saturation Concentration of Radiation Damage in NaCl. - The temperature of the Repository-salt will range between 20 and 350°C, depending on its proximity to the waste and the thermal power of the source.¹ The maximum accumulated gamma ray dose in salt will range from 2×10^{11} rads adjacent to the wastes to about 82 rads at a distance of 5 ft. The dose rates will range downward from about 5×10^5 rad/hr.²

The radionuclides within the wastes will include uranium and transuranic elements so that the solidified wastes will be irradiated by alpha, beta, and gamma radiations. In the event of leakage from the can and penetration into the salt, some alpha and beta radiations will be absorbed in the salt.

Nuclear radiations produce damage in NaCl (as well as in other ionic polar crystals) primarily through ionization effects which lead to ejection of anions out of their lattice positions and into interstitial positions. Clustering of anion vacancies takes place and, under some conditions, some or all of the clusters are in the form of colloidal sodium. Colloid-formation is generally promoted by increasing the temperature although the concentration of anion vacancies which is in equilibrium with colloidal sodium increases with increasing temperature.³⁻⁸ Also, plastic deformation of the salt, and the presence of OH⁻

within the crystal, favor colloid formation.⁹ The interstitial chlorine may also form clusters at high concentrations of damage, but there is no information regarding this.

Particulate radiations such as alphas, neutrons, and protons which can transfer appreciable energy to lattice ions through elastic collisions can cause displacement of cations as well as of anions. Energetic electrons can also cause displacement of ions through elastic collision, but with very low efficiency. Generally, the damage in NaCl which results from the ionization effects of one of these particles far outweighs that resulting from transfer of energy through elastic collision.

Annealing of radiation damage in crystals results from thermal processes which proceed in the absence or presence of radiation (thermal annealing) and from processes which take place only during irradiation (radiation annealing). Theorists have predicted that radiation annealing will limit the damage in crystalline solids to a few percent (1 to 5%) of the number of atoms in the solid. The stored energy associated with a displaced atom in NaCl is in the range of 4 to 6 ev; 1% damage in NaCl corresponds to 22 cal/g at 5.5 ev per displaced atom.

Thermal annealing of the colloidal-sodium defects in NaCl becomes appreciable at temperatures above about 160°C.^{4,10} Thermal annealing of anion vacancies and of clusters of a few anion vacancies takes place at somewhat lower temperatures.^{11,12}

Tabulated in Table 10.2 are some reported experimental data which bear on the concentration of damage in NaCl at high doses. These data suggest that radiation annealing will limit the energy storage to about 22 cal/g or less with both β , γ , and α rays (although there will be negligible numbers of protons in the Repository, it is interesting to note that the above limit appears to apply to protons also). The effects of dose rates at high doses are not delineated by these data, and additional experimental information is required, especially with γ -rays, on energy storage at the low dose rates which will prevail in the Repository.¹⁰

Table 10.2 Experimental Information on Concentration of Radiation Damage in NaCl in High Doses

Sample form and Number of Samples	Radiation	Exposure Temperature (°C)	Average Dose Rate (M Rads/hr)	Total Dose (10 ⁹ Rad)	Stored Energy (cal/g)	Defect conc. (μ mole/g)	Reference	Remarks
Rock salt (5)	electron	210 ± 10	>1000	20 to 75	2.2 to 7.5	17 to 59 ^a	Sonder and Lindenbaum ^{2,10}	c
Rock salt (1)	electron	250 ± 150	>1000	100	14	110 ^a	Sonder and Lindenbaum ^{2,10}	—
Synthetic crystal (7)	electron	40 to 80	2000 to 7000	4 to 6	1.1 to 1.6	8.7 to 1.3 ^a	Sonder and Lindenbaum ^{2,10}	c
Rock salt (1)	gamma	160	0.1	0.70	6	46 ^a	Zeller et al. ^{10,13}	d
Rock salt (?)	gamma	160	0.1	0.70	0 ± 0.2	—	Sonder and Lindenbaum ^{2,10}	e
Rock salt (2)	gamma	180	0.08	0.60	1.2 and 1.6	10.5 ^a	Mastroianni and Bopp ¹⁰	f
Reagent (?)	gamma	250	1	0.3	—	<0.1	Kubota ¹⁰	—
Synthetic crystal (?)	0.3 mev H ⁺	room	greater than about 1000	from about 1 to >6	3.0 ^b	25	Pooley ¹⁵	g
Synthetic crystal (2)	350 mev H ⁺	room	—	1.4	2.3	16 ^a	Kobayashi ¹¹	h
Synthetic crystal (?)	1 mev H ⁺	room	40,000	120	19.6	150 ^a	Dreschoff ¹⁴	i
Crystal (?)	5 mev α from Po	room	—	2.0	1 ^b	8	Prizbram ¹⁶	j
Synthetic crystal (?)	1.5 mev α	room	300,000	900	24	180 ^a	Dreschoff ¹⁴	j

a. Calculated from stored energy using 5.5 ev per displaced atom.

b. Calculated from concentration of displaced atoms using 5.5 ev per displaced atom.

c. The data indicated that a saturation concentration of defects was reached.

d. Scraping from hole 4, Project Salt Vault (at 11 ft). Darkest crystals selected for measurement.

e. Scraping from hole 4 (11 ft) of Project Salt Vault. Average sample of salt selected for measurement.

f. Sample from hole 6 of Project Salt Vault. Average sample of salt selected for measurement.

g. Protons stopped within sample. Pooley concluded that the concentration of displaced atoms was at saturation.

h. Protons passed through 0.4-cm samples.

i. Protons stopped within sample.

j. Alpha particles stopped within sample.

There is an indication in these data that thermal annealing at temperatures above about 160°C will limit the stored energy in the Repository salt to a few cal/g.¹⁰

Saturation Concentration of Radiation Damage in the Radioactive

Wastes. - The radionuclides within the wastes will include uranium and transuranic elements so that the waste boule will absorb both alpha, beta and gamma radiations. The correspondence between alpha activity and total decay heat in 6-in.-diam waste cans is such that wastes which give rise to 5 kW of thermal power after aging 10 years will have 0.68, 0.34, 0.23, 0.19 and 0.14 Ci of alpha per cm³ at 1, 2, 5, 10 and 20 years after reprocessing. These values correspond to 10^{18} , 1.5×10^{18} , 2.5×10^{18} , 4×10^{18} , and 6×10^{18} α disintegrations per cm³, respectively. They also correspond, respectively, to about 3×10^{-5} , 5×10^{-5} , 8×10^{-5} , 1×10^{-4} and 2×10^{-4} α disintegrations per atom of waste. The total decay heat of the 5 kW of 10-year-old wastes will decrease by a factor of seven during the period between 1 and 10 years after reprocessing.¹⁷

It is expected that storage of energy in the calcined oxides will result only from displacements caused by elastic collision of α rays (including, importantly, the recoiling nucleus which is formed by the α disintegration) and, to a lesser extent, energetic electrons. Ionization effects are expected to be of little importance.¹⁸ The same probably is true for the glassy solids. However, there is some uncertainty as to whether ionization can also effect substantial amounts of damage in glasses.¹⁹

Temperature ranges of the wastes within their cans are given in Table 10.3. Available information bearing on the probable amounts of stored energy in the wastes can be summarized as follows.

1. Roux²⁰ and others have shown that storage of energy in sintered polycrystalline MgO and Al₂O₃, and in fused silica glass under reactor radiations (fast neutrons) at temperatures < 100°C but > 25°C reaches

Table 10.3 Ranges of Waste Temperature Within a Can

Location	Temperature of Wastes (°C)	
	During aging with water cooling	Maximum after burial
Contact with inner surface of can.	~40	up to 350
Not in contact with inner surface of can.	up to permissible maximum of 650 to 900.	up to permissible maximum of 650 to 900.

saturation at < 50 cal/g. The behavior of sintered polycrystalline BeO was different from that of Al_2O_3 and MgO. There was no evidence that saturation was reached up to 80 cal/g (at 4×10^{20} nvt > 1 mev).²¹ However, the number of Be atoms per gram of BeO is nearly twice that of Al in Al_2O_3 and of Mg in MgO, and at 10 ev per Frenkel pair, 80 cal/g corresponds to slightly less than 1% displacement of beryllium ions. Accordingly, it is possible that the stored energy in BeO would saturate at slightly more than 80 cal/g. Also, Heuer and Stolarski²¹ concluded from their observations on BeO made at a heating rate of 4°C/min that the energy is released over a temperature range of at least 600°C and that the rate of release would be below that required to cause spontaneous temperature rises when the total amounts of stored energy range up to 135 cal/g (we infer by extrapolation that this would be true also for up to 225 cal/g in BeO).

The few data which pertain to effects of higher irradiation temperatures indicate that lower rates of damage-formation will obtain at elevated temperatures. For example, Roux²⁰ found 21 and 10 cal/g in fused silica glass at irradiation temperature of 220 and 500°C, respectively, and at 6×10^{19} nvt > 1 mev. At 60°C the stored energy was at saturation (42 cal/g) at this dose. Also for example, Barner²² found roughly 20 cal/g in BeO irradiated with neutrons (4×10^{20} nvt > 1 mev) at 375°C to 500°C. For comparison, Heuer et al.,²¹ found 80 cal/g for BeO irradiated to the same dose at 75 to 100°C. There is no information on the effects of temperature on the amounts of damage at saturation.

2. Bopp and coworkers^{23,24} measured the stored energy produced by reactor radiations in Steatite 228 ($\text{MgO} \cdot \text{SiO}_2$), Cordierite 202 ($2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2$), Forsterite 243 ($2\text{MgO} \cdot \text{SiO}_2$), and Lava A (natural aluminum silicate of indefinite composition). Heating at a rate of 3°C/min caused annealing and release of energy above threshold temperatures of 830 to 990°C. The reaction peaks were 50 to 150°C in width. The amounts of heat released ranged from 30 cal/g with Forsterite to 60 cal/g with Steatite. X-rays showed that the materials were about 50% amorphous.²⁵ Completely amorphous Zircon (fission recoil irradiation) released up to 30 to 50 cal/g at temperatures comparable to those mentioned above.
3. Certain natural minerals have suffered substantial amounts of radiation damage due to α disintegration of the uranium or thorium included in the minerals. The damage apparently reaches saturation when the minerals are in an amorphous state as indicated by the absence of optical birefringence and by little or no trace of coherent X-ray diffraction. This

mineralogic state is generally referred to as the metamict state.²⁶⁻²⁸ A list of some metamict minerals reported by B. Lustman²⁸ is given in Table 10.4.

Generally, metamict minerals anneal with release of heat at elevated temperatures. Some of the metamict minerals heat spontaneously to incandescence after reaching a certain temperature during rapid heating from room temperature. However, the minerals can be annealed with prolonged exposure to lower temperatures without encountering spontaneous heating.²⁶

In summary, the available data indicate that for irradiation temperatures less than about 100°C, the stored energy in the wastes at saturation will be in the range of 30 to 200 cal/g. We assume that the stored energy will not exceed 200 cal/g on the bases: (1) that the stored energies for the two metamict minerals which have been determined, Zircon and Gadolinite, are less than this; (2) Bopp's work with partially amorphous minerals indicated less than 200 cal/g for the fully amorphous materials; and (3) theory and experiment indicate that the saturation concentration of interstitial atoms is 1% or so corresponding to about 50 to 100 cal/g of stored energy. The time to reach saturation is uncertain. Probably the time would be < 10 years after reprocessing for a waste can having 5 kW of decay heat at 10 years after reprocessing.

This rate of formation of stored energy at the high temperatures which will prevail after burial probably will be below those indicated for irradiation temperatures of < 100°C. However, there is no information on the amounts of stored energy at saturation at irradiation temperatures greater than 100°C but less

Table 10.4 Metamict Minerals (After Lustman²⁸)

Mineral	General Composition	Normal crystal structure	Remarks
Allanite	$R_2^{2+} R_3^{3+} (OH) Si_3 O_{12}$	Monoclinic	Becomes metamict at about 6×10^{-4} α /atom.
Fergusonite (Yttrotantalite) (Polymignite).	$Y(Cb, Ta) O_4$	Tetragonal	Becomes metamict at about 2×10^{-3} α /atom; releases heat at 600° to 700°C on heating metamict crystal, and polycrystalline crystal structure reconstituted.
Brannerite	$R_3^{4+} Ti_5 O_{16}$	Tetragonal	
Thorite	$ThSiO_4$	Tetragonal	Becomes metamict at 0.13 α /atom. Monoclinic $ThSiO_4$ (Huttonite) is not metamict. Annealing of metamict thorite begins at about 600°C, forming tetragonal $ThSiO_4$ and ThO_2 ; at temperatures above 935°C, monoclinic $ThSiO_4$ forms.
Gadolinite	$Y_2 Fe^{2+} Be_2 Si_2 O_{10}$	Monoclinic	Evolves 81 to 89 cal/g on heating; polycrystalline X-ray pattern produced after heating at 950°C.
Ellsworthite	$CaO \cdot Cb_2 O_5 \cdot 2H_2O$	Cubic	Exothermic peaks at 980°C and above.
Euxenite	$(Y, Ca)(Cb, Ta, Ti)_2 O_6$	Orthorhombic	Exothermic peaks at 600° to 650°C.
Samarskite	$Y(Cb, Ta)_2 O_6$		
Eschynite	$Ce(Cb, Ti)_2 O_6$		
Zircon	$ZrSiO_4$	Tetragonal	Becomes metamict at 3×10^{-4} α /atom; partly metamict crystals form single crystals on heating; fully amorphous zircon forms ZrO_2 and, at higher temperatures, polycrystalline $ZrSiO_4$.

than those at which rapid annealing occurs. Presumably, the amounts at saturation will not exceed the 200 cal/g maximum expected at $< 100^{\circ}\text{C}$.

It appears likely that high temperatures ($> 600^{\circ}\text{C}$) will be required to produce rapid annealing of damage which may be formed within the wastes. Lower temperatures will produce thermal annealing at low rates.

Rates of Release of Stored Energy and Effects of Release on Repository. - The effects on the Repository of release of stored energy from the wastes and/or from salt will depend upon (1) the amount of energy which is released within a given temperature interval and (2) the rate of release of the given amount within the temperature interval. For example, if the amount of energy released in the temperature interval ($\text{cal}, \text{g}^{-1}, \text{deg}^{-1}\text{C}$) is less than the specific heat of the radiation-damaged material, there will be no spontaneous temperature rise of the material. Also, if the release of energy within the interval is not instantaneous, heat will be lost to the surroundings and the temperature rise will be below that for instantaneous release. As mentioned above, Heuer et al.,²⁰ concluded that the amount of stored energy released from BeO within a given temperature interval is insufficient to trigger additional release at a higher temperature when the total stored energy is $< 135 \text{ cal/g}$.

In general, it appears likely that, starting with a negligible amount of stored energy in the wastes at burial, the rates of temperature rise within the wastes or salt will never be sufficient to trigger rapid release of stored energy. That is, at the low rates of temperature rise which prevail with no release of stored energy, the stored energy which is accumulated at one temperature would be annealed slowly at some higher temperature which is below that required for very rapid release of the stored energy. Note that it may

be necessary to require that the wastes be annealed prior to burial in order to assure that no rapid release occurs during the shipment and burial operations.

In the unlikely event that large amounts of stored energy are released instantaneously and simultaneously from the buried wastes and surrounding salt, our estimates indicate no serious mechanical or thermal effects.¹ Assuming 200 cal/g in the wastes and 20 cal/g in the salt lying within a radius of 1.1 ft from the center of the can, the maximum amount of mechanical energy generated would be conservatively less than 1 lb of TNT. This amount of energy release is well within the limits of tolerance. The thermal effects of the release of stored energy was to cause no melting of the salt and a temperature rise of < 2°F at the midpoint between adjacent cans (13.5 ft from the center of the can). Thus, adjacent cans would not be affected. Maximum temperatures of the wastes after energy release were in the range, 2500 to 3000°F, but declined after one day to approximately the temperatures prevailing before the energy release. These transient temperatures in the wastes were considered acceptable. As mentioned above, we expect that the maximum energy storage in the wastes will be < 200 cal/g and that in salt will be < 20 cal/g. The maximum values under Repository conditions remain to be established.

10.3 Geophysical Impact

10.3.1 Stress-Structural Analysis of Excavation

The geophysical impact upon the facilities can be minimized by proper design, and the intent of the design in any underground excavation is to minimize stress buildup in the rock around the openings. To develop the design concepts for the Repository, reliance will be placed upon the accepted mine design standards, USBM Safety Codes, past experience since 1890 at the existing Lyons Mine, Project Salt Vault (PSV) experience, and most importantly, a thorough rock mechanics analysis of the final mine design, layout, and various alternatives.

Shafts. - Experience with the existing mine shafts indicates that the site has a very stable geological environment for shaft construction. This shaft was constructed in 1890, is rectangular in cross section, and is of cribbed-timber construction. The shaft is now 80 years old but in good condition in spite of the fact that many of the original timbers are in place.

The new shafts which are required for the Repository will be of circular cross section, a better shape for controlling stresses. In addition, they will be concrete-lined, and this reinforced concrete lining will effectively seal the various formations against air and water slacking and provide adequate structural strength. To protect the costly surface facilities which are to be installed, a shaft pillar is specified into which only essential access entries to the shaft are to be excavated, thus minimizing the possibility of subsidence. The existing Carey mine shaft does not have a classical shaft pillar; however, the percent of extraction around the shaft was limited to 40%. This acted as a partial shaft pillar, and only a minor amount of subsidence has occurred at the shaft bottom, as is evidenced by the partial failure of the shaft bottom timbers. A classic example of a sizable shaft pillar is represented by the Hutchinson mine of The Carey Salt Company where the shaft pillar excavation is less than 20% and the pillar has a diameter equal to the shaft depth. The Hutchinson shaft was constructed in 1923, and no evidence of subsidence is apparent.

Current design practice is to use a shaft pillar diameter somewhat less than the shaft depth. This conservative approach will be used in specifying the shaft pillars to provide long life and isolate the shafts from the high-level storage operations. The high-level storage operations will ultimately introduce much heat into the formations; thus a generous shaft pillar will provide a thermal barrier between the storage operations and the shafts.

Tunnels. - The existence of the Lyons Mine will be a great asset in designing future openings. The shape of the new horizontal openings will be rectangular, as this shape has been shown to be the most stable in this geological environment. The size of the openings will be determined by safe mining procedures and the equipment which will be used in the storage operation.

Past experience gained in PSV will be very valuable in establishing the maximum width of openings. Conceptual engineering studies have indicated that the tunnels or entries should be 30 ft wide to pass equipment and provide adequate clearance. The height will be a minimum of 16 ft to allow sufficient clearance for the high-level transporter. As the tunnels will be smaller than the PSV openings, it can be concluded that they will be stable since they will not be subjected to the thermal stress conditions (both heating and cooling) imposed during PSV.

Since the tunnels and entries will be used for up to 25 years and the mine master plan is a single-entry system, the use of rock bolts installed on the same pattern developed during Project Salt Vault may be indicated in the main entries, depending on the character of the immediate roof. This will provide extra insurance that roof problems will not interrupt the flow of material to and from the mining and storage areas during operations.

Rooms. - The exact configuration of the underground disposal areas, especially the widths of the disposal room and intervening pillars, has not yet been finalized. These dimensions will be determined during a thorough rock mechanics analysis of various alternative designs and the dimensions may vary from place-to-place; for example, near the boundaries of the repository area. Factors which will be considered in the analysis and the selection of room and pillar widths include:

1. Optimum thermal utilization of the mine space.
2. If other factors do not control, the overall extraction ratio will be limited to 50%. All other Kansas

salt mines operate satisfactorily with extraction ratios of 60 to 80%, and this limitation will guarantee that no major closure problems will be encountered.

3. In order to take maximum advantage of the plastic nature of the salt for permanently and totally isolating the wastes, it is desired to permit the backfilled mine excavations to completely close as soon as possible. Other considerations (see below) suggest that the earliest practical time will be approximately 100 years.
4. The total deformations and strain rates in overlying shales should be minimized. These deformations will result from both the mine closure and thermal expansion.
5. Since an individual disposal soon may have an operational lifetime of several months, its stability (without artificial supports) during that period will be provided for. Among other things, this limits the maximum room width to 50 ft based on experience from operational mines in Kansas and data from the PSV experiment.

10.3.2 Convergence, Thermal Expansion, and Subsidence

In the high-level waste disposal area, the sizes of the disposal rooms and the support pillars between them will be designed in such a way that, in time, the underground openings will completely close, causing a consolidation and recrystallization of the crushed salt used to backfill the rooms. The pillar deformation necessary to effect this closure results from the overburden load and will occur much more rapidly (65 to 100 years) because of the elevated temperatures than is ordinarily the case. At a distance of perhaps 10 to 20 ft from the walls and ceiling, fracturing, bed separation, localized crushing, and other extreme effects will take place as a result of this deformation. At distances greater than about 20 ft, plastic deformation of the salt will accommodate the

imposed motions without any of these effects. As the mine closes, inducing a net decrease in the volume of the geologic system, the rocks begin to become heated from the radioactive decay with the resulting thermal expansion representing a net increase in the total volume. Preliminary calculations of the rates of these two processes indicate that they almost exactly cancel each other at all locations in the system, including the surface, except in and immediately around the rooms and entries. This means that the overlying protective rocks (and the surface) will be subjected to only very small deformations and motions for approximately the first 200 years following waste burial. The rates of these deformations and motions will be only slightly greater than those resulting from normal salt mining operations. Beginning about 200 years after waste burial, the heat loss at the surface will exceed the heat input from the waste, and the rocks will begin to contract; that is, begin a recovery of the previous thermal expansion. This process will be very slow, requiring several thousand years to complete, and will eventually result in the development of a very broad, flat, and shallow (about 3-1/2 ft) subsidence basin over the area. The rate of development of this basin will be so slow and gradual that the shale rocks overlying the salt formation can easily accommodate it without even approaching conditions leading to fracturing or other adverse effect. Likewise, the surface and shallow aquifers will easily adjust to these motions which are only slightly greater than the current rate of surface erosion in the area. It also should be pointed out that the rate of this subsidence over the waste disposal area will be approximately the same as the rate of subsidence over an equally-sized producing salt mine; furthermore, the total amount of subsidence will be approximately half that expected in operating mines because of the backfilled rooms.

Current best estimates of the chronology of the various thermal effects are presented in Figure 10.5 and Table 10.5.

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Fig. 10.5. The Effect of Time Since Commissioning on the Projected Total Thermal Power, Surface Rise Due to Thermal Expansion, Surface Fall Due to Subsidence, and Temperatures Within the Formation.

Table 10.5 Chronology of Thermal Effects in the Repository

Years	Effect
25	Decommissioning. Power peaks at 95 MW.
30	400°F peak temperature rise at 8 in. from waste cans. 10 liters total brine inflow per waste can.
100	95% closure of voids by subsidence. 0.9-ft increase in typical surface level.
150	110°F peak temperature rise at 750-ft depth.
200	5.2-ft peak in net thermal expansion. 1.3-ft peak in typical surface level.
500	60°F peak temperature rise at 500-ft depth.
700	20°F peak temperature rise at 200-ft depth. 0.1°F peak temperature rise of surface.
3,000	1°F peak temperature rise at 1700 ft from edge of mine at 1000-ft depth.
~15,000	Total ~4 ft subsidence essentially complete. All temperatures within 5°F of initial condition.

10.3.3 Analysis of Abnormal Events

Tectonics and Seismicity. - Central Kansas, which includes the Lyons site, is located within the "stable interior," a region where earthquakes occur rather infrequently. Furthermore, the area has not been subjected to intense deformation in the geologic past, but prominent structural basins and arches were developed slowly and apparently without intense earthquake activity. Figure 4-8 shows the location of historic earthquakes

and their relationships to the major structural features in Kansas. Note the almost complete absence of earthquakes along the central Kansas uplift, which is the nearest structural feature to the site. The earthquakes that have occurred in the central Kansas area (the nearest one was centered some 40 miles east of the proposed Repository) range up to a modified-Mercalli Intensity Scale rating of VI (damage small). These shocks, as well as others in Kansas, have occurred at rather shallow depths (16 to 38 miles) and probably represent minor adjustments in the underlying granitic crustal rocks.²⁹ Epicentral locations of many of the earthquakes, including the two most damaging, were centered along the Nemaha anticline in eastern Kansas. This apparent correlation of earthquakes and structure indicate that the structure is probably still tectonically active and minor adjustments are occurring in the deep-seated rocks beneath it. Based on the recent seismic history of all of the other structures in Kansas, it is likely that they are tectonically inactive.

Figure 10.6 is the most recent seismic risk map of the United States published by ESSA and the Coast and Geodetic Survey. As seen, the site lies within zone 1 (expected minor damage), and the area of the seismically active Nemaha anticline east of the site is designated as zone 2 (expected moderate damage). The areas of expected major damage (zone 3) in the United States are associated with major active fault zones or have experienced great historic earthquakes; these areas are hundreds of miles distant from the site.

Fig. 10.6. Seismic Risk Map for Conterminous U.S., Developed by ESSA/Coast and Geodetic Survey and Issued in January 1969. Subject to revision as continuing research warrants, it is an updated edition of the map first published in 1948 and revised in 1951. The map divides the U.S. into four zones: Zone 0, areas with no reasonable expectancy of earthquake damage; Zone 1, expected minor damage; Zone 2, expected moderate damage; and Zone 3, where major destructive earthquakes may occur.

Subsurface Leaching of Rock Salt Deposits. - As seen in Figure 4.12, the Hutchinson salt member of the Wellington formation underlies south-central Kansas and extends southward into Oklahoma. Toward the southeast, west, north, and northeast, there is a gradual thinning of the salt bed which undoubtedly represents the original limits of salt deposition; however, along the eastern boundary of the deposit from Saline County to northwestern Sumner County (Fig. 10.7), the salt deposit ends abruptly and a series of subsidence ponds and salt water springs overlying the present stratigraphic position of the salt member suggests that the original limits of the salt deposit extended somewhat further east. In northwest Saline County precise dating of subsidence features indicates that the salt front has retreated a distance of 5 miles or less in the last 1 million years (or throughout the Pleistocene), while in McPherson and Harvey counties westward migration of the salt has been 13 and 12 miles, respectively, from Delmore (Pliocene) to Kansas (a time span of about 5 million years).³⁰ According to Fent, the natural leaching of the salt body by circulating groundwater depends on the development of secondary permeability in the overlying shales which, in turn, is brought about by erosion when the protective Cretaceous shales and clays are removed.³⁰ In areas where the overlying shale section is complete, which includes the Lyons site and essentially all of the central Kansas salt area west of the eastern boundary of Rice County, it may be considered to be protected for geologic time periods of at least 1 million years or for about the time span of the Pleistocene.³⁰

In addition to the series of salt water springs along the eastern limit of the Hutchinson salt member, brine flows have been observed in Barton and Stafford counties; however, in these counties it has been established that the brine is issuing from Cretaceous sandstones that lie stratigraphically well above the Hutchinson.³⁰

Several sinkholes and depressions in central Kansas have been ascribed to subsurface solution within the underlying salt beds; however, in the case of some that have been studied intensively, it has been shown that other geologic processes have caused

EXPLANATION

— INFORMATION BASED ON ELECTRIC LOGS
 - - - INFORMATION BASED ON CABLE TOOL LOGS, DISTANT LOGS, OR LOGS REVEALING
 THE PRESENCE OF SALT BUT IN WHICH THICKNESS DATA ARE NOT RELIABLE

X KNOWN CASES OF SALT DISSOLUTIONING
 AND SURFACE SUBSIDENCE

Fig. 10.7. Map of Central Kansas Showing the Extent and Thickness of the Hutchinson Salt and the Locations of Solution Subsidence Features (after Kulstad, R. O., "Thickness and Salt Percentage of the Hutchinson Salt," Symposium on Geophysics in Kansas, Kansas Geological Survey Bulletin 137, 1959.

them. For instance, the Cheyenne Bottoms located in northern Barton County was once thought to be due to solution of the underlying Hutchinson salt followed by collapse of the overlying rocks. Later test drilling within the area, however, has demonstrated that this large undrained depression is simply a buried Pleistocene valley.

Salt Flow. - In general all salt deposits buried to any appreciable depth in the geologic past show some deformation. The extent of deformation varies greatly, ranging from slight post-depositional thickening and thinning, such as may have been the case in the central Kansas deposits, to the forming of salt domes from deep-lying "mother" salt beds, as in the Gulf Coast Embayment. Salt beds, like other rocks, will deform by folding and even by faulting where subjected to lateral or vertical tectonic forces. Unlike other rocks, however, salt flows plastically under relatively low temperatures and pressures; thus, salt is commonly squeezed from the limbs of folds into the structurally higher apices of anticlines when subjected to compressional forces. It is unlikely that tectonically-induced folding or faulting of the central Kansas salt deposits, including those underlying the Repository site, will occur since the major structures in the area are presently inactive and the geologic past of the area is one of tectonic stability.

It seems clear that tectonic forces alone would not have been sufficient for the formation of the salt domes in the Gulf Coast Embayment. Rather, the forces responsible for these structures are largely gravitational in nature. The static weight of several miles of heavy sediments on the bedded salt is considered adequate to cause it to flow upward. The salt can only rise when the force applied by it exceeds the shear strength of the overburden; thus the physical properties of the overburden are also important in the process. In view of the large volumes of salt present in individual domes within the Gulf Coastal Region and the limited extension of the source area from which the salt was derived, it is clear that this process requires a thick "mother" bed. In the Gulf Coast area

the "mother" bed is probably at least several thousand feet in thickness. The rate of growth of salt domes and other diapiric structures is not accurately known, but there is good evidence that growth is generally slow and occurs unevenly and whenever conditions are appropriate.

Considering the conditions under which salt domes have been formed in the Gulf Coastal area, it seems clear that the rock salt in central Kansas, including the Lyons site, is much too shallow and too thin to deform in a similar fashion. In addition, the cover rock is competent and relatively free from faults and other zones of weakness through which the salt could move. Certainly, the increase in temperature of the salt due to decay heat generated in the waste will increase the plasticity of the salt within the confines of the Repository, but the limited area affected and the geologically short heating period (a few thousand years) will almost certainly limit the ensuing deformations to the mined openings.

Solutioning of Salt Around Boreholes. - Within the immediate vicinity of the proposed Repository site, a total of 30 oil and gas borings are known to penetrate the rock salt beds. Moreover, in central Kansas literally hundreds to thousands of wells have been made through the salt in search of oil and gas. With this large number of borings, it is not surprising that in a few cases, solutioning of the salt has occurred where the wells have been improperly plugged or sealed or the casing has deteriorated. To date, four cases of salt dissolution and subsequent surface subsidence have been reported in the central Kansas area. As seen in Fig. 10.7, these features are north and west of the Repository site. The most extensively investigated one is located in Russell County some 55 miles northwest of Lyons. This sink includes a portion of U. S. Interstate Highway 70 and was consequently investigated by the Kansas State Highway Department. According to their report the land surface has subsided at the rate of about 0.7 ft per year, and since 1954

when the depression originated, it has developed into a cavity spreading over an area of some 700 to 800 ft in diameter with a maximum depth of about 20 ft.³⁰ Exploratory drill holes into the sinkhole have revealed that extensive solutioning has occurred in the upper part of the salt bed with the subsequent collapse of the overlying Permian and Cretaceous age beds. Apparently the sinkhole developed around a single oil well that was first completed in 1936 and later converted to a salt water disposal well. Records of the hole indicate casing deterioration in the salt zone and solutioning before abandonment. The prolific waterbearing Cretaceous sandstone above the salt and the highly permeable production and/or disposal beds below the salt are the principal geohydrologic parameters governing solutioning at the well. In 1957 a second sinkhole developed about 1/2 mile west of the aforementioned one. It, too, progressed from solutioning of the salt around an abandoned oil well which was reported to have casing deterioration in the salt zone. In both cases, a freshwater aquifer exists above the salt and a dispersal aquifer below the salt at the well site.

The sinkhole in Barton County and the one in Rice County about 9 miles west of the Repository site are both associated with solutioning in the salt around previously producing oil wells that were later converted to brine disposal wells and then abandoned. As is the case for all of these features, the borings serve as a conduit for the overlying freshwaters to migrate downward where they contact the soluble rock salt; the resulting brine then migrates to a deeper permeable zone below the salt.

The first question raised by this borehole dissolution phenomena concerns the location of existing holes on and adjacent to the site. We have been assured by our consultants that because of the history of oil and gas exploration in the area, all existing holes penetrating the salt formation will be a matter of record: either formally in the State Corporation Commissions' files or adequately in newspaper accounts and other histories. If there is any indication that all of the holes have not been found by

this historical search, it is possible to survey the area using aerial remote sensing technique (magnetic, infrared photography, etc.) as a check of any questionable features.

All of existing holes on and within one mile of the site will be reentered, cleaned out and replugged. A development program is currently in progress to generate the required information on suitable plugging materials and procedures. Effort at the present time is directed toward a review of the state-of-the-art, especially the tapping of unpublished information and expertise in the U. S. Bureau of Mines, U. S. Bureau of Reclamation, Halliburton Company, and others. It is anticipated that this review will lead to a compilation of potentially suitable materials to meet specific requirements which will then be further narrowed by a limited amount of laboratory testing.

The immediate objective of this program is to select a suite of the most promising plugging materials and conduct a field demonstration and test in a borehole near, but not necessarily on, the proposed site. Based upon the analysis and evaluation of that test, and perhaps subsequent ones, specific designs for plugging the holes at the site will be developed. These plugs will probably consist of layers of expanding, sulfate resistant cements interspersed with layers of clays and/or gels.

Erosion and Denudation. - Since a portion of the radioactive wastes to be stored at the proposed Repository will remain active for periods of hundreds of thousands of years, estimates

are being made of the expected erosion by stream action and glaciation at the site and its effect on the stability of the underlying salt formation for long periods of geologic time. The present rate of denudation for the Arkansas River basin, which includes the Lyons site, has been determined to be about 1.4 in./1000 years.³¹ This value, which is a measure only of the uniform lowering of the land surface within the entire basin, suggests that at the current denudation rate, perhaps a hundred feet or so of rock cover would be removed from the salt formation at the site during the effective lifetime of the waste. Another estimate of the expected erosion can be made from measured stream incisions in the bedrock in the vicinity of the site during the Pleistocene epoch or the last 1 million years of geologic time. With a recorded measuring channel incision depth of 200 ft and a projected incision having a similar depth during the next 1 million years of geologic time, it can be concluded that a 200-ft-deep channel could be cut into the present unincised bedrock at the site or an additional 200 ft deepening of the present gravel-filled channels in the immediate vicinity of the site could occur. In either case the salt formation would not be breached as it lies some 800 ft below the present land surface.

To determine more precisely the nature and extent of erosion in the area of central Kansas during the next 1 million years, a study has been initiated whereby estimates of future erosion will be arrived at by statistical treatment and extrapolation of modern rates of erosion in several climatic zones that would be representative of the kinds of climate that have existed in the midcontinent during the last 1 million years and would be expected to prevail during the next 1 million years.

10.4 Ecological Impact

Isolation of radioactive wastes in a salt formation assuredly removes hazardous materials from the biosphere. The secure integrity and projected infinitesimally small risks notwithstanding, effects on ecology or human health and safety could accrue either from an accumulation of low-intensity chronic actions or from direct acute impacts resulting from an accident.

Rational judgment concerning real or alleged ecological impacts is possible, provided a well-designed data acquisition program parallels facility development and operation. The 1970 ecology surveys only indeterminately allude to possible effects, and additional research on ecological processes is essential to improve our understanding of radionuclide movement in the Lyons vicinity. In spite of voids in the data base, information from the surveys and literature sources has allowed us to describe, at least partially, the behavior of ^{90}Sr , which could conceivably have long-term effects on man and his ecosystem. Similarly, the energy balance for grassland and heat flux for soil were evaluated from calculations based on average data from records maintained by the Agriculture Experiment Station.

10.4.1 Ecosystem Character

Reversion from a cultivated state to a native condition would greatly increase the number and diversity of species. Over 1000 taxa of a prospective grassland community (Table 10.6) would fill nearly all niches, and the resulting distribution of many species among producer-consumer-decomposer trophic levels would contribute to a balanced and stable ecosystem. Such a taxonomic and trophic mixture also would ensure ecological diversity of the ecosystem. A native community would enhance long-term aesthetic and recreational benefits, and, more importantly, would provide a frame of reference for examining long-term environmental effects of Repository operations in perpetuity.

10.4.2 Radioecological Processes

An infinite number of pathways would exist for radionuclide movement in an ecosystem containing more than 1000 interacting species. Such a situation is obviously too complex to evaluate in detail; alternatively, however, the potential hazard to humans and other organisms can be identified from most probable pathways of radionuclide movement through ecosystems and ultimately to man (Figure 10.8). Trophic level concentration factors³² will also be useful guidelines for initial identification of potential radioecological problems. Following initial deposition, most radionuclides are dispersed in terrestrial environments, but some are

Table 10.6. Expected Minimum Numbers of Plants
and Animals at Repository Site

Organism	Taxonomic Level	Number of Taxa
Higher plants (woody, grass, forbs)	Species	90+
Lower plants (bacteria, actinomycetes, fungi)	Genus	14+
Mammals (wild, domestic)	Species	52
Birds (summer, winter, transient)	Species	229
Reptiles and Amphibians (aquatic and terrestrial)	Species	36+
Fish	Species	20
Insects (aquatic and terrestrial)	Order, family and species	600+
Total		1,041+

Fig. 10.8. Major Ecosystems and Pathways Responsible for Radionuclide Movement to Man.

concentrated in aquatic systems. Magnitudes of movement can be predicted from compartmental³³ or specific activity models,^{32,34} provided that basic data on metabolic, population, environmental, and transport function parameters exist and assuming that information on radionuclide and mineral element behavior in these components is available.

10.4.3 Models of Radionuclide Movement

Proximity to the source of radioactivity will determine initial concentrations in different environments. Chronic, low-level releases will be dispersed over the environs, with the air concentration diminishing as a function of distance from the center of operations. Nearby ecosystems would receive the highest levels of radioactivity, and distant ecosystems considerably less. Radioecological analyses, therefore, will focus on the proposed on-site grassland and adjacent agroecosystems, with distant landscape and aquatic systems commanding a lower priority.

The behavior of principal fission products can be approximated from models of commodity flow in an ecosystem.³³ For example, a framework for describing the important components and transfers among the soil-plant segments is depicted in a simplified systems diagram (Fig. 10.9). If the input, transfer rates, and initial conditions are given, the distribution of a nuclide among different plant and soil components can be predicted as a function of time after initial deposition. This procedure will apply to both chronic and acute inputs, provided transfer parameters are based on "pulse" experimental data. The model can estimate various secondary source terms (foliage, root, litter), which, in turn, serve as potential inputs to ecological and agricultural food chains. While this example describes radiostrontium dynamics in the grass-litter-soil component, similar modeling techniques can be used to illustrate radionuclide movement or concentration for other organisms and pathways of the ecosystem. Specific activity models³² are most applicable for predicting radionuclide concentrations in aquatic systems, provided sufficient information exists on the stable chemistry of the environments and organisms.

Fig. 10.9. Pathways of ^{90}Sr Movement Among Plant-Soil Segments of a Grassland Ecosystem.

An important advantage of the compartmental modeling approach is that the basic design of the flow model can apply to evaluations of different contaminants; thus base-line ecological data can be used for several specific nuclide assessments. For purposes of preliminary hazard assessment, and as an illustration of how the technique can predict distribution of a contaminant throughout the system, the dynamics of ^{90}Sr is evaluated for a generalized grassland ecosystem. Since this nuclide will constitute about one-third of the routine fission-product release, and it possesses a relatively high health-hazard potential, it is of major interest in this case. Compartmental variables and transfer parameters are defined and enumerated in Tables 10.7 and 10.8 respectively, for grass-litter-soil segments of an "average" grassland. Attendant assumptions and calculations of transfer functions are given in Table 10.9. Examination of these derivations will show that oversimplification was often necessary because the essential data for assessing radiostrontium movement in the environment were not available.

Table 10.7. Initial Conditions of Compartments

Compartment	Definition	Initial Condition (pCi/m ²)
Q_1	Surface deposition	0.86
Q_2	Root	6
Q_3	Internal portion of foliage	30
Q_4	Foliage surface	120
Q_5	Litter	150
Q_6	Soil	270,000

For the grass-soil segments of the ecosystem, based on various flow rates, the model partitions the nuclide among different foodbase components. In turn, these components can serve as source terms for herbivorous and detritus-feeding organisms. Determination of ^{90}Sr and other nuclide movement, dispersion, or concentration through principal trophic levels and food chains are assessment tasks that remain to be accomplished. When

Table 10.8. Fractional Transfer for Flows Among Compartments

Flow	Definition	Fractional Transfer (day ⁻¹)
$\lambda_{1,4}$	Deposition on foliage	0.15
$\lambda_{1,5}$	Deposition on litter	0.85
$\lambda_{4,3}$	Direct uptake by foliage	0.005
$\lambda_{4,5}$	Fraction lost from foliage surface to litter	0.017
$\lambda_{3,5}$	Loss due to defoliation	0.0055
$\lambda_{3,2}$	Translocation from leaf to root	0.00006
$\lambda_{5,4}$	Fraction moved back to foliage as dust from litter	0.000027
$\lambda_{5,6}$	Fraction lost from litter to soil (mineralization)	0.005
$\lambda_{6,4}$	Fraction redeposited on foliage as dust from soil	0.000001
$\lambda_{6,2}$	Fraction taken up by roots	0.0000045
$\lambda_{2,3}$	Translocation from root to leaf	0.35
$\lambda_{2,6}$	Fraction transferred back to soil	0.00069

Table 10.9. Calculations for Transfer Functions for ^{90}Sr Movement in a Generalized Grassland Ecosystem

Flow	Calculation
$\lambda_{1,4}$	Deposition on foliage (0.15), inferred from Krieger et al. ³⁵ results on permanent grass pasture.
$\lambda_{1,5}$	Deposition on litter, $1.0 - 0.15 = 0.85$.
$\lambda_{4,3}$	Internal uptake from surface deposition (0.005), inferred from the maximum rate of translocation found for foliar-applied ^{85}Sr in corn. ³⁶
$\lambda_{4,5}$	Thirty days were required for radioactivity of leaves to decrease by a factor of 2 when ^{85}Sr was deposited on foliage permanent grass pasture. ³⁷ Daily loss would be 0.017 ($0.5 \times 1/30$), assuming a linear weathering process.
$\lambda_{3,5}$	Radionuclides in leaves are lost as litter at the time of defoliation. Hence maximum daily transfer function would be $1/180 = 0.0055$ (180 days/year). Daily foliar attrition is assumed rather than end of season pulse.
$\lambda_{3,2}$	Translocation of ^{85}Sr from leaf to root has been reported to be no more than 0.006% of total applied on corn leaves. ³⁶ Hence daily transfer function would be 0.00006.
$\lambda_{5,4}$	Assuming 1%/year moves from litter to foliage as dust, daily transfer would be $0.01 \times 1/360 = 0.000027$.
$\lambda_{5,6}$	The loss rate from litter to soil was 0.01/day for subhumid conditions. ³⁸ Slower decomposition and mineral turnover would be expected in drier Kansas grassland; hence a lower loss rate function was assumed ($0.01 \times 1/2 = 0.005$).
$\lambda_{6,4}$	Radionuclides on the ground surface are expected to be redeposited as dust. No experimental data are available on the rate of this movement; however, it would be less than that from soil to litter, possibly $1/25$ of redeposition from litter to foliage ($\lambda_{5,4}$). Daily transfer would be $0.000027 \times 1/25 = 0.000001$.
$\lambda_{6,2}$	Radioactivity surveillance data from Kansas showed that grass foliage had 0.00031% (0.0000031) of radioactivity in soil (Table 10.7). Calculated daily uptake by grass from soil was 0.0000058 (ref. 35). Hence, daily uptake rate from soil was based on average of these values or 0.0000045.
$\lambda_{2,3}$	For tomato plants grown in a 1 ppm strontium nutrient solution, 39% of root strontium moved to leaves in 4 days. ³⁹ Root and solution concentrations were roughly equivalent; thus total root uptake was estimated as $1.0 + 0.39 = 1.39$ units, and daily root to shoot transfer would be $1.39 \times 0.25 = 0.35$.
$\lambda_{2,6}$	Annual turnover of grass roots to soil has been reported to be 25% of total dry weight. ⁴⁰ Hence daily turnover of roots and minerals would be $0.25 \times \frac{1}{360} = 6.9 \times 10^{-4} \times \text{day}^{-1}.$

sufficient quantitative data become available from the site or ecosystems adjacent to the Repository, it will be possible to estimate concentration levels and their attendant hazards more precisely.

Provisional estimates of dynamic distribution of a chronic ^{90}Sr input throughout the grassland system were determined using the transfer and compartmental parameters of Tables 10.8 and 10.9. Change in state of a compartment is a function of inflows and outflows, each of which specifies a term in a difference equation. By using linear transfer functions, which are actually oversimplifications of nuclide movement between principal components, the behavior of ^{90}Sr is given for five compartments from the solution of five differential equations. Program CSS⁴¹ was used to facilitate the large number of calculations for various time intervals.

Chronic input was calculated from estimated releases and deposition velocities (Table 10.10) which gave a daily deposition to the grassland ecosystem of 0.86 pCi/m^2 . The redistribution of ^{90}Sr throughout the grass-soil components as a function of time is graphed in Fig. 10.10. The greatest increase in radioactivity occurs in the litter compartment (i.e., the activity nearly triples in two to three years). Relative to background levels, the concentration decreases slightly for roots and increases by 50% for foliage as new equilibria become established. A decrease in soil radioactivity is predicted from this simulation (Table 10.11) because the total input (860 and 8600 pCi/m^2 for 1000 and $10,000$ days) initially was an insignificant fraction of the background level after 2.5 and 25 years, respectively, and the decrease in radiostrontium from physical decay exceeds new deposition. Reequilibrium in the biological components occurs within 1 to 2 years. The state conditions of these components may vary somewhat, depending on the verity of the transfer coefficients, but probably by less than a factor of 3 to 5 . The dynamic character of the ecosystem precludes significant ^{90}Sr accumulation or concentration in the plant-soil components, and additional analyses will be done to determine if a similar condition would exist for faunal components.

Major pathways of radionuclide redistribution to other organisms are indicated for the grassland ecosystem (Fig. 10.8). Some of these involve transfers through herbivore, omnivore, and carnivore trophic levels.

Table 10.10. Calculations for Initial Conditions of ^{90}Sr in Compartments in Fig. 10.9

Compartment	Initial Condition (pCi/m ²)	Calculation
Q ₁ (surface deposition)	0.86	Radiostrontium deposition to the on-site terrestrial landscape was calculated from data in Table 11.5, where concentration in the atmosphere is given as $\sim 1 \times 10^{-14}$ Ci/m ³ . This was assumed to be a steady-state value where ground deposition is balanced by input from mine exhaust. A deposition velocity of 10^{-3} m/sec was used to estimate rate of movement from atmosphere to surface features. Thus, $(1 \times 10^{-14} \text{ Ci/m}^3) \times (10^{-3} \text{ m/sec}) = 1 \times 10^{-17} \text{ Ci m}^{-2} \text{ sec}^{-1}$ or $8.64 \times 10^{-13} \text{ Ci m}^{-2} \text{ day}^{-1}$.
Q ₂ (root)	6.0	Guliakin and Yudintseva's water-culture data ^a show that about 1/25 of total ^{89}Sr absorbed by wheat remained in roots. Since 150 pCi/m ² was found for foliage in Butler County, radioactivity in roots would be 6 pCi/m ² .
Q ₃ (internal foliage)	30.0	Radiostrontium content of foliage samples from Butler County was 485 pCi/kg. Estimating 300 g m ⁻² year ⁻¹ dry matter production for grassland, the content in grass would be $485 \times 0.3 \approx 150 \text{ pCi/m}^2$. From field fallout studies, it was estimated that 20% of grass radiostrontium was from root uptake, and 80% was from deposition; ³⁵ then $Q_3 = 150 \times 0.20 = 30 \text{ pCi/m}^2$ and $Q_4 = 150 \times 0.80 = 120 \text{ pCi/m}^2$.
Q ₄ (external foliage)	120.0	
Q ₅ (litter)	150.0	Equal amounts of radioactivity are assumed to be present in litter as in foliage in grassland. Litter accumulation seldom exceeds annual production because of rapid decomposition.
Q ₆ (soil)	270,000	Average of two soil samples from Butler County.

^aI. V. Guliakin and E. V. Yudintseva, 1957, "Plant Uptake of Fission Products from Soil," in On the Behavior of Radioactive Fission Products in Soil, Their Absorption by Plants and Their Accumulation in Crops, ed. by Klechovsky, USAEC-tr-2869.

Fig. 10.10. Change in ^{90}Sr Concentration for Plant-Soil Segment of a Grassland Ecosystem Following Chronic Deposition of $0.86 \text{ pCi m}^{-2} \text{ day}^{-1}$. Values corrected for decay. Note different scale for soil compartment and for 10^3 to 10^4 time interval. Decrease was nearly linear from 10^3 to 10^4 days.

Table 10.11. Calculated Concentrations of ^{90}Sr in Each
Compartment Following Deposition of $0.86 \text{ pCi m}^{-2} \text{ day}^{-1}$
for Selected Time Intervals

(Values from Fig. 10.10)

	(pCi/m ²)				
	Initial	10 days	100 days	1000 days	10,000 days
Foliage	150	141	156	238	133
Root	6	10	12	11	6
Litter	150	170	259	438	316
Soil	270,000	270,000	268,000	252,000	135,000
Total deposition ^a	9	9	86	860	8,600

^aValues not corrected for decay.

Several pathways may lead to man (grass-deer, rabbit-man, pheasant-man), although food consumption habits would provide limited hazard to humans from ingestion. Except for the milk pathway, most radionuclides would be dispersed rather than concentrated as they move through the terrestrial ecosystem because fission-product concentration factors are usually less than 1 for many terrestrial food chains according to Reichle et al.³² Certain tissues (thyroid, bone, milk) may concentrate specific fission products (I, Sr) to higher levels than whole-body averages, but, in most cases, accumulation will not exceed that of the food base by more than a factor of 3 to 5. Provisionally then, one would not expect ⁹⁰Sr levels of native animal populations to be more than three to five times the level indicated for plant parts (Table 10.11). For such conclusions, however, one must recognize that faunal population densities, food habits, and feeding ranges also influence concentration magnitudes, and it is inappropriate to estimate the nuclide dynamics of these components in the absence of population, biomass, and food-web data for the herbivore-omnivore-carnivore components of the ecosystem.

Other pathways of radionuclide movement are identified for major ecosystems in the vicinity of the proposed site (Fig. 10.8). Analysis of the dynamics of ⁹⁰Sr in the plant-soil components of the grassland ecosystem showed only small increases in biotic components relative to existing residual fallout. Additionally, the extent of potential hazards should be evaluated for adjacent agroecosystems, particularly for the aquatic ecosystems. While the initial concentration of radioactivity deposited in aquatic environments would be substantially less than that closer to the Repository site, potential hazards should be examined because aquatic organisms characteristically concentrate radionuclides by several orders of magnitude. Additional stream chemical (including stable and radioactive elements) data, coupled with probabilistic models of population dynamics, will be required to determine the extent of radiological hazard associated with aquatic systems. Although subject to considerably smaller radioactivity inputs, pathways of movement in the agroecosystem should be examined in greater detail because this system provides the most direct route for entry of nuclides via human ingestion. Data on domestic animal

management and local food consumption will be required in order to determine if a peculiar hazard may exist in the vicinity of the Repository.

10.4.4 Acute Situations

Ecosystem models of radionuclide dynamics will serve dual roles: (1) assessment of long-term effects from chronic releases (discussed above), and (2) evaluation of the fate of contaminants in the event of an accidental release. The same modeling efforts can predict the extent of contamination equally well for both chronic and acute events, provided model parameters are derived from acute input data. The same ecosystem structural and process information would apply in both situations. Data on ecosystem processes and nuclide behavior should be readily available for rational assessment of possible consequences in an emergency situation. Judgments for contingency actions, then, could be based on the best available information on environmental factors coupled with predictive models and computer simulations, rather than on assumption and speculation.

10.4.5 Thermal Effects

The dissipation of waste heat from high-level wastes may increase the temperature of the soil surface. However, a heat flux of 10 times the geothermal rate is not expected to change the surface temperature more than a fraction of a degree Fahrenheit — a negligible amount when compared with observed seasonal variations (Fig. 10.11). Daily bidirectional radiation flux in the soil surface ranges from 0 to 0.1 cal/cm², which is at least 1000 times greater than the predicted heat flux from waste deposits. As compared with calculations in radiant energy balance and resultant soil heat flux, the increases in the surface temperature from waste heat will be small or negligible.

Specific low-intensity effects on energy balance components include the following:

- (1) Net radiation (R_n) would decrease slightly, possibly 0.01 langley/min, because outgoing long-wave radiation is proportional to the fourth power of the surface temperature.
- (2) Evapo-transpiration (E) could be affected by a 10% increase in the

Fig. 10.11. Maximum Soil Temperature (Average for Nine Years of Data).

vapor pressure gradient, one factor of the evaporation equation. Other complex processes affect E, but not all of them are directly influenced by temperature.

- (3) Sensible heat fluxes of air and soil also are dependent on several factors (e.g., water, eddy diffusivity, conductance, soil texture, and organic content), and specific effects of additional heat are not easily identified.

Some biological processes that may be affected by subtle changes in soil temperature include the following:

- (1) Seed germination and seedling development could be advanced by only slightly higher temperatures, but death of the emerging plant could also result if the event were not synchronized with other facets of the environment.
- (2) Insect life cycles and phenology conceivably could be affected because their reproductive responses are triggered by temperature-controlled metabolic development.
- (3) Increased metabolism from slightly higher temperatures of plant storage organs could lead to carbohydrate deficits and decreased vigor.
- (4) With increased geothermal fluxes as the driving force, a slight redistribution of soil moisture could occur, vertically as well as horizontally. This phenomenon could influence water reserves in the subsoil on which deep-rooted plants depend during periods of drought stress.

The fact that physical and biotic effects could occur from an increased geothermal flux does not necessarily mean that devastating consequences will result. The identification of reasonable impacts should be followed by more detailed analysis of those manifestations which substantively could be detrimental over centuries of biotic exposure to such a heat source. Experience concerning low-level effects from chronic heat sources is very limited, however.

10.5 Sociological Impact

10.5.1 Population

The population impact created by the Federal Repository on the area in the vicinity of Lyons and on the remainder of the State of Kansas has been estimated through the use of an Input-Output Study⁴² and the projected Repository employment for 1980 and 1990. The input-output analysis examined the interaction between the various sectors of the Kansas economy and established multipliers for the indirect and induced effects of the employment at the Repository. Local employment effects were established by estimating the fractions of the total employment increase for each sector of the economy that would occur in the Lyons vicinity. (The Lyons vicinity is defined as the area within 50 miles of the Repository, since commuting that distance would be possible for an employee).

Table 10.12 summarizes the employment estimates for 1980 and 1990. The data shown under Direct Employment include the estimated Repository employment in 1980 and 1990. Repository-associated employment is an estimate of the additional persons who might be stationed at the site to perform research, surveillance, consulting, and liaison duties.

An estimate of the direct plus indirect employment impact of the Repository in 1980 is shown under Direct and Indirect Employment. Indirect employment results from the changes in employment in other industries or sectors of the economy when the employment of the industry under consideration is changed. For example, the changes in employment (indirect employment) in the Kansas transportation industry for each incremental employee added to the non-metallic mining industry (this industry was assumed to represent the Repository) can be determined using input-output analysis. In a similar manner, the total employment changes for all of the other Kansas industries can also be determined, and this total plus the direct employment in the non-metallic mining industry represents the impact of a change in the non-metallic mining industry on the employment in Kansas. To determine the local employment impact, an estimate was made of the fraction of employment change for each industry that would be located in the Lyons vicinity. The remainder of the employment change

Table 1C.12. Estimate of Employment Impact of Repository

Status	Year	
	1980	1990
Direct Employment		
Repository	130	320
Repository-Associated	20	30
Total	150	350
Direct and Indirect Employment		
Local	185	-
Kansas (Non-local)	55	-
Total	240	-
Direct, Indirect, and Induced Employment		
Local	-	465
Kansas (Non-local)	-	165
Total	-	630

would then represent the non-local employment impact in Kansas. The input-output data employed in this estimate were available in the form of a matrix of direct-plus-indirect employment multipliers for each major state industry.

An induced employment effect was added to the estimate for 1990. Induced employment occurs when the additional income to households resulting from an increase in employment enables consumers to spend more, which creates additional demand for the output of industries. This effect was

not included in the 1980 estimate because a longer period of time is required for it to mature. The 1990 employment impact (see Direct, Indirect, and Induced Employment, Table 10.12) was determined in the same manner as the 1980 impact, except that a matrix of multipliers which included the direct, indirect, and induced effects was used. Results predict that the local employment in 1980 and 1990 will be 185 and 465 respectively. This is higher by 35 for 1980 and 115 for 1990 than the estimated direct Repository employment.

The estimated population impact on the Lyons vicinity due to the employment at the Repository is summarized in Table 10.13. Family population was projected using a factor of three persons per family, which was the average for Kansas in 1968. It is difficult to estimate the number of new families that might move into the area because many local residents would probably find employment initially at the Repository. However, the unemployment rate in the vicinity of Lyons is not high at the present time and is not expected to increase significantly, because it is essentially an agricultural area. Also many of the positions require skilled technical employees who may not be available locally. The estimated increase in local population assumes that about 100 employees would be available locally and the remainder would move into the area. Population estimates are based on the total number of jobs created locally (direct, indirect, plus induced) as presented in Table 10.12. The results indicate that an increase of about 220 persons by 1980 and an increase of about 960 persons by 1990 might be expected.* If 50% of these persons settle in Lyons, the population could increase to about 4800 by 1990 (assuming a zero growth rate without the Repository).

The above estimates do not include the possible establishment of any satellite industries in the Lyons vicinity. If satellite facilities are established, the above estimates will probably be on the low side.

*This agrees roughly with the population increase in Idaho Falls and Blackfoot, Idaho during 1950 - 1970 due to the NRTS. Their population increase was about 19,500 for an employment increase of 5100 which results in a ratio of 3.8 persons per employee.

Table 10.13. Estimate of Impact on Local Population Due to Repository

Status	Year	
	1980	1990
Local Population Connected with Repository		
Family Population	455	1215
Single Persons	25	70
Total	480	1285
Increase in Local Population Due to Repository		
Family Population	210	905
Single Persons	10	55
Total Increase	220	960

10.5.2 Research Activities

Baseline studies of the Repository site will be established to provide a data base for the biotic, meteorologic and soil resources as well as the radiation levels prevalent before construction. Long-term monitoring studies will then identify the impact on the local environment which may result from operation of the Repository. Geological investigations will also be continued during the long-term operation to study thermal and geophysical impacts (see Sects. 10.2 and 10.3).

It is planned to convert the Repository site to native prairie to simplify monitoring of the area and surveillance of radiological and thermal effects on the geologic and hydrologic formations. This native grassland will provide a very useful ecological research tool, since there is no similar prairie in Kansas or elsewhere. The site would assure the maintenance of genetic pools of the various exotic prairie plant species which normally would not be available commercially.

10.5.3 Aesthetics

The Repository will not be offensive with respect to sprawl, noise, waste effluents, or conspicuous engineered features. If the general areas not occupied by Repository facilities were converted to native prairie, the site would represent an interesting and educational natural asset to the community and state.

10.5.4 Relocation

There are a total of five residences to be acquired within the Repository area. Three of the homes are owner-occupied, one is occupied by a tenant and one has been abandoned. Approximately 13 people may have to be relocated from the area. Farm operations that might be discontinued include four owner-operated and eight tenant-operated farms having a total of 921 acres.

10.5.5 Archeology

There are no known prehistoric Indian relics or other antiquities on the intended Repository site. Most of the Indian relics found in the

area were located along the stream beds north and south of Lyons. One such site is located on Cow Creek about four miles to the west and another is located about eight miles northeast of Lyons. Archeological parties who have worked in the Rice County area during the 1960's know of no archeological sites located with the proposed Repository site area. Acquisition of the site will, however, comply with the requirements of the Federal Antiquities Act, if applicable.

10.5.6 Restricted Land Uses

That portion of the Repository site surrounding the surface structures will be a controlled limited access area, and exclusion fences will be installed around the area. Structures inside the controlled area will include the Repository buildings, hoists, magazine, central filter station, and utilities. This area (approximately 150 acres) will be utilized primarily for Repository operations.

10.5.7 Impact on Resources

Rock Salt. - Rock salt resources are essentially inexhaustible. It is estimated that the rock salt resources in the state of Kansas alone exceed 5×10^{12} tons or enough to meet the present needs of the United States for the next 500,000 years.⁴³ Salt deposits are known to exist in most sections of the country, having been found in 24 of the 50 states. With the vast amount of rock salt deposits existing within the U. S., it is evident that the few million tons of salt that would be used to retain the radioactive wastes at the Repository are too small to have any measurable effect on the reserves of this abundant natural resource.

Oil-Gas. - Oil and gas were discovered in Kansas in 1860, but no production was reported for about 20 years. Through 1966 nearly 4 billion barrels of crude oil and about 13 trillion cubic feet of natural gas have been produced.⁴⁴ The oil and gas industry of Kansas has made important contributions to the state's economy; however, crude oil production peaked in 1956 and has been steadily declining since, while natural gas production appears to have stabilized.

At the present time there is one producing oil well (Stockham No. 1 - see Fig. 4.16) located within the boundaries of the proposed site. This well, which constitutes the only producing well in the 40-acre Lyons Townsite pool, has always been a very minor producer, and there is evidence that production will be terminated in the near future. Wells adjacent to the producing wells, including a recently drilled offset hole, known as Stockham No. 2 (Fig. 4.16), have all been dry holes. There are no other producing oil or gas wells in the immediate vicinity, although several wells have been drilled. The Lyons gas field located to the southeast of the site is depleted and the once-producing wells have been plugged. Based on this, it can be concluded that there are apparently no significant quantities of oil and gas underlying the Repository site which would be interdicted.

Groundwater. - The sedimentary rocks of Cretaceous age that underlie most of the northern half of central Kansas and, in particular, the Repository site are relatively unimportant sources of groundwater.⁴⁵ Locally, small supplies of water are available from outcropping sandstone beds and from patches of Tertiary and Quaternary deposits, but only the large river valleys contain sand and gravel deposits in sufficient quantities to provide commercial supplies of groundwater. It can be concluded that there will be no significant impact from the Repository on groundwater supplies.

10.6. References

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11. SAFETY ANALYSIS

11.1 Summary of Safety Provisions

As indicated in many places throughout this report, numerous design and operational safeguards have been instituted to cope with all normal and abnormal conditions that have the potential for subjecting man and his environment to exposures from excessive radiation, noxious gases, and other industrial hazards. To facilitate a thorough review of the safety considerations associated with the Repository, the various safeguards that have been incorporated into the design, or which are naturally present, are summarized for normal operating conditions in Tables 11.1 and 11.2. Provisions for abnormal operating conditions are summarized in Tables 11.3 and 11.4.

11.2 Effluents During Normal Conditions

Very small quantities of radioactive and other materials will be released to the atmosphere as a result of the normal operations of the Repository. The concentrations of these materials in normal working areas and off-site will be well below concentrations that are considered acceptable for occupational exposure and for exposure of the general public, respectively.

The materials that will become airborne in small concentrations include solid waste particles resulting from resuspension of surface contamination; gases (e.g. ^{85}Kr , ^3H , He) that result from decay of the waste; radon isotopes that occur naturally in the mine; nonradioactive gases (H_2 and HCl) that are formed by corrosion, electrolysis, radiolysis, and decomposition of brine; exhaust gases from the diesel-powered transporter; and salt particles resulting from mining operations.

Applicable concentration guides for these materials in air and estimates of their concentrations that presently exist in the air and in the soil in the central United States are presented in Tables 11.5 and 11.6. The guides for exposure of the public are one-third of the values from Table 2 of 40 CFR 20 and correspond nominally to an exposure rate

Table 11.1. Summary of Alpha Facility System Safeguards: Normal Operation

System	Safety Consideration	Safeguard
Shipping container receipt, handling, and return	Prevention of contamination of the environs and plant personnel.	1. Air sample taken from rail car before opening.
		2. Smear samples taken from car interior and cargo container exterior.
		3. Unloading done inside weather-protected area.
		4. Cargo container moved through airlock to confinement area before opening.
		5. Empty cargo containers decontaminated before return to rail car.
	Protection of plant personnel from excessive radiation exposure.	1. Criteria limit penetrating radiation level to acceptable values.
		2. Outside of rail car and cargo container surveyed.
	Avoidance of potential for cargo container and primary containment rupture.	1. Appropriate design of container.
		2. Restriction on quantity of oxidant in burial unit (limited combustion).
		3. Scheduled inspection, testing and maintenance of handling equipment.
		4. Trained and licensed personnel.

Table 11.1 (continued)

System	Safety Consideration	Safeguard	
Burial unit receipt and handling at surface level	Prevention of contamination of the environs and plant personnel.	1. Cargo container moved through airlock to the unloading and decontamination room.	
		2. Air sample taken from cargo container before opening.	
		3. Outer surface of cargo container surveyed for contamination and penetrating radiation.	
		4. Burial units subjected to smear test.	
		5. Airlock between surface facilities and mine area at base of alpha shaft.	11-3
	Protection of plant personnel from excessive radiation exposure.	Burial units surveyed for penetrating radiation and checked against manifest.	
	Prevention of criticality.	1. Criteria regarding permissible reactivity per individual package permit close packing of burial units.	
		2. Nondestructive assay.	
	Prevention of overheating.	1. Criteria pertaining to permissible power densities per package permit close packing.	
		2. Assay.	

Table 11.1 (continued)

System	Safety Consideration	Safeguard
Burial unit receipt and handling at surface level (continued)	Avoidance of potential for burial unit rupture.	<ol style="list-style-type: none"> 1. Appropriate design of container. 2. Scheduled inspection, testing, and maintenance of handling equipment. 3. Trained and licensed personnel.
Burial unit transfer from ground level to mine level	Avoidance of potential for burial unit rupture.	<ol style="list-style-type: none"> 1. Appropriate design of container. 2. Scheduled inspection, testing, and maintenance of handling equipment. 3. Trained and licensed personnel.
	Prevention of overheating.	<ol style="list-style-type: none"> 1. Criteria pertaining to permissible power densities per package permit close packing. 2. Assay.
All normal operations at mine level (mining, burial unit handling, backfilling, etc.)	Prevention of overheating.	<ol style="list-style-type: none"> 1. Criteria pertaining to permissible power densities per package permit close packing. 2. Assay.
	Prevention of criticality.	<ol style="list-style-type: none"> 1. Criteria regarding permissible reactivity per individual package permit close packing of burial units. 2. Nondestructive assay.

Table 11.1 (continued)

System	Safety Consideration	Safeguard
All normal operations at mine level (mining, burial unit handling, backfilling, etc.) (continued)	Avoidance of potential for burial unit rupture.	<ol style="list-style-type: none"> 1. Appropriate design of container. 2. Scheduled inspection, testing, and maintenance of handling equipment. 3. Trained and licensed personnel.
	Prevention of contamination of the environs and plant personnel.	<ol style="list-style-type: none"> 1. Rooms backfilled with crushed salt and "sealed." 2. Tunnels and rooms ventilated. 3. Continuous monitoring of air. 4. Burial unit containment integrity generally good for room operating period.
Mine ventilation exhaust	Prevention of contamination of environs external to facility.	<ol style="list-style-type: none"> 1. Filtration prior to stack discharge. 2. Continuous monitoring of stack discharge. 3. Adequate dilution and stack height.
Long-term confinement	Long-term confinement without contamination of inhabitable and useful environment.	<ol style="list-style-type: none"> 1. Rooms, tunnels, and shafts backfilled with crushed salt and the shaft sealed. 2. Prior analysis and design precludes leakage from salt bed. 3. Long-term monitoring.
	Overheating of geologic formations and aquifers.	Prior analysis and design precludes excessive temperatures.

Table 11.2. Summary of High-Level Facility System Safeguards: Normal Operation

System	Safety Consideration	Safeguards
Cask receipt, handling, and return	Prevention of contamination of the environs and plant personnel.	1. Cask and car surveyed upon arrival at facility.
		2. Rail car unloading area located in confinement building.
		3. Confinement buildings designed to withstand "probable maximum flood," and typical tornado and earthquake conditions for the area.
		4. Cask interior atmosphere sampled before opening and before steam lines connected.
		5. Continuous monitoring of steam coolant and room air.
		6. Cask cover not removed until cask becomes integral part of hot cell.
		7. Empty cask surveyed and decontaminated, if necessary, before returning to car.
	Protection of plant personnel from excessive radiation exposure.	1. Cask shielding adequate to meet exterior radiation limits of 10 CFR 71.
		2. Coolant monitored remotely.
		3. Cask cover not removed until cask becomes integral part of hot cell.

Table 11.2 (continued)

System	Safety Consideration	Safeguards
Cask receipt, handling, and return (continued)	Avoidance of potential for cask rupture.	<ol style="list-style-type: none"> 1. Scheduled inspection, testing, and maintenance of handling equipment. 2. Cask lift cannot exceed the 10 CFR 71 drop test height. 3. Trained and licensed personnel.
Waste package receipt and handling	Protection of personnel from excessive radiation exposure.	<ol style="list-style-type: none"> 1. Cask cover not removed until cask becomes integral part of hot cell. 2. Waste packages removed from cask, transferred to mine shaft cage, lowered to bottom of shaft, and placed in transporter by remote means within hot-cell-type confines. 3. Transporter provides adequate shielding. 4. Waste package lowered from transporter into burial hole, and the burial hole backfilled by remote means.
	Prevention of criticality.	Assay prior to shipment.

Table 11.2 (continued)

System	Safety Consideration	Safeguards
Waste package receipt and handling (continued)	Prevention of overheating.	<ol style="list-style-type: none"> 1. Assay prior to shipment. 2. Temperatures of waste packages and cask lowered prior to package removal from cask. 3. Natural convection cooling in air sufficient following removal of waste package from cask. 4. Transporter designed for steady state heat removal. 5. Annealing prior to shipment to remove stored energy.
	Protection of environs.	<ol style="list-style-type: none"> 1. All operations performed within confinement buildings that are equipped with filtered exhaust. 2. Confinement buildings designed to withstand "maximum probable floor," and typical tornado and earthquake conditions for the area. 3. Waste containers not intentionally breached.
	Assuring proper identification of waste packages	<ol style="list-style-type: none"> 1. Cask will be marked to facilitate identification. 2. Waste packages will be permanently marked for identification. 3. Cask and waste package identification marks will be checked against shipping schedule.

Table 11.2 (continued)

System	Safety Consideration	Safeguards
All operations at mine level.	Protection of personnel from radioactive and noxious gases emanating from burial holes containing waste.	<ol style="list-style-type: none"> 1. Burial holes and rooms are back-filled immediately after burial, reducing rate of and total emission of volatiles. 2. Rooms are ventilated while open.
	Prevention of hydrogen explosions.	<ol style="list-style-type: none"> 1. All open spaces are ventilated. 2. Backfilling of rooms and ventilation of corridors prevents formation of combustible mixtures in unventilated areas (backfilled rooms).
Long-term confinement	Long-term confinement without contamination of the habitable environment.	<ol style="list-style-type: none"> 1. Burial holes, rooms, and corridors, backfilled with crushed salt and shafts sealed. 2. Prior analysis and design preclude leakage from salt bed. 3. Confirmation period (several years) with minimal burial of waste will precede mass burial. 4. Repository site will be identified for future generations to help prevent intrusion.
	Over-heating of geologic formations and aquifers.	Prior analysis and design preclude excessive temperatures.

Table 11.2 (continued)

System	Safety Consideration	Safeguards
Process waste	Collection of liquid wastes.	All potentially contaminated solutions (process and non-process) routed through drains to process waste sump and/or waste collection tank.
	Transfer of liquid wastes from alpha facility waste collection tank to high-level facility waste collection tank.	<ol style="list-style-type: none"> 1. Contamination of alpha facility liquid wastes normally very low. 2. Transported by means of special tank truck and metal containers.
	Prevention of contamination of the environs and plant personnel.	<ol style="list-style-type: none"> 1. All equipment handling potentially contaminated fluids located in confinement area. 2. All gaseous discharges are filtered and monitored. 3. With the exception of filtered vents, process system is essentially closed.
	Prevention of plant personnel exposure.	<ol style="list-style-type: none"> 1. Waste collection tanks confined in concrete pits. 2. All piping adequately shielded. 3. Continuous monitoring at critical points. 4. Waste processing equipment operated remotely with adequate shielding. 5. Solidified end product transported to burial site in shielded container.

Table 11.2 (continued)

System	Safety Consideration	Safeguards
Process waste (continued)	Assuring containment within storage tanks and sumps.	<ol style="list-style-type: none"> 1. Corrosion-resistant materials used throughout. 2. All tanks designed in accordance with appropriate specifications. 3. Periodic inspection and testing for leaks.
	Prevention of overheating of solutions and equipment (volatilization of radioactive wastes).	<ol style="list-style-type: none"> 1. Concentration of radioactive nuclides in solutions, including evaporator concentrate, very low. 2. Temperatures monitored at critical points. 3. Low pressure steam used in evaporator.
	Prevention of criticality.	<ol style="list-style-type: none"> 1. Concentration of fissionable nuclides very low. 2. Assays.
	Prevention of excess activity in batch evaporator condensate.	<ol style="list-style-type: none"> 1. Design precludes foamovers and excessive entrainment under normal conditions. 2. Condensate activity continuously monitored.
	Prevention of excess activity in effluent from ion exchange columns.	Effluent monitored.
	Transfer of solidified process waste from process waste facility to alpha facility for burial.	Waste solidified and contained within metal container.

Table 11.3. Summary of Alpha Facility System Safeguards: Abnormal Conditions

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Shipping container receipt, handling, and return	Interior of rail car contaminated.	1. Burial unit and cargo container seal leakage.	Air sample from rail car.	1. Air sample taken prior to opening car.	1. Airborne. 2. Loose solid material.	1. Low concentrations several times a year. 2. Ruptured units once in several years.
		2. Burial unit and cargo container rupture.		2. Special confinement procedures if necessary.		
	Exterior of cargo container contaminated.	Burial unit and cargo container seal leakage.	Cargo container surface smears.	3. Disposition of rail car and contents decided at time of occurrence.	1. Airborne. 2. Surface.	Low contamination several times a year.
				4. Cargo container transferred to decontamination and unloading area.		
	Cargo container and burial unit ruptured after removal from rail car.	Mishandling, dropped from crane.	Visual observation and monitoring following mishap.	5. Cargo container decontaminated prior to return.	Airborne and loose solid material.	Once in several years.
				1. Special confinement (plastic cover, etc.).		
	Fire in burial unit following rupture of cargo container and burial unit.	Spontaneous combustion after exposure to air.	1. Visual observation. 2. Air monitoring.	2. Protective clothing and breathing equipment.	Airborne.	Very small probability.
				3. Weather-protected unloading area reasonably tight.		
				3. Building dampers and vents closed.		
				4. Cargo container (with contents) moved through air lock to confinement area as rapidly as possible.		

Table 11.3 (continued)

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Burial unit receipt and handling at surface level (within decontamination area)	Exterior of cargo container contaminated.	Cargo container and burial unit seal leakage and/or rupture.	Monitoring in unloading area.	1. Ventilation system. 2. Decontamination of cargo container exterior surface. 3. Protective clothing and breathing equipment.	Airborne and surface.	Low concentrations several times per year.
	Interior of cargo container and/or exterior of burial unit contaminated.	Burial unit seal leakage and/or rupture prior to or after entering decontamination area.	1. Air sample from inside cargo container.	1. Ventilation system. 2. Unloading of cargo container done in confinement area. 3. Decontamination of cargo container and burial units. 4. Special additional containment for burial units or individual packages (plastic, sheet metal, etc.) 5. Protective clothing and breathing equipment.	Airborne and surface.	1. Low concentrations several times per year. 2. High concentrations once in several years.
	Fire in burial unit following rupture of burial unit.	Spontaneous combustion after exposure to air.	1. Visual observation. 2. Air monitoring.	1. Fire fighting equipment. 2. Special containment. 3. Ventilating system.	Airborne.	Very small probability.
Burial unit transfer from surface level to mine level	Burial unit ruptures.	Hoist cable failure and impact as safety dogs engage.	1. Air sample from cage. 2. Observation of cable failure.	1. Cage is airtight. 2. Special containment of ruptured unit. 3. Decontamination of cage.	Airborne and surface.	Once in several years.
	Burial unit and cage rupture.	Hoist cable failure and impact as safety dogs engage or as cage hits bottom of shaft.	1. Air sample from shaft. 2. Observation of cable failure.	1. Special ventilation of shaft with local filters (portable units). 2. Special containment of ruptured units. 3. Decontamination of shaft.	Airborne and surface.	Once in 10 years.

Table 11.3 (continued)

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Burial unit transfer from surface level to mine level (continued)	Fire in burial unit following rupture of burial unit	Spontaneous combustion after exposure to air.	1. Visual observation. 2. Air monitoring.	1. Fire fighting equipment. 2. Special containment. 3. Ventilating system.	Airborne.	Very small probability.
All operations at mine level	Burial unit ruptured during transfer.	Mishandling.	1. Observation of mishap. 2. Monitoring.	1. Ventilation. 2. Isolated area. 3. Special containment of ruptured units. 4. Protective clothing and breathing equipment.	Airborne.	Once in several years.
	Fire in combustible waste.	Excessive temperature rise.	Nuclear radiation monitoring.	1. Ventilation system. 2. Fire detection system. 3. Fire extinguisher system. 4. Crushed salt backfill retains most of aerosol and prevents propagation of combustion.	Airborne.	Very small probability.
Confinement buildings	Breach of building confinement other than ventilating system.	1. Faulty design. 2. Excessive loads.	1. Visual observation. 2. Monitoring. 3. Pressure drop between inside and outside of building.	1. Building normally operated under negative pressure. 2. At least two failures required for activity release outside building. 3. Repository located in low population density area.	Airborne.	Very small probability.

Table 11.3 (continued)

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Ventilating systems	Failure of filters and/or fans.	1. Filter failure. 2. Filter clogging. 3. Loss of power. 4. Equipment failure.	1. Change in Δp . 2. Stack discharge monitoring. 3. Change in flow rate. 4. Loss of line voltage.	1. Backup filter-fan systems are provided. 2. Dampers to prevent backflow. 3. Backup power supply.	None	Once in several years.
	Excessive discharge from stack.	1. Filter failure. 2. Excessive internal release.	Monitoring.	Stop fans.	Airborne.	Very small probability.
Long-term confinement	Contamination of habitable and useful environment.	Unknown.	Monitoring.	Retrieval capability.	Contaminated aquifers.	Very small probability.

Table 11.4. Summary of High-Level Facility Safeguards: Abnormal Operations

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Cask receipt, handling, and return	Car and/or cask contaminated above limits.	1. Leakage from cask.	Survey of car and cask upon arrival.	1. Car and cask decontaminated in confinement building.	1. Airborne contamination.	Once in several years.
		2. Improper monitoring prior to shipment.		2. Special precautions during transfer of cask to hot cell.	2. Contamination of receiving area.	
				3. Cask decontaminated before return to shipper.	3. Personnel contamination.	
	Reduction in shielding effectiveness.	Transport accident.	1. Observation of accident.	1. Special procedure and tools.	Personnel exposure.	Once in 10 years.
			2. Survey of cask exterior.	2. Temporary shielding.		
Interior of cask contaminated above limits.		1. Leakage from waste containers.	Cask interior atmosphere sampled.	1. Cask not opened, or cask transferred to hot cell before opening.	Contamination of hot cell.	Once in several years.
		2. Improper monitoring prior to shipment.		2. Special disposition of cask and contents.		
Release of activity from cask to steam cooling system.	Waste containers rupture during steam cooling process.		Continuous monitoring of coolant system.	1. Condensate routed to shielded storage tank, and coolant flow terminated.	1. Contamination of cooling system.	Once in several years.
				2. Secondary system is a closed system.	2. Personnel exposure.	
Release of activity from cask to environs (building, etc.).	Ruptured waste containers, ruptured steam-cooling hose, and/or ruptured secondary cooling system.		1. Continuous monitoring of coolant system.	1. Contaminated coolant to waste drain.	1. Contamination of environs and personnel. 2. Personnel exposure.	1. Once in several years. 2. Requires two or three failures.
			2. Observance of hose and other failures.	2. Coolant flow terminated.		
			3. Survey.	3. Within confinement building.		

Table 11.4 (continued)

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Cask receipt, handling, and return (continued)	Cask dropped with or without lid attached.	Equipment failure or operator error.	Observance of drop.	Special procedures and equipment.	1. Contamination of environs. 2. Personnel exposure.	Once in several years.
Waste package receipt, handling, and burial	Waste container ruptured.	1. Cask mishandled. 2. Container corrosion. 3. Container mishandled.	1. Observation in hot cell, etc. 2. Air sample from cask.	1. All handling done in hot cell-type quarters until waste package confined in transporter. 2. Special procedures and equipment.	Contamination of hot cell, shaft, mine-level receiving station, or transporter.	Once in several years
	Waste container detained in a way that requires abnormal handling procedures.	1. Equipment failure. 2. Power failure. 3. Discovery of container leakage.	1. Visual observation. 2. Monitoring	1. Heat removal by natural convection and/or radiation continuously satisfactory at all stages of transfer without power supply. 2. Special equipment and procedures.	Personnel exposure.	Once per year
Confinement buildings	Breach of building confinement other than ventilating system.	1. Faulty design. 2. Excessive loads.	1. Visual observation. 2. Monitoring. 3. Pressure drop between inside and outside of building.	1. Buildings normally operated under negative pressure. 2. At least two failures required for activity release outside building. 3. Repository located in low-population-density area.	Contamination of environs and inhabitants.	Very small probability

Table 11.4 (continued)

System	Abnormality	Mechanism	Detection	Safeguards	Type	Likelihood
Ventilating systems	Loss of filtering.	1. Filter failure. 2. Loss of flow.	1. Activity release monitoring. 2. Air flow monitoring. 3. Δp across filters. 4. Loss of line voltage.	1. Backup fan and filter system. 2. Backup power supply. 3. Dampers to prevent backflow. 4. Tornado proof.	Contamination of external environment and personnel.	Once in several years
	Disruption of air flow.	1. Equipment failure. 2. Filter clogging. 3. Loss of power.	1. Air-flow monitoring. 2. Loss of line voltage. 3. Δp across filter.	1. Backup fan system. 2. Backup power supply. 3. Evacuation.	Contamination of environs and personnel.	Twice a year.
All operations at mine level	Hydrogen explosion in burial hole.	Backfill bridges and seals in burial hole leaving pocket for H_2 and O_2 accumulation.	None	Rooms backfilled before combustible mixture can accumulate, isolating explosive effects.	None	Very small probability.
	Hydrogen explosion outside burial holes.	Pockets for H_2 and O_2 accumulation left in backfilled rooms.	Easily detected (audible, visual, etc.).	Normal operation of mine minimizes chances of personnel being in front of backfilled room when explosive mixture can exist.	None	Very small probability.
Long-term confinement	Contamination and/or overheating of habitable and useful environment.	Unknown.	Monitoring.	1. Repairs to terminate solutioning. 2. Waste retrieval capability.	1. Aquifer and mineral deposit contamination. 2. Excessive heating of aquifers, earth's surface, and geologic formations.	Very small probability.

Table 11.4 (continued)

System	Abnormality	Mechanism	Detection	Safeguard	Type	Likelihood
Process waste	Collection tanks and piping leak.	Corrosion, stress failure, bad seals, etc.	1. Monitoring. 2. Liquid level.	Tanks and piping located in vaults equipped with sumps.	No contamination or exposure.	Once in several years.
	Excessive activity in evaporator condensate and/or ion exchange column effluent.	1. Improper operation of equipment. 2. Equipment failure.	1. Monitoring. 2. Recording of process conditions.	Condensate returned to evaporator or ion exchange system.	None.	Once a year.
	Excessive activity in off-gases.	Filter failure.	Monitoring.	Ventilating and exhaust systems direct off-gases through a second set of filters.	Airborne.	Once a year.
	Leakage to secondary side of evaporator.	Equipment failure.	Monitoring of secondary (cask-cooling boiler condensate).	Secondary is closed system.	Personnel exposure.	Once in several years.
	Leakage to secondary side of condensers.	Equipment failure.	Monitoring of secondary coolant (glycol).	Secondary is closed system.	Personnel exposure.	Once in several years.
	Overflow of waste casting drum.	Equipment failure or malfunction.	1. Monitoring. 2. Visual observation.	1. Confinement area with shielding. 2. Batch operation limits quantity.	1. Personnel exposure. 2. Airborne.	Once a year.
	Rupture of solidified waste container and fracture of solid during transport to alpha facility.	Transport accident or mishandling of solidified waste.	1. Monitoring. 2. Visual observation.	Special containment and handling.	1. Airborne. 2. Personnel exposure. 3. Loose solid material.	Once in 10 years.

Table 11.5. Concentration Guides for Various Airborne Radionuclides and Estimated Present Concentrations in the Air and Soil in Central Kansas

Radionuclide	Concentration Guides (Ci/m ³)		Concentration in the Atmosphere (Ci/m ³)	Concentration in Soil Within 20 cm of Surface (Ci/m ²)
	Occupational Exposure ^a	Exposure of the Public ^b		
Natural Uranium	6x10 ⁻¹¹	7x10 ⁻¹³	~1x10 ⁻¹⁵	8x10 ^{-7c}
Natural U + daughters	3x10 ^{-8d}	1x10 ⁻⁹	1x10 ^{-10e}	5x10 ⁻⁶
²²² Rn				8x10 ⁻⁷
Natural Thorium	3x10 ⁻¹¹	3x10 ⁻¹³	~1x10 ⁻¹⁶	5x10 ^{-7c}
Natural Th + daughters	1x10 ^{-7d}	3x10 ⁻⁹	5x10 ^{-12e}	3x10 ⁻⁶
²²⁰ Rn				5x10 ⁻⁷
Aged Solid Fission Products			~4x10 ⁻¹⁴	3.5x10 ^{-7f}
⁹⁰ Sr	1x10 ⁻⁹	1x10 ⁻¹¹	~1x10 ⁻¹⁴	7x10 ^{-8f}
¹³⁷ Cs	1x10 ⁻⁸	2x10 ⁻¹⁰	~1x10 ⁻¹⁴	1x10 ⁻⁷
⁸⁵ Kr	1x10 ⁻⁵	1x10 ⁻⁷	2x10 ⁻¹¹	-
³ H	5x10 ⁻⁶	7x10 ⁻⁸	2x10 ⁻¹¹	-
Plutonium	2x10 ⁻¹²	2x10 ⁻¹⁴	~2x10 ⁻¹⁶	1x10 ^{-9g}

^aValues from Table I, Column 1 of 10CFR20, and AECM 0524.

^bOne-third of values in Table II, Column 1 of 10CFR20, and AECM 0524.

^cAssumes U and Th concentrations of 6 and 12 ppm, respectively.

^dOne-third Working Level (30CFR57.5-37).

^eC. E. Junge, Air Chemistry and Radioactivity, Academic Press (1963).

^fFederal Radiation Council Protective Action Guides, JCAE Hearings (June 29-30, 1965). This report summarizes weapons fallout data for the United States.

^gP. W. Krey and E. P. Hardy, "Plutonium in Soil Around the Rocky Flats Plant," HASL-235 (August 1970). This report presents weapons fallout data for plutonium and ⁹⁰Sr.

Table 11.6. Concentration Guides for Various Materials and Estimated Present Concentrations in the Air in Central Kansas

Material	Concentration Guides for Occupational Exposure ^a	Concentrations in the Atmosphere ^b
Gases (ppm by volume)		
H ₂	10,000 ^c	0.5
He	10,000 ^c	5.2
Cl ₂	1	0.0003
HCl	5 ^d	0.0003
O ₃	0.1	0.02
CH ₄	10,000 ^c	1.5
CO ₂	5000	300.
CO	50	0.13
N ₂ O	10,000 ^c	0.4
NO ₂	5 ^d	0.003
SO ₂	5	0.008
H ₂ S	10	0.006
HCHO	5 ^d	0.001
Inert Particles (mg/m ³)	10	0.10
Salt	10	0.024
Combustion Products	10	0.052
Soil	10	0.024

^aThreshold Limit Values of Airborne Contaminants, American Conference of Governmental Industrial Hygienists (1970).

^bC. E. Junge, Air Chemistry and Radioactivity, Academic Press, 1963.

^cThreshold Limit Values of inert gases are based upon maintaining a minimum oxygen content of 20% (i.e. 30CFR57.5-15).

^dCeiling value (i.e., not to be exceeded in work areas).

of 170 mrem/year. The surface concentrations of strontium, cesium, and plutonium that have resulted from fallout are based upon measurements in Colorado.^{1,2} The corresponding atmospheric concentrations of these nuclides are based upon typical experimental values of resuspension factors. From these values, we estimate that the current near-surface air concentration of ⁹⁰Sr corresponds to about 0.1% of the guides and that the air concentration of plutonium may be as high as 1% of the guides.

The concentrations of ⁸⁵Kr and ³H in the atmosphere are in the range of 0.02-0.03% of the guides and each contribute about 0.05 mrem/year of exposure.³ Radon-222 occurs naturally at a concentration that is about 10-15% of the guides, corresponding to 20-30 mrem/year of exposure.

It should be pointed out, however, that recent measurements in the salt mine at Lyons have shown that the radon concentration in the mine is about a factor of 10 higher than the average concentration of the atmosphere (or roughly 10^{-9} Ci/m³).⁴ This concentration, however, is only about 3% of the level that is currently considered acceptable for occupational exposure in mines.

Typical normal air concentrations of nonradioactive species were based on data published by Junge.⁵

11.2.1 Sources of Normal Effluents

High-Level Waste Receiving Building. - In spite of periodic cleaning operations, equipment and surfaces in the confined area of the high-level receiving building will develop surface contamination, and a small fraction of the radioactive material will become airborne by resuspension (Table 11.7). The filtered (HEPA) effluent released from the stack of this facility will have concentrations estimated as no greater than 5×10^{-11} curies/m³, which is 5% of the permissible concentration for occupational exposure (Table 11.8). It is estimated that the stack effluent will consist of oxides of mixed fission products and actinides that have mean particle size of about 0.3 micron and density of about 1.5 g/cm³.

Table 11.7. Estimated Airborne Concentrations of Radioactive Materials in Surface Facilities and Average Annual Rate of Discharge of These Materials to the Atmosphere

High-Level Receiving Cell

Concentration of airborne waste particles ^a	$1 \times 10^{-7} \text{ Ci/m}^3$
Concentration in filtered effluent ^b	$5 \times 10^{-11} \text{ Ci/m}^3$
Average annual discharge to atmosphere	0.007 Ci/yr

High-Level Facility Confinement Zones

Concentration of airborne waste particles ^a	$2 \times 10^{-11} \text{ Ci/m}^3$
Fraction of 10CFR20, Table I, Column 1	0.02
Concentration in filtered effluent ^b	$1 \times 10^{-14} \text{ Ci/m}^3$
Average annual discharge to atmosphere	0.9 $\mu\text{Ci/yr}$

Alpha Waste Unloading and Transfer Rooms

Concentration of airborne waste particles ^a	$2 \times 10^{-13} \alpha\text{Ci/m}^3$
Fraction of 10CFR20, Table I, Column 1	0.2
Concentration in filtered effluent ^b	$1 \times 10^{-16} \alpha\text{Ci/m}^3$
Average annual discharge to atmosphere	0.0009 $\alpha \mu\text{Ci/yr}$

^aThese are the estimated maximum concentrations that will be maintained in these areas by routine decontamination operations. It has been found from experience that the air concentration is about $4 \times 10^{-5} \text{ Ci/m}^3$ per Ci/m^2 of average surface contamination in work areas.

^bAssumes a filter efficiency of 99.95%.

Table 11.8. Properties of Typical Calcined High-Level Waste Having
a Density of 1.5 g/cm^3 and Age of 10 Years Since Processing

Radioactivity of Principal Isotopes, curies/g of waste			
^{90}Sr	0.428	^{151}Sm	0.0076
^{90}Y	0.428	^{154}Eu	0.0316
^{99}Tc	0.00010	^{155}Eu	0.00098
^{106}Ru	0.0029	^{239}Np	0.00013
^{106}Rh	0.0029	^{238}Pu	0.00075
^{125}Sb	0.0044	^{239}Pu	0.000011
$^{125\text{m}}\text{Te}$	0.0018	^{240}Pu	0.000031
^{134}Cs	0.0519	^{241}Pu	0.0023
^{137}Cs	0.603	^{241}Am	0.0011
$^{137\text{m}}\text{Ba}$	0.564	^{243}Am	0.00013
^{144}Ce	0.0074	^{242}Cm	0.000023
^{144}Pr	0.0074	^{244}Cm	0.0113
^{147}Pm	0.0503	Total	2.19

Weighted Values of Concentration Guides for Air, Ci/m^3
 Occupational Exposure (10CFR20, Table I, Column 1): 1.0×10^{-9}
 Public Exposure 1/3X (10CFR20, Table II, Column 1): 1.0×10^{-11}

Weighted Value of Maximum Permissible Body Burden (NBS-69), μCi : 2.0

Dose Commitments to Body Organs from Inhalation of 1 μCi of waste:^a

Organ	Dose Commitment, rems	
	First Year	50 Years
Total body	0.060	0.87
Bone	0.80	15.0
G. I. Tract	0.029	0.029

^aCalculated with the INREM Program, USAEC Report K-1752 (1968).

Alpha Waste Receiving Building. - Normal activities in the alpha waste receiving building are expected to result in the release of practically negligible quantities of activity to the building ventilation system (Table 11.7). Periodic decontamination procedures will be employed to assure that surface contamination levels do not build up to unacceptable levels. As an added precaution all ventilation air from this building will pass through HEPA filters before discharge to the atmosphere through a short stack. Any material that passes through the filters is expected to consist of submicron particles of soluble or insoluble forms of plutonium having typical properties that are summarized in Table 11.9.

High-Level Mine. - Ventilation air from sections of the high-level mine that have been exposed to waste will be blended with the air from mining operations and the alpha mine, and exhausted to the atmosphere through HEPA filters and a short stack. This air will contain small concentrations of radioactive particles and gases, chemically noxious gases, and salt particles. Estimated maximum concentrations of these materials in the mine air and the maximum average annual release to the atmosphere (after HEPA filtration) are presented in Table 11.10.

The mine operating policy (burial of waste containers below 7 1/2 ft of crushed salt in rooms, progressive backfilling of the utilized rooms and corridors, and eventually, backfilling of the entire mine and sealing of the shafts) will provide that once buried, virtually no radioactive particles can be transported from the wastes to the mine ventilation air and, thus, to the surface. It is estimated that all gases produced in the mine will eventually be discharged to the surface but that particulate activity will not be released after the mine is sealed and de-commissioned.

The maximum concentration of radioactive particles in the mine ventilation air is estimated as 2×10^{-4} curies/m³ (2% of the permissible concentration for occupational exposure). This

Table 11.9. Properties of Plutonium Having Isotopic Composition
 Typical of That to be Received at the Repository
 (1% ^{238}Pu , 60% ^{239}Pu , 24% ^{240}Pu , 11% ^{241}Pu , 4% ^{242}Pu)

Radioactivity, curies/g of Pu

^{238}Pu	0.172
^{239}Pu	0.0368
^{240}Pu	0.0545
^{241}Pu	10.9
^{242}Pu	0.00015
Total	11.16
Total alpha curies/g of Pu	0.263

Weighted values of concentration guides for air, alpha Ci/m³:

Occupational exposure (10CFR20, Table I, Column 1): 1.0×10^{-12}

Public exposure 1/3X (10CFR20, Table II, Column 1): 1.1×10^{-14}

Weighted value of maximum permissible body burden
 (NBS-69), μg :

0.05

Dose Commitments to Body Organs from Inhalation of 1 μg of
 Plutonium Mixture^a

<u>Organ</u>	<u>Dose Commitment, rems</u>	
	<u>First</u> <u>Year</u>	<u>50</u> <u>Years</u>
Total body	2.58	67.0
Bone	117.	2931.
Liver	10.4	292.
Kidneys	12.7	299.
Lungs	25.4	50.4
G.I. Tract	0.023	0.023

^aCalculated with the INREM Program, USAEC Report K-1752 (1968).

Table 11.10. Estimated Airborne Concentrations of Radioactive and Other Materials in Underground Facilities and Average Annual Rate of Discharge of These Materials to the Atmosphere

Material	High-Level Mine ^a		Alpha Mine ^a		Average Annual Release to Atmosphere After HEPA Filtration
	Concentration in Mine Exhaust Air	Fraction of Concentration Guide for Occupational Exposure	Concentration in Mine Exhaust Air	Fraction of Concentration Guide for Occupational Exposure	
High-level waste particles	2×10^{-11} Ci/m ³	0.02	-	-	6 μ Ci/yr
Alpha waste particles ^b	-	-	2×10^{-13} Ci/m ³	0.2	0.03 μ Ci/yr
⁸⁵ Kr	2.3×10^{-11} Ci/m ³	2×10^{-6}	5×10^{-14} Ci/m ³	5×10^{-9}	0.014 Ci/yr
³ H	1.5×10^{-12} Ci/m ³	3×10^{-7}	3×10^{-15} Ci/m ³	6×10^{-10}	0.0009 Ci/yr
²²² Rn	1×10^{-9} Ci/m ³	0.03	1×10^{-9} Ci/m ³	0.03	0.9 Ci/yr
²²⁰ Rn	5×10^{-11} Ci/m ³	0.0005	5×10^{-11} Ci/m ³	0.0005	0.04 Ci/yr
H ₂ (corrosion, radiolysis, electrolysis)	90 ppm	0.009	20 ppm	0.002	4. scfm
He (alpha decay)	0.04 ppm	4×10^{-6}	0.001 ppm	1×10^{-7}	0.001 scfm
HCl (brine decomposition)	2 ppm	0.4	-	-	0.07 scfm
CO ₂	1100 ppm	0.2	300 ppm	0.06	50 scfm
CO	1 ppm	0.02	-	-	0.05 scfm
NO ₂	1 ppm	0.2	-	-	0.05 scfm
SO ₂	0.7 ppm	0.14	-	-	0.03 scfm
HCHO	0.02 ppm	0.004	-	-	0.0007 scfm
Soot	3 mg/m ³	0.2	-	-	2 lbs/yr
Salt particles	5 mg/m ³	0.3	5 mg/m ³	0.3	5 lbs/yr

^aThese concentrations occur simultaneously only in the air exhaust tunnel, which is not normally occupied.

^bExpressed in terms of alpha curies.

would result from resuspension of minor levels of contamination that may eventually develop on surfaces exposed to the ventilation streams.

The rate of release of gases from the mine is determined by their rate of production, the rate of temperature rise, and the rate of convergence of the mine. It is assumed that the waste containers will not be perforated (by stress corrosion cracking) for at least 90 days after emplacement and that they will not corrode at a rate exceeding 10% per year. Disposal rooms will have been backfilled with crushed salt (leaving about 25 volume % air) before the containers begin to leak gas. Following perforation of the containers, gases (Xe, Kr, Rn, He, and H₂) produced by spontaneous fission and decay of actinides (principally ²⁴⁴Cm) will migrate slowly from the storage hole into the backfilled room in a mean time of several days. These gases, as well as small volumes of H₂ and HCl from radiolysis and decomposition of the brine, will migrate from the room into active air corridors. Following release to the ventilation air stream, the gases will be discharged to the atmosphere through the mine exhaust. The time required for migration of gases through the backfilled room to the ventilation stream is such that ⁸⁵Kr and ³H (half-lives 10.76 and 12.26 years, respectively) will be the only radioisotopes that are released in measurable concentrations.

It is estimated that the air discharged from the mine will contain radon isotopes, principally from natural sources, at concentrations of about 1×10^{-9} curies per cubic meter. This concentration is about 10 times the concentration that occurs naturally in the atmosphere but is only 3% of the permissible concentration for occupational exposure. These isotopes (²²²Rn and ²²⁰Rn) occur naturally in most subsurface deposits and are released in all mining operations.

Fumes from diesel equipment in the mine and an aerosol of salt will be discharged from the mine in the ventilation air. The total rate of purge air has been selected to provide for

adequate dilution of diesel exhaust gases in conformance with Schedule 24 (Diesel Equipment for Nongassy, Noncoal Mines) of the U. S. Bureau of Mines. Practically all of the soot from the diesel exhaust and salt that has become airborne in the mining operations will be removed in the mine exhaust filters.

Alpha Mine. - The air in the alpha mine may contain small concentrations of radioactive particles and gases, chemically noxious gases and salt particles (Table 11.10). Concentrations of radioactive particles (containing plutonium) in mine ventilation air will be maintained less than 20% of the permissible concentrations for occupational exposure. The gaseous radioactivity will consist primarily of radon from natural sources.

11.2.2 Off-Site Consequences of Normal Releases

Based upon results of meteorological calculations (Table 11.11), the average annual airborne concentrations at the site boundary (~ 470 meters to the south) are estimated to be no greater than 8.5×10^{-6} units/ m^3 per unit/sec released. The estimated average annual off-site concentrations of airborne radioactive materials that originate in the radioactive wastes are no greater than 0.1% of the permissible concentrations for exposure of a suitable sample of an exposed population group (Table 11.12). The inhalation hazards from these sources are small as compared with radon that occurs naturally in the atmosphere.

The maximum level of off-site surface contamination contributed by sources in the Repository over its 25-year life is estimated as approximately 10^{-9} curies per square meter. This estimate is based on washout and fallout with a pessimistically high effective deposition velocity of 0.01 meters/sec. This level of surface contamination is less than 1% of the level that presently exists from man-made sources (see Table 11.5) and is well below FRC guidelines. At these levels of surface contamination, the experience has been that the materials cannot be reconcentrated to hazardous levels in food chains.

Table 11.11. Estimated Air Concentrations Per Unit of Release
at the Site Boundary of the Repository for Average
Annual and Short-Term Releases

Direction from Nearest Stack	Distance from Nearest Stack to Site Boundary, m	Average Annual Concentration, ^a Ci/m ³ per Ci/sec average release rate	Maximum Exposure Resulting from Short-Term Release, Ci·sec/m ³ per Ci released ^b
SSW	820	2.0×10^{-6}	9.0×10^{-4}
SW	890	1.5×10^{-6}	8.0×10^{-4}
WSW	530	2.4×10^{-6}	2.0×10^{-4}
W	400	5.3×10^{-6}	3.5×10^{-3}
WNW	300	5.0×10^{-6}	5.5×10^{-3}
NW	400	4.4×10^{-6}	3.5×10^{-3}
NNW	720	1.7×10^{-6}	1.2×10^{-3}
N	1800	6.5×10^{-7}	2.8×10^{-4}
NNE	2000	1.7×10^{-7}	2.5×10^{-4}
NE	1400	2.3×10^{-7}	4.0×10^{-4}
ENE	1100	1.6×10^{-7}	6.0×10^{-4}
E	980	3.7×10^{-7}	7.0×10^{-4}
ESE	580	7.2×10^{-7}	1.9×10^{-3}
SE	420	3.8×10^{-6}	3.3×10^{-3}
SSE	440	5.4×10^{-6}	3.0×10^{-3}
S	470	8.6×10^{-6}	2.8×10^{-3}

^aComputed with STAREL program (USAEC Report ORNL-TM-3187) assuming ground level source, wind rose data from the Wichita weather station, "C" stability conditions during the day, and "E" stability conditions at night.

^bComputed with the RELISH program (USAEC Report ORNL-TM-3187) assuming a ground level source and inversion ("F" stability category) conditions, and a wind speed of 0.67 m/sec.

Table 11.12. Estimated Release Rates and Average Annual Off-site Concentrations of Radioactive and Other Materials Resulting from Full-Scale Operation of the Repository

Material	Average Annual Rate of Release to Atmosphere	Average Annual Off-site Concentrations Resulting from Repository Effluents ^a	Percent of Applicable Standards for Exposure of the Public ^b	Percent of Estimated Present Concentration in the Atmosphere
High-level waste particles	0.007 Ci/yr	2×10^{-15} Ci/m ³	0.02	5.0
Alpha waste particles	0.03 μ Ci/yr	1×10^{-20} Ci/m ³	0.0001	0.005
⁸⁵ Kr (spontaneous fission)	0.014 Ci/yr	4×10^{-15} Ci/m ³	0.000004	0.02
³ H (spontaneous fission)	0.0009 Ci/yr	3×10^{-16} Ci/m ³	0.0000004	0.002
²²² Rn (natural sources)	0.9 Ci/yr	2×10^{-13} Ci/m ³	0.02	0.2
²²⁰ Rn (natural sources)	0.04 Ci/yr	1×10^{-14} Ci/m ³	0.0003	0.2
H ₂ (corrosion, radiolysis, electrolysis)	4 scfm	0.02 ppm	0.0002	4.
He (alpha decay)	0.001 scfm	0.000004 ppm	4×10^{-8}	0.00008
HCl (brine decomposition)	0.07 scfm	0.0003 ppm	0.006	100.
CO ₂ (diesel exhaust)	50 scfm	0.2 ppm	0.004	0.07
CO (diesel exhaust)	0.05 scfm	0.0002 ppm	0.0004	0.2
NO ₂ (diesel exhaust)	0.05 scfm	0.0002 ppm	0.004	7
SO ₂ (diesel exhaust)	0.03 scfm	0.0001 ppm	0.002	1
CH ₂ O (diesel exhaust)	0.0007 scfm	0.000003 ppm	0.00003	0.05
Soot (diesel exhaust)	2 lb/yr	0.1 μ g/m ³	0.0007	0.2
Salt particles	5 lb/yr	0.2 μ g/m ³	0.001	0.8

^aThese are the maximum concentrations which result at the southern boundary of the site.

^bBased on one-third of limits in 10CFR20, Table II, Column 1 for radionuclides and threshold limit values (American Conference of Governmental Industrial Hygienists) for other materials.

11.3 Consequences of Upper Limit Accidents

Certain highly improbable dispersive events that could result from operation of the Repository have been considered to provide some relative appreciation for the maximum consequences that could result from unplanned or unforeseen circumstances. All significant quantities of radioactive materials will be handled as tightly sealed packages of solid materials within confinement zones of the Repository. The only significant mechanism for sudden and acute release of radioactive materials from the Repository must involve rupture of a package and passage of airborne particulates through a series of two High Efficiency Particulate Air (HEPA) filters. These filter systems will be physically isolated from operating areas; preceded by a series of roughing filters; followed by differential-pressure-sensitive, quick-operation check valves; and tested routinely to provide protection against pressure surges, plugging, and deterioration.

11.3.1 Alpha-Operations Facility

Combustion of alpha waste, accompanied by rupture of the involved container(s) has the potential of generating more radioactive aerosol than any other type of accident that has been postulated for the Alpha-Operations Facility. The release to the atmosphere following such a fire would be maximized if this accident were to take place in the alpha waste receiving building, since a large fraction of the contaminated smoke would reach the filters. By comparison, smoke from a fire involving an exposed container in the mine would travel with low superficial velocity through many tortuous passages and be deposited largely on exposed surfaces upstream of the filters. Because of the filtration capability and decreased diffusivity of gases in thick layers of crushed salt it is expected that there would be no detectable release of aerosols from smouldering combustion within containers after they are backfilled.

Consequences of a fire in the alpha waste receiving building have been estimated by assuming there is a fire of 30-min duration that involves the contents of many packages of alpha waste. The rationale for this accident is that the contents of a single package containing undetected

solid oxidants, such as nitrate-soaked rags, are ignited by spontaneous combustion. The resulting fire is assumed to rupture the package and spread to other packages within the burial unit and to any adjacent burial units. The time period of 30 min is believed to be a very conservative overestimate of the time that would be required for complete combustion of the contents of the package containing solid oxidants and extinguishment - by the sprinkler system - of the combustion in other containers.

For this accident, it is assumed that the waste within the container contains plutonium at the maximum acceptable concentration of 5 g/ft^3 and that the waste (cloth, tissue paper, and plastic) has bulk density of 5 lb/ft^3 . Assuming 2% ash and soot resulting from combustion⁶ the plutonium concentration in the airborne particulate matter would be 0.11 g Pu/g .

The release of plutonium to the atmosphere through the HEPA filters is estimated by assuming that the concentration of particles in the filter effluent is 0.02 mg/m^3 and that the flow rate of air and smoke is 2600 cfm. The concentration of 0.02 mg/m^3 is considered to be a very conservative overestimate of the HEPA effluent concentration resulting from an influent that has the maximum stable concentration of small particles.⁷

Based upon the above assumptions, the estimated release of plutonium from the stack of the Alpha-Operations Facility would be approximately 0.005 g. Based upon the estimated maximum off-site concentration of $5.5 \times 10^{-3} \text{ g-sec/m}^3$ per gram released (Table 11.11) and the standard breathing rate of $0.0208 \text{ m}^3/\text{min}$,² the maximum quantity of plutonium inhaled by a hypothetical person standing at the site boundary during the entire period of release would be approximately $0.01 \text{ } \mu\text{g}$ of Pu. This hypothetical intake, corresponding to 20% of the maximum permissible body burden of the plutonium (Table 11.9), is considered acceptable in view of its very low probability of occurrence.

11.3.2 High-Level Facility

The upper-limit accident in the High-Level Facility is assumed to result from complete dispersal of the contents of a package of high-level waste in the air of the high-level transfer cell. Such an accident occurring in the mine would result in a much lower release to the atmosphere.

In particular, virtually no off-site exposure would result from dropping of a package in the waste shaft since it is planned that there will be no sustained flow of air from the shaft either into the mine or into surface facilities.

A maximum release of 0.009 curies of high-level waste to the atmosphere is estimated, based upon a filter effluent concentration of 0.02 mg/m³ for one complete volume change (7280 ft³) of the air in the high-level transfer cell. The estimated maximum quantity of high-level waste that could be inhaled by a hypothetical person standing at the site boundary is 0.02 μ Ci. This intake by inhalation corresponds to 1% of the maximum acceptable body burden for occupational exposure (Table 11.8).

11.3.3 Accidents in Transportation and Unloading of Rail Cars

Accident analyses for the transportation of wastes will be provided by the shippers of the wastes. With one exception, these analyses will also be applicable to the unloading of rail cars within the alpha and high-level waste receiving buildings. The exception is the possible release of radioactive material that could result from dropping a cargo container in the container unloading and storage area of the alpha waste receiving building. Since this area does not have the confinement features of the remainder of the facility in which alpha waste will be handled, procedural safeguards will be relied upon to minimize the spread of any radioactive material that is released from a cargo container that has sustained such an accident. These procedures will include covering the cargo container with, for example, a plastic tent. These immediate procedures would be followed by a careful assessment of the situation leading to decontamination procedures.

11.4 Consequences of Loss of Geological Containment

The primary objective of radioactive disposal is that of minimizing the risk of radiation exposure of the population within the foreseeable limits of technology. In view of technical alternatives, this objective proscribes the intentional discharge of wastes to the atmosphere or to

surface waters. At the present time, it is technically infeasible to destroy these wastes or to propel them into the sun. On the other hand, their perpetual storage at the surface is subject to uncertainties with respect to longevity of governments and forces involving sabotage and war. The most reasonable alternative is to dispose of them in an isolated, natural, solid environment, deep underground. Long-term safety is promoted by: (1) a high degree of confinement; (2) the option of retrievability in the event that it becomes necessary; and (3) storage of the wastes in a relatively dilute form such that the average concentration does not greatly exceed that of similar radioactive materials that occur naturally. For the reasons discussed in Sect. 2, a salt-mine repository provides the best method of satisfying these objectives.

As can be ascertained from Table 3.1, the Alpha Mine at the time of its decommissioning will contain 37 metric tons of plutonium in about 1 million tons of waste. Since the ingestion hazard of plutonium, on a mass basis, is about 10,000 times greater than that of aged uranium, the waste (containing 37 ppm of plutonium) has a hazard equivalent to material containing 37% uranium. The mineral pitchblend has been known to contain up to 80% uranium. If the plutonium is considered to be spread uniformly throughout the 180-acre by 300-ft-thick bed of salt and shale (150 million metric tons) that is associated with this mine, the resulting plutonium concentration of 0.25 ppm has a hazard equivalent to a material containing 2500 ppm of uranium. This concentration of uranium corresponds to that of the large deposits of uranium ore that exist on the Colorado Plateau.

Similarly, the High-Level Mine (1000 years after decommissioning when the ^{90}Sr and ^{137}Cs will have decayed to innocuous levels) will contain about 5 metric tons of plutonium, associated with 760 million metric tons of salt and shale (900 acres by 300 ft thick). A 10-ft-thick layer through the burial horizon would have an average plutonium content of 0.2 ppm, and a hazard equivalent to material containing 2000 ppm of uranium (uranium ore deposits). The concentration of plutonium, if mixed with the entire 760 million tons of salt and shale, would be only 0.006 ppm and have a hazard equivalent to a material containing about 60 ppm of uranium. This is typical of the uranium content of Chattanooga shales which are fairly evenly distributed over an area of hundreds of square miles in east-central Tennessee.

Table 11.13 relates projections of the average radiation density of waste materials in the salt bed after decommissioning to the radiation density that occurs naturally in the earth's crust. Rather than comparing activity densities, per se, however, the densities weighted by the appropriate concentration guide for ingestion are compared such that a more precise measure of the relative potential of these materials for contamination of surface waters is obtained.

These figures show that at the time of decommissioning the ingestion hazard of the salt bed in the high-level portion of the repository is about 190,000 times the hazard of an average of the earth's crust containing about 6 ppm of uranium and 12 ppm of thorium. The relative hazard decreases to unity after about 1 million years. Initially, the hazard is caused predominantly by ^{90}Sr . After progressively longer periods of decay, the most important nuclides are ^{241}Am , ^{243}Am , ^{226}Ra , and ^{129}I .

On the same basis, the relative hazard of the salt bed of the alpha facility is initially 230 - caused predominantly by ^{241}Pu and ^{241}Am - and becomes unity after about 300,000 years when most of the ^{239}Pu has decayed.

This analysis provides perhaps the most pessimistic view of the containment time that is required for the waste. Another measure of the containment time may be made by estimating the time that is required such that, if the salt and radioactive constituents were dissolved by water, the ingestion hazard of the resulting salt water would be determined more by its salinity than its radionuclide content. Assuming that the acceptable upper limit of salt content is 500 ppm, an acceptably low radiation density would be attained after about 1000 years in the high-level facility and 10,000 years in the alpha facility.

While these types of considerations certainly do not provide a final answer (we need to know more about solubility and mobility), they do indicate that the hazard associated with this facility will be diminished appreciably after periods of 1000 to 10,000 years (which are relatively short periods from the geologic point of view).

Table 11.13. Average Concentrations and Relative Hazards of Radioisotopes in the Repository as a Function of Time After Decommissioning

Time (years)	High-Level Facility				Alpha Facility		
	Radiation Density ^a (Ci/m ³)		Hazard Relative to Average U-Th in Earth's Crust ^{b,c}		Alpha Radiation Density ^d (Ci/m ³)	Hazard Relative to Average U-Th in Earth's Crust ^{b,c}	
	Beta	Alpha	Ingestion	Inhalation		Ingestion	Inhalation
0	82.6	0.485	188,000 (⁹⁰ Sr)	31,700 (²⁴⁴ Cm)	0.21	230 (²⁴¹ Pu)	46,400 (²⁴¹ Pu)
30	38.8	0.206	89,200 (⁹⁰ Sr)	16,000 (²⁴⁴ Cm)	0.297	250 (²⁴¹ Am)	36,500 (²³⁹ Pu)
100	7.15	0.073	16,000 (⁹⁰ Sr)	6660 (²⁴¹ Am)	0.279	223 (²⁴¹ Am)	28,200 (²⁴¹ Am)
300	0.101	0.0416	151 (⁹⁰ Sr)	3220 (²⁴¹ Am)	0.195	156 (²⁴¹ Am)	19,500 (²⁴¹ Am)
1000	0.0109	0.0176	15.4 (²⁴¹ Am)	1440 (²⁴¹ Am)	0.0928	70.5 (²⁴¹ Am)	12,100 (²⁴⁰ Pu)
3000	0.00997	0.00718	6.53 (²⁴³ Am)	794 (²⁴⁰ Pu)	0.0437	30.1 (²⁴⁰ Pu)	8340 (²⁴⁰ Pu)
10,000	0.00796	0.00438	4.25 (²⁴³ Am)	549 (²³⁹ Pu)	0.0270	18.7 (²³⁹ Pu)	5290 (²³⁹ Pu)
30,000	0.00588	0.00174	2.35 (²³⁹ Pu)	267 (²³⁹ Pu)	0.0106	8.38 (²³⁹ Pu)	2070 (²³⁹ Pu)
100,000	0.00462	0.000535	1.87 (²²⁶ Ra)	47.1 (²³⁹ Pu)	0.00158	3.62 (²³⁹ Pu)	266 (²³⁹ Pu)
300,000	0.00299	0.000577	1.81 (²²⁶ Ra)	13.4 (²³⁷ Np)	0.000406	2.94 (²³⁷ Np)	19.1 (²⁴² Pu)
1,000,000	0.00126	0.000600	0.941 (¹²⁹ I)	9.92 (²³⁷ Np)	0.000284	0.542 (²³⁷ Np)	7.53 (²³⁷ Np)
3,000,000	0.000495	0.000304	0.675 (¹²⁹ I)	5.14 (²³⁷ Np)	0.000132	0.0335 (²³⁷ Np)	2.43 (²³⁷ Np)
10,000,000	0.0000462	0.0000356	0.487 (¹²⁹ I)	0.645 (²³⁷ Np)	0.0000236	0.0122 (²²³ Ra)	0.551 (²³¹ Pa)
30,000,000	0.00000597	0.00000525	0.253 (¹²⁹ I)	0.122 (²³⁰ Th)	0.00000869	0.0101 (²²³ Ra)	0.329 (²³¹ Pa)

^aAssumes 100,000 containers of 5-year-old waste and 100,000 containers of 10-year-old waste dispersed in a 900-acre by 300-ft-thick bed of salt.

^bBased on maximum permissible concentrations in air and water from 10CFR20, and average concentrations of U and Th in the earth's crust of 6 ppm (5×10^{-6} Ci/m³ of ²³⁸U) and 12 ppm (3×10^{-6} Ci/m³ of ²³²Th), respectively. The U and Th are assumed to be in equilibrium with all radioactive daughters.

^cThe principal contributor to the relative hazard is shown in parentheses.

^dAssumes 38,300 kg Pu and daughters dispersed in a 180-acre by 300-ft-thick bed of salt.

11.5 Sabotage

Acts of sabotage could be directed at any part of the Repository causing damage or destruction of AEC property of great monetary value but, more important, they could result in the release of radioactivity to the extent that it jeopardizes public safety. Review of the Repository design and operation indicates that the radioactive waste is most vulnerable to sabotage while it is stored on-site before being unloaded from the rail car.

The waste is less vulnerable after it is moved inside the high-level and alpha waste receiving buildings, since it is either attended by operating personnel or securely locked and subject to guard patrol when unattended. Sabotage is least effective toward release of radioactivity after the material is moved below the surface and buried.

The design of the ATMX-600 series car for shipping alpha wastes and the shipping casks to be used for high-level wastes would make it very difficult for an act of sabotage to effect a release of radioactivity. However since the possibility exists, the following security measures will be enforced, once the cars are spotted on-site:

1. A thorough inspection of each car for explosive or incendiary devices.
2. Periodic inspections of each car until the radioactive material is removed.
3. An additional check before it is spotted inside the unloading area.

The Repository will have a seven-foot chain link fence topped with three strands of barbed wire surrounding all surface structures. All gates will be locked or under guard control. The fence will be located at least 100 ft from the nearest structure or section of track storing loaded rail cars; this distance should be sufficient to safeguard against explosive or incendiary devices being thrown over the fence onto or near rail cars or structures.

The surface structures will be of fire resistant construction and the waste handling areas will be designed to withstand tornadoes and earthquakes. The structures for the most part will be windowless with exterior

doors constructed of steel. Buildings constructed in this manner offer resistance to the effects of sabotage and serve as excellent physical barriers against illegal entry. Adequate locks will be installed, positive key controls will be established, and periodic guard checks will be made.

The design of the powder magazine will preclude sabotage from the outside, and positive controls will be established to prevent unauthorized entry.

Other considerations will include:

1. Protective force. The protective force proposed will consist of nine personnel deployed with three guards on the day shift and with two guards on each off-shift. Guards will be armed and will have available two separate means of off-site communications to summon help if needed. Supervisory tour systems will be utilized to assure that necessary areas are patrolled and other functions performed. Alarm systems will be used to supplement guard patrols of certain structures.
2. Protective lighting. Protective lighting of entrances, surface structures and rail car storage sites is planned to assist in detection of intruders and reveal unauthorized persons.
3. Access. Access to the facility during working hours will be controlled by guards, receptionists, or employees specifically designated as having responsibility for assuring that only persons with proper authorization are admitted. An employee identification system will aid in executing this function.
4. Prohibited articles. Signs will be posted at entrances warning that firearms, explosives, incendiary devices, and similar articles shall not be taken into AEC facilities without proper authorization. As a condition of access, packages and briefcases of persons entering the facility may be examined to ascertain that they do not contain such prohibited articles. This would include searches of vehicles entering the fenced site.

11.6 References

1. P. W. Krey and E. P. Hardy, Plutonium in Soil Around the Rocky Flats Plant, HASL-235 (August 1970).
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3. Environmental Effects of Producing Electric Power, Hearings before the Joint Committee on Atomic Energy, October 28, 29, 30, 31; November 4, 5, 6, and 7, 1969, pp. 254 and 255.
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5. C. E. Junge, Air Chemistry and Radioactivity, Academic Press (1963).
6. P. L. Magill, F. R. Holden, and C. Ackley, Air Pollution Handbook, pp. 1-42, McGraw-Hill, New York, 1956.
7. ORNL Staff, Siting of Fuel Reprocessing Plants and Waste Management Facilities, ORNL-4451 (July 1970).

12. DESIGN CONFIRMATION PROGRAM

Prior to acceptance of waste at the Repository, analyses will have been completed to assure safe operation of the facility. However, as an additional precaution, a design confirmation program for the high-level waste will be conducted in situ during the first several years of the Repository's operation. Many aspects of the high-level waste burial concept will be monitored and analyzed. If results indicate that containment integrity will not be adequately maintained, the waste will be removed from the Repository. To minimize the time and effort required for retrieval of the wastes, in the very improbable event that this is required, equipment for this purpose will be on standby. For the duration of the confirmation program, which is expected to be about 5 years, only enough waste to accomplish the objectives of the program will be buried. Many details of the experimental aspects of this program are yet to be developed pending the completion of laboratory studies and theoretical analyses.

12.1 Burial and Retrieval Concepts

12.1.1 Secondary "Containment" Within a Lined Hole

A high-level waste package consisting of solidified waste in a sealed metal container will be placed within a second container that is partially open at the top. This assembly will be placed in a vertical hole in the floor of a room (Fig. 12.1). The hole will contain a full-length metal or ceramic liner that will prevent collapse of the hole and ingress of brine for the duration of the confirmation program. No back-fill will be placed in the hole or in the room, and retrieval, if necessary, will be accomplished by lifting the two containers as a single unit out of the hole.

12.1.2 Proposed Long-Term Concept

A high-level waste package consisting of solidified waste in a sealed metal container will be placed directly in the salt, and crushed

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Fig. 12.1. Proposed Burial Schemes for Confirmation Period--High-Level Mine.

salt will be used as a backfill (Fig. 12.1). For a few experiments, some of the containers may be intentionally ruptured to expose waste directly to the salt environment. Retrieval will be by means of overcoring, in which case a core of salt containing the waste package will be removed. This burial concept will be restricted to about 10 waste packages during the confirmation program.

12.2 Specific Experiments

12.2.1 Handling and Burial

About 100 high-level waste packages will be accepted at the Repository to confirm that routine handling and burial procedures are safe. These waste packages will include the secondary "containment" and will be placed in the lined holes. Following burial, the annulus between the two containers will be monitored periodically to check for any breach of containment. A breach of the primary containment prior to confirmation of a long-term burial concept would be considered unacceptable for the confirmation period, and the leaker would be removed and recanned in a facility provided for that purpose.

12.2.2 Temperature Measurements

Temperature measurements will be made in the waste, on the container surface, and at various points in the salt to confirm the thermal analysis. Most of these data will be obtained from measurements in that part of the mine that is devoted to storage of doubly contained wastes. Electrically-heated, simulated waste containers may be used to supplement the waste heat source so that more realistic temperatures will be obtained.

12.2.3 Strain and Deformation Measurements

Strain and deformation data in the salt will be obtained from all areas containing heat sources.

12.2.4 Isotope Transport

These experiments will be conducted with the intentionally-ruptured waste packages. The upper end of the backfilled hole will be monitored for gas leakage, and small diameter cores will be extracted from the salt above and adjacent to the waste.

12.2.5 Waste Package Movement

Pressure taps will be installed in a few waste and electrically-heated containers to monitor steam and gas pressure surrounding the containers. Also, a stylus will be attached to the top of a waste container so that relative vertical movement between container and room floor can be determined.

13. MANAGEMENT

13.1 Project Organization

Overall direction and administration for the Repository project is the responsibility of the U. S. Atomic Energy Commission (AEC). Technical direction of the project has been assigned to Oak Ridge National Laboratory (ORNL) which has prepared the basic project criteria for the conceptual design of the Repository. ORNL will provide planning, direction, evaluation, and coordination of the entire project; establish and maintain a project plan and schedule; direct and approve the preparation and editing of project documentation and funding schedules; review all drawings and specifications; and procure certain equipment.

Engineering for the conceptual design has been accomplished by a qualified architect-engineer (A-E) firm, Kaiser Engineers, Inc., under contract with the Oak Ridge Operations Office (ORO) of the AEC with optional provisions therein for performance by the A-E of such Title I, II, and III engineering services as may be requested by the AEC. ORNL will maintain technical direction of the A-E at all stages of the design. The A-E will prepare the appropriate construction drawings, mine development plans, quality assurance program, and cost estimate. ORNL, AEC, and Kaiser Engineers have collaborated on the preparation of a conceptual design report, which combines the essential features of a systems design description, and a facilities description.

Facility construction will be accomplished by one or more qualified construction contractors under prime AEC contract. The construction activities will include construction of all facilities above and below ground, including shafts; procurement, inspection and installation of certain pieces of fixed and operating equipment; and maintenance of quality assurance standards.

Repository operation will be the responsibility of an operating contractor under prime contract with the AEC. The contractor will be selected by the AEC as soon as it is feasible, using established selection procedures. The operating contractor will establish operational

procedures, conduct operator training programs, prepare operational safety analyses, and operate the facility.

The AEC will coordinate reviews for Repository licensing and safety analysis. They will be assisted in this function by ORNL, the operating contractor, and the A-E.

Project-related research and development programs will be conducted by ORNL and other agencies, as required, under technical cognizance of ORNL. These programs include, but are not necessarily limited to:

1. Analysis, projection of quantities, and characterization of wastes.
2. Development of criteria for packaging and shipping of wastes.
3. Establishment of alpha waste nondestructive assaying procedures.
4. Preparation and refinement of the Environmental Quality Statement.
5. Preparation of preliminary estimates of waste burial costs, based on full recovery of capital and operating costs.
6. Engineering and testing of certain specific equipment and components.
7. Geological, ecological, hydrological and environmental studies as necessary to assure the safe operation of the Repository, including
 - a Planning, direction, and evaluation of the environmental program required in support of the Repository;
 - b Preparing and maintaining a detailed plan for the ecological, geological, and hydrological investigations necessary to establish the adequacy of the site for the Repository;
 - c Completion of shallow hole hydrology, investigation of on-site aquifers, drilling of core holes for studies of stratigraphy, hydrology, geophysical logging and analysis of thermal and mechanical properties;

- d Continuing the ecological review to determine the effects, if any, of Repository operations on the area.
8. Conduct a design confirmation program during the initial 5 years of Repository operation. This program will include in situ tests using high-level wastes in order to establish the safety and feasibility of the burial concept. A Repository demonstration program will be implemented after completion of the design confirmation program (see Sect. 12).

13.2 Operating Organization

Repository operations will be the responsibility of an operating contractor under prime contract to the AEC. Early selection of an operating contractor is necessary, since this organization will not only develop their staffing requirements but will also assist in the preparation of operating procedures, operational safety analyses, and operator training programs prior to the start of Repository operations. In addition, it is anticipated that the initial underground development work in both the alpha mine and the high-level mine will be performed or administered by the operating contractor. The design and arrangement of administrative, service, and mine development facilities can also benefit from the early involvement of the operating contractor.

The operating organization for the Repository will require a unique combination of technologies - mining operations and radioactive waste handling operations. The operating organization must, therefore, consist of a combination of the required skills and experience, organized to form one integrated operating unit. Because of its functions and its geographical location, the Repository organization must also include the necessary personnel to make it essentially a self-sufficient unit, recognizing that for certain major maintenance, repair or other work, the operating contractor can be expected to rely on commercial capabilities outside the Repository.

The planned Repository operating organization is shown in Fig. 13.1. This organizational arrangement must be considered preliminary at

Fig. 13.1. Planned Repository Operating Organization.

this time since the operating contractor, when selected, may wish to make some changes in the structure. Repository operations will be under the direction of a plant manager who will be responsible to the AEC for satisfactory operation of the Repository. Because of its importance to Repository operations, the plant manager must also develop the close liaison and coordination required with the waste-generating sites.

The general superintendent will be responsible to the plant manager for all plant operations, including waste handling and burial and mining operations, as well as the required maintenance and operations support. During an initial period, it is anticipated that a one-shift-per-day operation will be sufficient to handle the projected waste receipt rates. As waste rates increase, second and third shifts will be added for alpha and high level receiving operations as required. When this occurs, the organization will include shift superintendents, one of which will be responsible for Repository operations on each shift. In either case, the superintendent on duty at the Repository during an emergency period will act as the emergency coordinator.

The plant manager will be provided staff engineering and technical support by a group headed by the chief engineer. This group will include the technical disciplines required to support Repository operations and planning and provide safety evaluation and operating standards. While this group will include a health physics supervisor, health physics surveyors will be included in both the surface and mine operating groups.

An administration group, headed by an office manager, will provide the administrative services required by the Repository. An important element of Repository functions will be the accurate accounting and reporting of costs, since these costs will be used in establishing charges to waste-generating sites. This group will also be responsible for scheduling and maintaining accurate records of waste shipment and burial data.

The estimated schedule of operating personnel during the design, construction and initial operating periods is shown in Table 13.1. It is expected that, after operator contractor selection, key technical personnel of the contractor will be assigned for project indoctrination and training

Table 13.1. Estimate of Operating Personnel During Design,
Construction, and Initial Period of Operations

Category	Fiscal Year						
	73	74	75	76	77	78	85
I ALPHA OPERATIONS							
A. Surface Handling		1	3	20	20	20	38
B. Mine Cleanup and Waste Burial		11	11	16	16	16	22
II HIGH-LEVEL OPERATIONS							
A. Surface Handling		1	3	17	17	17	32
B. Mining and Waste Burial		8	8	11	11	11	44
III MAINTENANCE AND OPERATIONS SUPPORT		8	8	32	32	32	50
IV GENERAL ADMINISTRATION AND TECHNICAL SUPPORT	7	12	13	29	30	30	34
	—	—	—	—	—	—	—
TOTAL PERSONNEL	7	41	46	125	126	126	220

purposes. This technical group would be enlarged during the period prior to operation to assist in the preparation of operating procedures and operational safety analyses. The schedule assumes that the operating contractor would perform or administer the mine development work starting in FY 74 on a one-shift operation. It furthermore assumes that burial operations will begin late in FY 76. Operating personnel training programs would be conducted starting in FY 76. By 1985, the alpha and high level burial operations will be a two-shift operation.

13.3 Emergency Plan

The design and method of operation of the Federal Repository will minimize the probability of incidents which could have adverse consequences offsite or within the general vicinity of the Repository. However, it is considered prudent to establish emergency plans to cope with unforeseen on-site emergency situations, to further minimize potential adverse consequences offsite, to minimize hazards to plant personnel, and to reduce potential loss to plant equipment.

The emergency planning program at the Federal Repository will be directed specifically to radiological emergencies, but it also will be intended to cope with major accidents, fires, natural disasters, release of toxic materials, and other unforeseen emergencies.

13.3.1 Organization

The personnel comprising the emergency organization will be selected from the operating organization described in Sect. 13.2. This organization will be formulated to meet not only radiological emergencies but also major accidents, fires, natural disasters, release of toxic materials and other emergencies. Emergency squads such as first aid teams, radioactivity monitoring and decontamination personnel, fire fighting squads, etc. will be made up of designated and specially trained operating personnel, both at surface and mine level. The emergency plan will define the lines of authority, responsibilities, and functions of the assigned qualified individuals and groups.

The emergency plan will specify the emergency organization personnel to be notified in the event of an emergency and the means of notification.

As noted above, during each operating shift there will be a shift superintendent who will be responsible for all plant operations. During emergencies the shift superintendent or his designated alternate will act as emergency coordinator until supplanted by higher authority. In addition to the normal telephone service, there will be a two-way short-wave radio communication system for emergency back-up service, both within the Repository and with outside emergency organizations.

13.3.2 Coordination with Off-Site Groups

Coordination of emergency planning with offsite groups will be required since the operating contractor will be primarily responsible for coping with emergencies onsite and will have no authority for dealing with offsite emergencies. In addition, for some emergencies, the operating contractor will place significant reliance upon assistance from offsite groups for coping with onsite emergencies; i.e., medical and fire.

The emergency planning program will anticipate possible emergency needs and provide for obtaining the required capabilities. It will set forth when actions are to be taken onsite and offsite, and the conditions required for notification of offsite groups. Plans for coordination of both the onsite emergency organization (as defined in Sect. 13.3.4) and the offsite assistance groups will be set forth in emergency procedures, and training of both groups will assure a high degree of cooperative effort for effectively coping with any emergency. To the extent deemed necessary and practical, as more definitive emergency plans are developed, agreements or understandings will be developed with offsite organizations such as the following:

1. Civil defense
2. State government
3. County government
4. City government
5. State highway department
6. Other Federal agencies
7. Local health authorities
8. State health authorities
9. Radiological Assistance Team (Region 4)

10. Local hospitals
11. Local or private fire departments
12. Ambulance service
13. Local police departments

Periodic updating of emergency planning activities and the testing of the effectiveness of emergency planning programs will be coordinated with those appropriate agencies indicated above.

13.3.3 Emergency Procedures

Detailed emergency procedures for the implementation of emergency planning will specify the protective measures required to place the facility in a safe condition. These procedures will include:

1. Action levels and limits to specify when emergency actions are to be taken.
2. The actions and tasks required to provide the appropriate protective measures, including testing and maintenance of emergency equipment.
3. The procedures for evacuation or take-cover, and personnel accounting.
4. The procedures for re-entry and rescue.
5. The delineation of the individual assignments of authorities and responsibilities for performance of specific tasks.
6. The identification of specific actions to be performed by coordinated support groups, both the onsite emergency teams and the offsite assistance groups.
7. The procedures for medical treatment and the handling of contaminated individuals.
8. The listing of the special emergency equipment required for rescue and treatment. At the Repository, the mine operations building at the top of the alpha-M&M shaft will serve as the control center at surface level for emergency equipment and operations, since this building contains the dispensary and the central control and monitoring station. At mine level, the air lock in

the man and materials station of the alpha-M&M shaft will serve as a refuge for mine personnel in case of fire or other emergency conditions.

9. The designation of an alternate emergency control center.
10. The use of the available communication networks.
11. The procedures required to restore the emergency situation to normal.
12. The procedures for releasing statements concerning accidents or emergency situations to the public news media.

The procedures will be tested periodically and reviewed and updated as required to meet changing conditions. These procedures will be utilized in the training program for Repository employees and off-site groups who will be a part of the emergency organization.

13.3.4 Training Program

The training program for Repository personnel and offsite groups that will comprise the emergency organization will be carried out in two phases:

1. An initial training program prior to the start of Repository operations.
2. Periodic drills using the established emergency plans after operations commence.

Prior to the start of Repository operations, the emergency squads and teams will be formed from qualified operating personnel and given a special training program using the developed emergency procedures and simulations of emergency conditions. This will provide an initial testing of the procedures and ensure that both Repository employees and offsite groups are familiar with their specific duties in case of an emergency.

After operations commence, periodic simulation of emergency conditions will be made to provide assurance that personnel continue to be familiar with their duties and to retest the applicability of the emergency procedures. Periodic fire drills and radiological incident drills will be held, unannounced and during working hours. An evaluation

will be made to determine the effectiveness of the drills and any deviation from established procedures.

13.4 Quality Assurance

The objective of the quality assurance program for the Federal Repository project will be to assure that the quality required for safe, reliable, and economical operation will be achieved. To attain this objective, assurance must be obtained that the structures, components, systems and facilities that comprise the Federal Repository are designed, developed, manufactured and constructed in compliance with established engineering criteria. Further, the quality assurance program will establish the means of control and verification to prevent, detect and correct any deficiencies.

The quality assurance requirements applicable to the design and construction phases of the Federal Repository project can be arranged in the following categories:

1. Management and Planning
2. Design and Development
3. Procurement
4. Manufacturing, Fabrication and Assembly
5. Construction and Installation

13.4.1 Management and Planning

The management and planning activities for quality assurance include the development and implementation of a quality assurance program plan; the organization, training and indoctrination of personnel; the generation of required documentation; and the performance of reviews and audits. The quality assurance program plan, established by ORNL and the A-E prior to start of Title II engineering, will describe policies, practices and procedures, and will identify the facility components to be included in the program. Such items will be classified in relation to their function and importance so that the efforts expended to attain and verify quality can be allocated in proportion to their importance.

Among the bases for establishing function and importance will be the end use of the item, the consequences of its failure, associated safety hazards, and the required operational capability and reliability.

Organizational responsibility for the quality assurance program will be clearly defined. During the design phase of the Repository project, the primary responsibility for implementing the program will rest with the A-E as a part of his Titles I and II work, with appropriate review and approval by ORNL and the AEC. The quality assurance for the procurement, manufacturing and construction phases will be established by the A-E during Title II design, and reviewed and approved by ORNL and the AEC. The A-E's Title III work will include implementation of the program during these three phases.

A basic principle for a quality assurance group is that personnel assigned to check, inspect and audit the work are not directly responsible for performing the work, and that the one responsible for direction of a quality assurance program will have direct access to management. Personnel performing quality assurance functions will have the organizational freedom, authority, and capability to identify and evaluate problems. Training programs for quality assurance personnel involve familiarization with the technical activities of the project, the codes and standards to be used in the engineering, and quality assurance practices to be employed.

An essential part of a quality assurance program is the preparation and maintenance of adequate documentation. Documentary evidence of the performance of activities affecting quality will include quality assurance program plans, procedures, personnel training records, quality audit reports, summaries of nonconformances and reports on failures and corrective actions.

4.2 Design and Development

The quality assurance requirements applicable to the design and development activities include the planning, definition, and control of design; any required development and qualification testing; and appropriate documentation and audit of the design and development activities.

The design planning activities will include outlining the approach and measures to be used in achieving project objectives; these activities will be documented in an appropriate form. Repository items will be classified with respect to function, relative importance, and contribution to achieve project objectives; this classification will serve as the basis for determining the level of effort to be applied in verifying quality. Items requiring development work and qualification testing will be designated so that satisfactory performance of new design concepts can be demonstrated prior to the start of Repository operations. Interrelationships among those responsible for the preparation of designs, coordination of interfaces and lines of communication will be defined.

Design criteria which will provide the requirements to be satisfied by the design will include performance objectives, operating conditions, and requirements for safety and availability, as well as the requirements for materials, fabrication, construction, testing, operation, maintenance and quality assurance. Methods for controlling design activities will be established to assure that design criteria and applicable quality requirements are set forth correctly in the drawings and specifications.

Document review and control during the design and development phase will be systematically conducted to verify the completeness and accuracy of the drawings and specifications with respect to contract requirements, engineering standards, design practices and intended application. Design reviews will be conducted by the Repository project participants to assure that the design being developed meets project requirements. These design reviews will be documented to record significant problems, decisions and action items.

13.4.3 Procurement

Requirements in this category include procurement plans, selection and evaluation of procurement sources, preparation and review of procurement documents, source and receiving inspection activities, control of finished items, and recording and auditing of procurement

activities. The necessary controls will be employed to assure that procurement functions are accomplished in accordance with project requirements.

13.4.4 Manufacturing, Fabrication and Assembly

The quality assurance requirements for inspection and testing to be applied during the manufacturing, fabrication, and assembly of equipment and materials for the Federal Repository will be specified by the A-E in the drawings and specifications. To achieve economy consistent with the function and importance of an item, the requirements will vary with item classification. Quality assurance requirements during manufacturing, fabrication and assembly may include manufacturing planning, control of materials and processes, inspection and testing of in-process and completed items, control of non-conforming items, preparation for shipping, and documentation of these activities. The level of these requirements will be consistent with the function and importance of the item; appropriate documentation will be required on the fabrication and testing of special and important items whereas only standard commercial testing and documentation will be required for standard items of lesser importance.

13.4.5 Construction and Installation

The quality assurance program requirements applied during the construction and installation phase will be intended to assure that the structures, components and systems essential to the safety, operability, and reliability of the Repository are installed, constructed and tested in conformance with the drawings and specifications. The quality assurance functions during this phase will be undertaken by the A-E as a portion of his Title III work.

Quality assurance activities during this phase will include:

1. The participation in construction planning so that the construction activities and the associated quality assurance work are properly coordinated.

2. The inspection of construction and installation to assure that contract requirements are being met.
3. The witnessing of startup tests on equipment and systems.
4. The compilation and maintenance of quality assurance records and data generated during this phase of the work. These records will include not only such items as inspection and test reports, but also a definition of the as-built project so that the A-E may complete the as-built drawings as a part of his Title III work.

13.5 Coordination with Waste-Generating Sites

Efficient operation of the Repository will depend in a large measure upon a close working relationship among the operating contractor, the AEC, and the waste-generating sites. Liaison and coordination will be provided with the waste-generating sites.

Principal responsibilities of waste generating sites will be:

1. Submission of alpha waste cargo container, waste can and shipping cask drawings to the Repository for approval.
2. Checking waste shipments to ensure that Repository contamination and radiation acceptance criteria are met and to assure that shipments are of certified integrity prior to transport to the Repository.
3. Certifying the contents of the waste packages.
4. Coordination with the Repository on all shipping schedules to minimize the buildup of a large inventory of loaded rail cars at the site.
5. Notifying the Repository immediately after a shipment leaves his plant, transmitting the following information:
 - a. Method of shipment and routing.
 - b. Expected arrival date.
 - c. Number of rail cars in shipment.
 - d. Rail car identification numbers.
 - e. Cask or cargo container identification numbers.
 - f. Waste composition of each cask or cargo container.

- g. Cask surface temperature at equilibrium.
 - h. Heat evolution and total nuclear energy of each waste can in shipment.
 - i. Fissile content of each waste container in shipment.
 - j. Cask primary coolant activity in curies.
 - k. Cask or cargo container exterior radiation and surface contamination levels.
6. Submission of an itemized listing for each cask or cargo container providing the following information:
- a. Identification number of each high level waste can, and each alpha waste burial unit and each individual drum included therein.
 - b. History and waste composition - each can and burial unit.
 - c. Fission product content in curies - each can and burial unit.
 - d. Fission product heat generation rate - each can and burial unit.
 - e. Individual and total fissionable isotopes content - each can and burial unit.
 - f. Weight of each can and burial unit.
7. Emergency coordination procedures in effect during each shipment of all wastes to the Repository.

14. DECOMMISSIONING

Current planning, based on the projected waste burial rates, has established that the salt bed area to be included in the Federal Repository will be sufficient for the burial of wastes until approximately the year 2000. At that time, or when Repository operations are completed, it is planned that the Federal Repository be decommissioned.

The process of decommissioning the Federal Repository will include the removal of the surface facilities and the sealing of the mine. It is planned that the surface vegetation will be converted back to native grassland. Permanent markers will be placed to designate the mine and former shaft locations and to warn of the potential hazards of drilling operations. The decommissioning procedures will conform to the intent of the proposed Appendix F to 10CFR50.

14.1 Surface Facilities

The need for or suitability of the surface facilities of the Repository for other uses after waste burial operations are complete cannot be foreseen at this time; therefore, it is planned that they be removed rather than converted to other uses. The removal of the surface facilities will involve removal of uncontaminated equipment, decontamination or disposal of contaminated equipment or portions of structures, followed by demolition and disposal of remaining structures.

14.1.1 Decontamination

Past experience within the AEC has demonstrated that buildings housing fuel reprocessing and other types of radiochemical facilities can be decontaminated to acceptably low levels. Prior to the time of decommissioning, procedures for performing the necessary decontamination will be prepared based upon experience accumulated to that date. It is anticipated that decontamination will be required for the transfer and recan cells and their equipment, the process waste system in the high level waste receiving building, and possibly some portions of the alpha

waste receiving building. Since the wastes handled at the Repository are to be confined within cans or burial units and areas will be routinely decontaminated where necessary during the operating period, the extent of the required decontamination prior to demolition should be minor.

14.1.2 Demolition and Disposal

Demolition and disposal of surface facilities and the transfer or disposal of equipment will be carried out in accordance with procedures to be prepared and approved prior to decommissioning. Included in the procedures will be a designation of the facilities that were not subject to possible radioactive contamination and those that were. The facilities not subject to possible contamination can be demolished and disposed of by conventional methods. For the facilities that have been subject to contamination, sufficient monitoring during demolition must be performed to ensure that the decontamination process previously performed has been complete.

The contaminated debris from the decontamination and demolition process could be packaged and disposed of in either the alpha mine, if still accessible, or in a new Repository.

14.2 Mine Sealing Procedures

All penetrations from the surface to the mine will be sealed in the decommissioning process to prevent intrusion of water into the salt stratum and to prevent any possible leakage of radioactivity from the burial areas to the surface. The penetrations to be sealed during or prior to decommissioning include:

1. The alpha-M&M shaft, an 18-ft ID circular shaft with a 1-ft thick concrete lining.
2. The high-level shaft, a 4-ft-ID circular shaft with a 1-ft thick concrete liner.
3. The upcast vent shaft, a 6-ft-ID circular shaft with a 1-ft thick concrete liner.

The procedures for sealing and testing these penetrations will be developed in the course of sealing the existing shafts and boreholes on the site and buffer zone (Sect. 5.5).

14.3 Perpetual Surveillance

Following the decommissioning of the Repository and sealing of the mine, it is planned that the site and certain subsurface mineral rights in the one-mi buffer zone bordering the Repository will be maintained in the perpetual care of governments and that permanent markers will be placed to warn of the potential hazard of drilling operations. Site and regional monitoring will be continued indefinitely under the auspices of State and Federal agencies, and permanent records will be maintained of the temperatures in the ground and the underground aquifers over and around the waste burial areas and of the radioactivity concentrations in the air and the surface water.

15. APPENDIX A: DESIGN CRITERIA FOR EARTHQUAKE AND WIND CONDITIONS

15.1 Site Description

15.1.1 Geology and Seismology

The rocks at the site are all of sedimentary origin and, for the most part, are flat lying. This sedimentary sequence lies unconformably on the Precambrian basement at a depth of about 4,000 feet and contains first about 700 feet of Cambro-Ordovician limestones and dolomites and a small (about 100 feet) section of Devonian-Mississippian shales. This is overlain by about 1,200 feet of Pennsylvanian limestone interbedded with various shales and sandstones. This is unconformably overlain by a thick (2,000 feet) series of Permian age which reaches to within 100 feet of the surface. The lower part of this section contains interbedded limestones and shales, while the upper is almost entirely shale. A 400-foot-thick series of evaporites containing interbedded anhydrite, salt, and shale occur near the middle of this section. This is overlain by a thin veneer of Cretaceous shale and Pleistocene unconsolidated silty terrace deposits.

The entire region is located within the "stable interior" and has been subjected to only very mild structural deformations, consisting mostly of slow vertical movements and gentle warping, throughout its geologic history. It can be demonstrated that the structural basins and arches (Fig. 4.10) have developed over a long period of geologic time and apparently without appreciable earthquake activity, as indicated by the lack of faulting. By plotting the locations of historic earthquakes (Table 15.1) and observing their relationships to the major structural features (Fig. 4.10) in Kansas, it can be shown that there is an almost complete absence of earthquakes along the central Kansas uplift which is the nearest structural feature to the site. The epicentral locations of many of the earthquakes were centered along the Nemaha anticline in eastern Kansas. Based on the recent seismic history of all of the other structures in Kansas, it is likely that they are tectonically inactive.

Based on this conclusion, it appears that the most violent shaking at the site would be caused by larger earthquakes at considerable distances.

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area
(Revised, December 11, 1970)

(In general, an area bounded on the south and north by the 36° and 42° north latitude lines and on the east and west by the 95° and 102° west longitude lines.)

Date	Time ^a	Epicenter Location	Modified Mercalli Intensity	Description
Dec. 16, 1811	02 00	36.3-89.6	X	Affected at least 2,000,000 square miles--New Madrid, Missouri. ^b
Jan. 23, 1812	09 00	36.6-89.6	X	Affected at least 2,000,000 square miles--New Madrid, Missouri.
Feb. 7, 1812	03 45	36.6-89.6	X	Affected at least 2,000,000 square miles--New Madrid, Missouri.
Apr. 24, 1867	14 22	39.5-96.7	VII	Affected 300,000 square miles. Near Manhattan, Kansas; several injured. ^b
Nov. 8, 1875	04 40	39.3-95.5	V	Near Valley Falls, Kansas. People awakened and buildings rocked. Felt at Leavenworth, Lawrence, Manhattan, and Burlingame, Kansas. Felt over 8000 square miles. ^c

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time ^a	Epicenter Location	Modified Mercalli Intensity	Description
Nov. 15, 1877	11 45 and 12 30	41.0-97.0	VII	Felt in eastern Nebraska, Iowa, Kansas, the Dakotas, and north-west Missouri. Two shocks 45 min apart, the second being the stronger. Walls cracked at North Platte, Nebraska. Buildings rocked at Lincoln; walls damaged at Columbus; and the shock was strong at Omaha. Intensity III at St. Joseph, Missouri. Felt over 140,000 square miles. ^c
May 19, 1881	09 00		I or II	Felt at Lawrence, Kansas. ^b
Nov. 7, 1882	10 30	40-105	V - VII	Epicenter in Colgrado. Felt in Salina, Kansas.
Dec. 2, 1897	13 10		III	Felt at Kansas City, Kansas. ^b
Oct. 27, 1904	Occurred in PM	37.7-100.0	V	Meade and Dodge City, Kansas. People awakened and dishes rattled. Three shocks at Dodge City. Felt over 2700 square miles. ^c

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Jan. 7, 1906	18 15	39.3-96.6	VII	Manhattan, Kansas, where a roar preceded the shock by 10 sec. Chimneys thrown down and walls cracked. Plaster was knocked from walls at Wamego, 15 miles west and at Junction City, 19 miles southwest. Felt from Plattsmouth, Nebraska, to Wichita, Kansas, and from Bethany, Missouri, to Beloit, Kansas. Two distinct shocks. Felt over 10,000 square miles. ^c
Jan. 23, 1906	08 00		II - III	Manhattan, Kansas. ^b
Feb. 26, 1910	02 00	41.4-97.3	IV to V	Columbus, Nebraska, local shock shaking houses. There were several shocks.
May 26, 1919	21 06		IV	Wichita, Kansas. ^b
July 26, 1919	05 00	37.7-97.3	III	Wichita, Kansas. ^b
Jan. 7, 1927	03 30	38.4-97.8	IV	McPherson, Kansas. ^b
Mar. 19, 1927	11 25	40.0-95.3	VI to VII	White Cloud, Kansas, where houses rocked and people rushed outside. Felt over 300 square miles. ^c

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Nov. 8, 1928	08 15	39.5-98.1	Local (no in- tensity given)	Felt at Industrial School, dishes rattled and windows shook. Extremely local--not reported elsewhere. ^d
Sept. 23, 1929	04 00 and 05 00	39.0-96.6	V	Manhattan and Junction City, Kansas, where houses were shaken. Two shocks on September 23, one on October 23, and another on December 7 in same vicinity of northeast Kansas. September 23 shocks felt over 15,000 square miles. ^c
Oct. 21, 1929	15 30	39.2-96.5	V	Manhattan aftershock felt over 8000 square miles. ^{c,d}
Oct. 23, 1929	(Time not given)	39.0-96.8	No intensity given	Junction City, Kansas. ^d
Nov. 26, 1929	22 20	37.2-99.7	IV or V	Ashland, Kansas. ^d
Dec. 7, 1929	02 02	39.2-96.5	V	Manhattan aftershock. Felt over 1000 square miles. ^{c,d}
Aug. 9, 1931	00 18		IV	Kansas City, Missouri. ^b
Jan. 28, 1932	18 15		III	Near Ellis, Kansas. ^b

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Feb 20, 1933	11 00	39.8-99.8	V	Northern Kansas and adjacent Nebraska. People left buildings at Norton, Kansas. Felt over 6000 square miles. ^c
Mar. 1, 1935	05 00	40.3-96.2	VI	Near Tecumseh, Nebraska, where a few windows were broken and walls and plaster cracked. Some damage occurred at St. Mary, Nebraska. Felt over an area of 50,000 square miles. ^{c,d}
Mar. 22, 1935	16 45			Southeastern Nebraska. Mild earthquake. ^d
June 19, 1936	21 24	35.8-101.3	VI	Epicenter in Texas Panhandle. Felt over 40,000 square miles. ^b
June 11, 1942	23 50	36.4-97.8	No intensity given	Near Enid, Oklahoma. Light shock. Reported felt at Ames, Billings, Breckinridge, Covington, Enid, Fairmont, Garber, Garfield, Hennessey, Hilldale, Hunter, Kremlin, Lahoma, Lamont, Nash, Saltfork, and Waukomis. Felt over an area of approximately 1500 square miles. ^e

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Sept. 10, 1942	05 00	38.9-99.3	No intensity given	Near Hays, Kansas, where vibrations were strong enough to awaken some residents there. Felt also at Plainville and Stockton. ^e
Mar. 11, 1948	21 29	36.0-102.5	VI	Northern Texas; moderately strong earthquake. Felt over approximately 50,000 square miles of Colorado, Kansas, Oklahoma, New Mexico, and Texas. Slight damage--mainly cracked plaster. ^e
Apr. 2, 1948	21 00 to 22 00	37.7-97.3	III	Near Wichita, Kansas. Six tremors felt in Beechwood area about 5 miles east of Wichita. Walls of homes in federal housing project (good construction, wood) trembled. Ripples and mild shaking of water noticed in goldfish bowls. ^{b,e}
Apr. 7, 1948	(No time given)	41.4-99.7	No intensity given	Broken Bow, Nebraska. Very slight ^e earth tremor reported felt.

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Apr. 9, 1952	10 29 15	35.4-97.8	5.5 ^g	Near Oklahoma City, Oklahoma. Felt over 140,000-square-mile area, including Oklahoma, eastern half of Kansas, southeastern Nebraska, northern and central section of Texas, and throughout the western section of Iowa, Missouri, and Arkansas. Portions of chimneys fell in El Reno and Ponca City, Oklahoma. Damage was not extensive. ^e
Feb. 24, 1955	19 45	41.4-98.7	IV	Cotesfield, Nebraska. Many residents startled. Windows and dishes rattled, houses creaked, and furniture trembled. Felt also at Dannebrog, Elba, Farwell, Ord, Scotia, and St. Paul. ^e
Jan. 6, 1956	05 57 59	37.3-98.5	VI	Southern Kansas. Shock caused minor damage at Coldwater and Medicine Lodge, Kansas, and at Alva, Oklahoma. Felt over an area of approximately 16,000 square miles of south central Kansas and northwestern Oklahoma. ^{c,e}

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Feb. 16, 1956	17 30	35.4-97.3	VI	Edmond Oklahoma. Felt by and alarmed many. Felt at Guthrie, Oklahoma City, Pawnee, Big Cabin, Chickasha, Cushing, Duncan, Shawnee, and Stillwater. Few windows broken and plaster cracked. Cracks enlarged in high school building at Pawnee where Intensity was 5. ^{c,e}
Oct. 30, 1956	04 36 21	36.2-95.8	VII	Maximum intensity at Foster Ranch just west of Catoosa near Tulsa, Oklahoma. An oil well there was shut down by a slippage of the formation and sticking of tools. Felt over an area of approximately 3700 square miles. ^{e,c}
June 17, 1959	04 27 07	34.5-98.5	VI	Southwest Oklahoma. Damage to plaster, foundations, and pavement. Felt over approximately 12,000 square miles, including Tulsa. ^{e,c}
Apr. 13, 1961	15 14 57.2	39.9-100.0	V	Kansas-Nebraska border. Felt by and frightened many in Norton County, Kansas, and Furnas County, Nebraska. No damage felt over 18,500 square miles. ^{e,b,c}

Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Dec. 25, 1961	06 20 02.8 and 06 58 21.4	39.1-94.6	V	Kansas-Missouri border. Many awakened. Plaster cracked at Corder, Hardin, and Kansas City, Missouri. Objects thrown from shelves and broken. Felt over an area of approximately 11,000 square miles. ^{c,e}
Mar. 27, 1964	~21 00	42.7-104.0	V	Near Van Tassell, Wyoming, not far from Wyoming-Nebraska border. Felt in Nebraska and South Dakota. Doors and dishes rattles and furniture vibrated. (No area in square miles given.) ^e
Mar. 28, 1964	03 08 45.0	42.9-101 6	VII	Northern Nebraska. Felt over an area of 90,000 square miles of Nebraska, South Dakota, and border areas of Montana and Wyoming. Cracks reported in road 10 miles south of Merriman, Nebraska. Steep banks tumbled along river. Plaster fell and Chimneys toppled at Alliance, Nebraska. ^e

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Table 15.1. Seismic History of the Nebraska-Kansas-Oklahoma Area (contd)

Date	Time	Epicenter Location	Modified Mercalli Intensity	Description
Oct. 20, 1965	20 04 39.3	37.9-91.1	5.2 ^g	Eastern Missouri. Felt over approximately 160,000 square miles of nine states: Arkansas, Illinois, Iowa, Kansas, Kentucky, Missouri, Nebraska, Oklahoma, and Tennessee. Various towns reported cracked walls, plaster and windows. Also cracked cisterns and fallen bricks were reported. ^e
May 2, 1969	11 36 19.8	35.2-96.3	4.6 ^g	Oklahoma. Felt in eastern Oklahoma. ^f
Jan. 12, 1970	11 21 15.4	36.1-103.2	3.5 ^g	New Mexico. Felt in Clayton area near Oklahoma-Texas-New Mexico border. ^f

^aTime is given in Standard time at the earthquake epicenter.

^bKansas Geological Survey Bulletin 162, 1963, pp. 288-290.

^cU. S. Coast and Geodetic Survey, Earthquake History of the United States, PTI-Stronger Earthquakes of the United States, ESSA Bull No. 41-1(1965); also PSAR Docket 50-278 (Fort St. Vrain Generating Station--from List of Colorado Earthquakes).

^dU. S. Coast and Geodetic Survey, United States Earthquakes, 1928-1935 (collected annual reports).

^eU. S. Coast and Geodetic Survey, United States Earthquakes, 1941-1967 (individual annual reports).

^fU. S. Coast and Geodetic Survey, Summary of Preliminary Determination of Epicenters, 1968-1970 (Monthly Summary of Seismic Events listed on PDE cards).

^gRichter Magnitude.

Some of the historic events in this category are included in Table 15.1. This data generally agrees with conclusions derived by the U. S. Coast and Geodetic Survey as summarized on their Seismic Risk Map of the United States (Fig. 10.6), which places the Lyons site in zone 1 but near the edge of a zone 2 area encompassing the Nemaha anticline and its continuations into Nebraska and Oklahoma.

The PSARs for several power reactors in the area were examined in an effort to ascertain appropriate and acceptable preliminary design criteria for earthquake loading at the Repository site. The results of this examination are given in Table 15.2. From these historical examinations and comparisons, the design basis and operating basis earthquakes, which are defined in Sect. 15.2, will be more than adequate for the Lyons, Kansas, site.

15.1.2 Tornado Meteorology

Culkowski¹ has stated that the probability of the 1000 acre Lyons, Kansas, site being struck by a tornado in a given year is .3%. For a 50-year interval it would increase to 15%. The severity level of the tornado is not included in this probability. Because of a lack of detailed information concerning tornado meteorology at the Federal Repository, the recommendations suggested by Doan² for a "design tornado" have been used herein. The design basis tornado is specified in Sect. 15.2.

15.2 Earthquake and Wind Loadings for Design

The Repository shall be designed to accommodate earthquakes and winds having the specific intensities as defined herein.

15.2.1 Earthquake

Design Basis Earthquake (DBE). - That earthquake which would induce at the Repository a free field vibratory ground motion having a maximum ground acceleration of 0.2 g. Dynamic amplification of this ground motion must be considered and is based on the frequency distribution curves shown in Fig. 15.1. These design spectra are

Table 15.2. Earthquake Design Factors at Power Reactors

Reactor Name	Location	Size [Mw(t)]	Construction Permit Date	Design Criteria (g) ^a	
				Operating Basis Earthquake (OBE)	Design Basis Earthquake (DBE)
Cooper	35 miles SSE of Omaha, Nebraska	2381	June 1968	0.1	0.2
Fort Calhoun	20 miles NNW of Omaha, Nebraska	1420	Jan. 1969	0.08	0.17
Arnold	10 miles NW of Cedar Rapids, Iowa	1593	June, 1970	0.06 - 0.09 ^b	0.12 - 0.18 ^b
Russellville	57 miles NW of Little Rock, Arkansas	2568	Dec. 1968	0.1	0.2
Fort St. Vrain	35 miles N of Denver, Colorado	879	Sept. 1968	0.05	0.1

^aStatic coefficient as a fraction of the acceleration of gravity for seismic loading.

^bThe lower number if structure placed on rock; the higher if placed on 30 to 50 ft of compacted fill.

Fig. 15.1. Smoothed Design Spectra for 0.2 g Earthquake, 0%, 1%, 2%, and 5% Critical Damping.

for horizontal motion and were developed from Newmark's maximum earthquake using his response amplification factors³ and appropriate scaling.

Operating Basis Earthquake (OBE). — That earthquake which would induce at the Repository a free field vibratory ground motion having a maximum ground acceleration of 0.1 g. Dynamic amplification must be considered using the design spectra of Fig. 15.2. These spectra are also for horizontal motion and are similar to those of Fig. 15.1 having been developed from the same maximum earthquake.

In each of the above earthquakes, vertical motion must also be considered and will have a magnitude of $2/3$ that of the horizontal motion given in Fig. 15.1 and 15.2.

15.2.2 Wind

Design Basis Tornado (DBT). — That tornado which will produce the following wind speeds and pressure drop at the Repository:

- (a) Horizontal tangential wind speed: 300 mph.
- (b) Horizontal translational speed: 60 mph.
- (c) Pressure drop: 3 psi in 3 seconds.

The pressures and forces which occur as a result of the horizontal tangential wind speed are assumed coincident with pressures and forces due to the pressure drop. The resulting stresses from each shall be combined directly in all design analyses.

Design Basis Wind (DBW). — The design wind speed for the site as specified in the Uniform Building Code.

15.3 Design Classifications

All structures, systems, and equipment within the Repository shall be classified by the following category groupings. This classification is applied in order to identify plant features for purposes of public safety and operational reliability during postulated earthquake and wind conditions.

ORNL-DWG. 71-6256

Fig.15.2. Smoothed Design Spectra for 0.1 g Earthquake, 0%, 1%, 2%, and 5% Critical Damping.

Category I. - All structures, systems, and equipment whose failure could cause release of excessive amounts of radioactivity; or those structures, systems, and equipment that are essential for the safe shutdown of waste handling operations without endangering the public health and safety during or following a design basis earthquake or design basis tornado.

Category II. - Those structures, systems, and equipment that are required to permit continuation of waste handling operations without endangering the public health and safety during and following an operating basis earthquake or design basis winds.

Category III. - Those structures, systems, and equipment whose failure will not result in release of excessive amounts of radioactivity, or are not essential to continued waste receipt and burial operations.

15.4 Design Requirements

All Category I structures and plant equipment shall be designed to remain functional so that a safe and orderly shutdown of waste handling operations can be achieved and maintained without endangering the public health and safety upon experiencing a design basis earthquake or a design basis tornado. All Category I and II structures and plant equipment shall be designed to remain functional as required for continued waste handling operations without endangering the public health and safety upon experiencing an operating basis earthquake or design basis winds. All Category III structures shall be designed to remain functional while accommodating Zone 1 seismic loadings as prescribed by the Uniform Building Code, 1970 edition, or forces due to design basis winds.

15.4.1 Definitions of Terms as Used Herein

Structures, Systems, and Components. - Includes all items essential to the operation and safety of waste receipt and burial functions. Structures relate to buildings, stacks, and similar items including their foundations and all structural supports for systems and

equipment; systems relate to mechanical fluid systems, ventilation systems, electrical power systems, etc.; components relate to items which comprise a system. Examples of components are pumps and valves in a piping system.

Plant Equipment. - Includes systems and components which, when combined, perform a service function necessary for plant operation.

Response Spectrum. - Means a plot of maximum responses for a family of idealized single degree-of-freedom damped oscillators to transient vibratory base input(s)

Design Spectrum. - Refers to a combined plot of idealized response spectra based on past recorded earthquake ground motions. The spectrum plot is given as a function of damping and frequency and is primarily a specification for required structural strength.

Coupled. - Refers to the connection relationship between structures and/or plant equipment which, because of their mass and stiffness properties, may significantly influence the dynamic response of each other.

Seismic Math Model. - Refers to the idealization of coupled structures and/or plant equipment as a dynamic system and in a mathematical form suitable for detailed dynamic analysis.

Major Supported Plant Equipment. - Refers to those systems and/or components which have their means of support furnished by structural members or buildings which are founded on ground or on other major supported systems.

Interface. - Means a point or junction between separate systems or between a seismic model and its foundation.

15.4.2 Analytical Requirements

Earthquake: Categories I and II. - All Category I and II structures and plant equipment shall be mathematically modeled and subjected to analyses for the applicable earthquakes. The results (i.e., stresses, displacements, etc.) of such analyses must then be

combined with the results of standard analyses for normal loadings. This combination is termed "Design Load Combinations" and is described in Sect. 15.4.3. The requirements herein do not exclude or specify any of the available valid methods of earthquake analysis. There are, however, certain minimum requirements which must be provided based on the approach used. These minimum requirements are as follows:

1. A simplified static analysis may be utilized if adequate justification is presented that such a simplified method does in fact produce conservative results for the Category I and II structures and plant equipment. The justification shall show that the site, structures, and plant equipment characteristics related to the specified earthquake were taken into account when deriving equivalent static response loadings for design analyses. Furthermore, the relative displacements occurring between structures and plant equipment and their bases or means of support must be fully accounted for by separate and additional analyses. The internal loadings produced by dynamic displacements may be determined by conventional analysis methods. The separate analyses due to inertial response loads and relative base displacement loadings must be superimposed to produce the most conservative design as directed by the applicable code or standard.
2. When adequate justification for simplified analyses of structures and plant equipment cannot be provided, a detailed dynamic analysis for such systems shall be made. The dynamic analysis method may include the mode superposition method or direct integration method or any other analysis method which provides an acceptable solution for the seismic problem. If the first of these is used, the procedure for combining the mode effects must be the root-mean-square method. The detailed analysis must include the following considerations.

3. Structures and plant equipment of physically connected systems shall be idealized as a single math model or as subdivided systems of one or more smaller math models. In the latter case there must be at least one primary supporting model which is founded on ground. There may be one or more major supported models which have their means of support furnished by other math models. Coupling between the math models always exists; however, the mathematical uncoupling of connected models is permitted when justified according to the following paragraph.
4. When the mathematical model of a physically connected system is subdivided into smaller systems with math models thereof, the interfaces between such math models serve as locations for amplified seismic response loadings, and further considerations are required. If the mass and stiffness of the supported system or subsystem are such that they do not appreciably affect the dynamic response of the supporting system or subsystem, or if the supported system and math model thereof can be suitably modified to account for the interreaction effects at support points, mathematical uncoupling can be justified. Table 15.3 summarizes conditions where such uncoupling is normally permitted.

In Case Ia of Table 15.3 the supported system model has a low mass ratio and is relatively flexible compared with its supporting system model; therefore, its effect can be neglected when analyzing the supporting model. Case Ib has a frequency ratio equal to Case Ia, but the mass ratio is sufficiently high to preclude neglect of its effect. Mathematical uncoupling is not permitted, and single model idealization or other acceptable analysis procedures are required. Case IIa permits mathematical uncoupling within the resonant range due to the small mass ratio, but input to the supported system must be the tie-point response determined from analysis of the supporting system. Case IIb is within the resonant range with a high mass ratio and requires that the idealization be as a single math model of the coupled system, or use of other acceptable and appropriate analysis procedures which account for the interreaction effects.

Table 15.3. Analyses of Seismic Math Models

Case	f_e/f_s^a	M_e/M_s^b	Supporting System	Supported System
Ia	≤ 0.5	$\leq 20.0\%$	As uncoupled - neglecting effects of supported system	As uncoupled - using specified design ground motion as input at support points
Ib	≤ 0.5	$> 20.0\%$	Single model as coupled system or the use of other acceptable analysis procedures which account for system interaction effects	
IIa	0.5 to 2.0	$\leq 0.1\%$	As uncoupled - neglecting effects of supported system	As uncoupled - using as input at support points the response determined from dynamic analysis of supporting system
IIb	0.5 to 2.0	$> 0.1\%$	Single model as coupled system or the use of other acceptable analysis procedures which account for system interaction effects	
IIIa	≥ 2.0	$\leq 20.0\%$	Modify supporting system and treat as uncoupled	As uncoupled using as input at support points the response determined from dynamic analysis of modified supporting system
IIIb	≥ 2.0	$> 20.0\%$	Single model as coupled system or the use of other acceptable analysis procedures which account for system interaction effects	

where

M_e and f_e = total mass and natural frequencies of the supported system

M_s and f_s = total mass and natural frequencies of the supporting system.

(a) f_e/f_s = frequency ratio.

(b) M_e/M_s = mass ratio.

Case IIIa permits model uncoupling, but only after modifying the supporting system model appropriately to account for the mass and stiffness effects at interfaces. The dynamic input for the supported system would then be the dynamic response at support points determined from the dynamic analysis of the modified supporting system. Case IIIb is similar to Case IIIa, but because of the high mass ratio it must be idealized as a single system as for Cases Ib and IIb.

5. For subdivided systems modeled as in "System Coupling" above , the analysis will result in reactive forces at interfaces. These forces are herein noted as interaction effects, and they must be fully accounted for in the design load combinations of Sect. 15.4.3 for the applicable cases.
6. Structures and plant equipment may be modeled as multi-degree of freedom spring-mass systems or other similar systems which have their mass and stiffness properties adequately represented. A sufficient number of degrees of freedom shall be used so that the seismic response is adequately described. Translational, torsional, and rocking degrees of freedom must be considered at foundations or points of support for all math models employed.
7. In the absence of comparative and applicable test data which could support estimates of the true damping of structures and plant equipment, the following listing of damping values is provided. Larger values than those listed may be employed where justification is provided. The values are given as percent of critical damping and are considered to be conservative.

Percent Critical Damping	
<u>OBE</u>	<u>DBE</u>

Prestressed and reinforced concrete
 confinement structures and concrete
 foundations and other prestressed
 concrete structures

2.0	5.0
-----	-----

	Percent Critical Damping	
	OBE	DBE
Conventionally reinforced concrete structures above ground, i.e., shear walls and rigid frames	5.0	7.0
Steel structures		
Welded steel structures	1.0	2.0
Bolted steel structures	2.0	5.0
Piping systems (welded)	0.5	1.0
Foundation materials for structures		
On rock $c > 6000$ fps	2.0	5.0
On firm soil $c \geq 2000$ fps	5.0	7.0
On soft soil $c < 2000$ fps	7.0	10.0

(Where c = velocity of sound in the material).

8. Because of modification to the input motion by the surrounding soil, the structural response may be significantly modified from that of the free field input motion. Where applicable, the mass and stiffness properties of the surrounding solid will be included in the seismic math model to account for such effects.
9. The effects of relative displacements of support points or foundations of all major supported math models must be considered in the overall analyses. These relative displacements shall be imposed on the seismic math model as a separate static load unless the appropriate time-history forcing function at each support point is used in the dynamic analyses such that the effects of these displacements are inherently included. It should be noted that, in general, for input motions other than time-histories at each support point, the displacement responses may or may not be in phase. Where separate analyses due to inertial loadings and differential support displacements

are required, the resulting stresses from each must then be superimposed. The superposition shall be the most conservative from a design basis as required by the applicable code or standard.

10. The seismic math model for any system must include consideration of the effects of torsion. Such features as geometry, mass, and stiffness must be adequately modeled so that the torsional response resulting from any nonsymmetry is correctly included in the analyses. .
11. Analytical load characteristics are as follows:
 - a. The form and magnitude of the OBE and DBE earthquakes are given in Sect. 15.2. Time-history analysis procedures may be used, but the earthquake time-history records which are submitted must have response spectra that equal or exceed the design spectra given in Figs. 15.1 and 15.2. Either the prescribed input or approved substitute input motion may be used in the analyses of all primary supporting models for the applicable earthquake and design classifications. The structural response of primary supporting models shall then serve as input motion to those applicable uncoupled major supported models following the requirements of number 4 (above). The derived input for Cases IIa and IIIa supported models of Table 15.3 may be a time-history response record or the ground response spectrum modified by the supporting structure. In the former case, the time-history response record may be used to generate a response spectrum for analysis of the supported system. For all derived response spectra input the procedures for combining the mode effects shall be the root-mean-square method. In addition, the maximum displacement response from analyses of primary supporting models shall be used to derive the relative support displacements for applicable major supported models.

- b. For convenience, seismic analyses may be performed considering the horizontal input motion to be applied coincident with the principal orthogonal axes of the seismic math model. However, when using the principal axes approach, care must be exercised to assure conservatism and not negate the possible governing effects due to torsion as prescribed under number 10 (above). Vertical input motion must also be included. Its effect shall be analyzed separately prior to combining with horizontal motion effects. For design purposes the most adverse situation (i.e., horizontal, vertical, or torsional alone or any combination thereof) must be used.

Earthquake: Category III. — All Category III structures may be analyzed for the prescribed seismic load using an equivalent static load method no less conservative than that prescribed by the Uniform Building Code, 1970 edition.

All Category III plant equipment shall be analyzed for appropriate seismic loads using methods or procedures as recommended by the applicable governing standard or code (i.e., ASME, ANSI, etc.).

Tornado and Wind: All Categories. — Analysis methods for tornado and wind forces shall be governed either by ASCE Paper No. 3269 or Uniform Building Code, 1970 edition, wherever provides more conservatism in the design. For the design basis tornado, the peak pressure due to wind velocity shall be assumed to act simultaneously with suction due to pressure drop.

15.4.3 Design Load Combinations

Structures and plant equipment shall be designed to accommodate, within the stress limits specified in Sect. 15.4.4, the coincident earthquake or wind loads in combination with the normal operating loads. The applicable combinations of design loadings include, but are not limited to, the following.

1. Normal Loadings: $W = D \pm 0.1$, where D = design results (i.e., stresses, displacements, etc.) due to any applied static or live load (i.e., pressure, snow loads, support loads, etc.) that is present during the life of the structure or plant equipment. The most adverse combination of $D \pm .1D$ shall be used. F = design results (i.e., stresses, displacements, etc.) from forces due to thermal expansion, including shrinkage and creep, where appropriate, or any other thermal source that could routinely be imposed during the design life of the structure of plant equipment.
2. Abnormal Loadings: Applicable earthquake or wind forces as prescribed in Sect. 15.2. Earthquake and wind are not assumed coincident.

Design loading combinations for Category I classifications shall meet those conditions considered to be the most adverse and shall include the following:

1. Design Condition I: $W + F + (DBE \text{ or } DBT)$.
2. Design Condition II: $W + F + (OBE \text{ or } DBW)$.

Design loading combinations for Category II classifications shall meet those conditions considered to be the most adverse and shall include the following:

Design Condition II: $W + F + (OBE \text{ or } DBW)$

Category III classifications shall meet the most critical of the following load combinations:

Design Condition III:

- a. $W + F$;
- b. $W + F + ES$ (where ES is the equivalent static horizontal load based on the Zone 1 seismic load factors contained in the Uniform Building Code, 1970 edition);
- c. $W + F + DBW$.

For any of the above conditions, those components which produce unconservative results are to be omitted; for example, design floor loads cannot be relied upon to resist overturning moments due to wind or earthquake. Similarly, if any component does not apply to a particular system, it shall be omitted from the load combination equation.

15.4.4 Design Stress Limits

Category I classifications shall be limited to the maximum allowable stresses as set forth in the applicable code and as modified herein:

1. Reinforced concrete confinement structures may be designed using either the working stress or ultimate strength design methods as given in the ACI Standard Building Code Requirements for Reinforced Concrete (ACI 318-63) or equivalent. Allowable stress limits shall meet the following criteria:

- a. The allowable stresses applicable to Design Condition I shall conform with those specified in Chapter 10 of ACI 318-63, including the 1/3 increase in the allowable stress. The allowable stresses applicable to Design Condition II shall conform with those specified in Chapter 10 of ACI 318-63 but not including the 1/3 increase in the allowable stress.

- b. The most adverse design capacity (U) as defined in ACI 318-63 shall be as follows:

$$\text{Design Condition I: } U = 1.3/\phi [W + F + (\text{DBE or DBT})].$$

$$\text{Design Condition II: } U = 1.7/\phi [W + F + (\text{OBE or DBW})].$$

(Where ϕ is the capacity reduction factor as specified in ACI 318-63).

- c. When the Ultimate Strength Method is used, allowable stresses shall be those specified in ACI 318-63 except that the concrete compressive stress shall be limited

to $.8f'_c$, where f'_c is defined by ACI 318-63. Also, the dynamic analysis method used to obtain seismic response loads must be capable of defining the inelastic response in order to be able to utilize ultimate strength methods, except where it can be demonstrated that elastic response produces conservative results and deformation limits are not exceeded.

2. Structural Steel for Building Structures and Supports - The allowable stresses applicable to Design Condition I shall conform to those specified within the Manual of Steel Construction, Seventh Edition (AISC Code) with a 1/3 increase in the allowable for seismic or wind. The allowable stresses applicable to Design Condition II shall conform to those specified in the AISC Code without the 1/3 increase in the allowable for seismic or wind.
3. Plant Equipment (Systems and Components) - The allowable stresses shall be those specified in the applicable components code (i.e., ASME, ANSI, etc.) with the following specifications:
 - a. Design Condition I - Considered as the emergency operating condition of the applicable components code.
 - b. Design Condition II - Considered as the upset operating condition of the applicable components code.
4. Liquid Storage Tanks - The allowable stresses shall be those specified in API Standard 620, dated 1966, for Large, Welded Low-Pressure Storage Tanks, or equivalent, with the same restrictions for allowable stresses as given in paragraph b, "structural steel" above for Design Conditions I and II.

Category II and III classifications shall have their allowable stresses governed by the applicable Codes and Standards which are normally applied for allowable stress criteria for cases involving wind or seismic loadings.

15.5 Testing in Lieu of Design Analysis

Empirical verification tests may be used to satisfy the requirements for design analyses, provided such verification tests are based upon the use of acceptable testing procedures, load levels, etc., to confirm the structural integrity. The justification, procedures and results of any such program shall be set forth in the Final Safety Analysis Report.

15.6 Documentation

A list of all structures, systems, and equipment, their respective category classifications, the selected method of seismic design analyses, mathematical models, input time-history (ies) and their corresponding response spectra, where used in lieu of design spectra given, and allowable stress criteria for each class of material used in the design analysis shall be documented. A summary of the methods of analyses and results of such analyses for all Category I and II structures, systems, and equipment shall be documented.

16. APPENDIX B: PROPOSED PROGRAM FOR THE DEVELOPMENT OF THE SALT MINE REPOSITORY

The program leading to the establishment of the Salt Repository for radioactive wastes at Lyons, Kansas, is described below. This program is based on an overall schedule of design and construction that will result in the beneficial occupancy of the Repository during the first half of FY 1976. We have included all of the investigative programs that we consider necessary at this time to ensure the safety and operability of the facility. If at any time during the course of these investigations other areas requiring attention arise, they will be factored into this program plan. It is intended that this plan be kept current by periodic modification as necessary.

In order to properly introduce the program plan as a whole, a Task Flow Diagram is presented in Fig. 16.1. This program illustrates in a graphic fashion the interrelationships between the various tasks and sub-tasks and the manner in which each is related to and contributes to the successful completion of the project.

The program plan is divided into three major sections: Sect. 1 describes the tasks which relate to Geologic Containment, Sect. 2 the tasks relating to Operational Safety, Sect. 3 the tasks relating to Program Management and Design, and Sect. 4 those tasks for which the responsibility rests elsewhere than at ORNL. Each of these three sections is followed by a chart titled "Schedule of Task Milestones and Priorities." On these charts, an A, B, or C priority is assigned to each task or milestone based on the following criteria:

- Priority A. - Milestone or task which must be completed before the start of facility construction (taken to be October 1, 1972, when grading of the site is scheduled to begin).
- Priority B. - Milestone or task which must be completed before the start of the demonstrational phase of operations (taken to be September 1975 and March 1976 for the alpha and high-level facilities, respectively).
- Priority C. - Milestone or task which is a long-term development which may be completed after the start of the demonstration phase.

Following each task or sub-task description and enclosed in parentheses is the date, by fiscal years, in which the task is scheduled to be performed. Those already completed are marked with an asterisk. Where applicable, each task or sub-task description is also followed by a code enclosed in square brackets which identifies it with the list of investigative work recommended by The National Academy of Sciences Committee on Radioactive Waste Disposal, The Kansas Geological Survey, and the U.S. Department of Interior which is included in Sect. 5. Each of the recommended items listed in Sect. 5 is also referenced in square brackets to the appropriate sub-section of the program plan.

1. GEOLOGIC CONTAINMENT

The objective of this investigation is to demonstrate that all wastes placed in the salt mine Repository will be contained for several hundred thousand years unless purposely removed by man.

The only natural means for transporting waste from the Repository is by circulating water. It is thus essential that water not be allowed to contact the wastes at any time during the long containment period.

It is conceivable that water could contact the wastes if:

- a. The area were subjected to a rapid rate of erosion that would strip the protective shale cover from the highly soluble salt rocks;
- b. Open and interconnecting fractures were to develop in the rocks above and/or below the salt due to seismic activity and other geologic processes or due to the heat and radiation associated with the wastes;
- c. Man-made openings in and through the salt, such as boreholes and mechanical and hydraulically mined cavities, should serve as passageways for movement.

To evaluate the possibility of water entering the Repository and contacting the wastes, it is necessary to conduct investigations that will lead to determinations of:

- a. The expected rates and depths of erosion and natural dissolution of the salt body;
- b. The likelihood of and the nature and extent of any probable fracturing in the rocks due to natural geologic events or to the imposition of the wastes; and
- c. The effects of the existing and any future holes and cavities in and through the salt on containment of the wastes.

1.1 Erosion and Dissolutioning

1.1.1 Erosion and Denudation

Erosion through natural geologic processes will eventually strip away the protective cover rocks and expose all of the salt in central Kansas. The likelihood of this happening during the effective lifetime of the wastes buried in the salt will be ascertained, as follows:

[I-B-1]

- a. Estimate future erosion at the Repository site using statistical treatment and extrapolation of modern rates of erosion in several climatic zones that would be representative of the kinds of climate that have existed in the midcontinent during the last 1 million years and would be expected to prevail during the next 1 million years (1971-1972). [I-E-2-a, I-E-2-b]
- b. Considering that some rock deformation will occur as a result of Repository operations, evaluate the potential for radical changes in flow in the Arkansas River system, changes in groundwater circulation, and long-term changes in land forms on the rates of erosion at the proposed Repository site. Preliminary findings will be reported prior to construction (1972-1975). [I-E-3-e]

1.1.2 Boundary Dissolutioning

Surface and subsurface subsidence features along a 100-mile length of the eastern margin of the salt basin in Kansas indicate that the salt face is slowly retreating toward the proposed Repository site some 25 miles to the west. The following studies which bear on this problem will be made:

- a. Determine gross rates of retreat of the salt margin primarily through studies of Pleistocene (the last 1 million years of geologic time) channel deposits that have migrated westward and parallel to the salt face. This will consist mainly of an interpretive study of the results of previous investigations of these channels which have established their locations and the ages of their sediments (1971).* [I-E-1-b, I-E-1-c]
- b. Date late Pleistocene dissolutioning (which would provide data on the more recent rates of boundary migration) in Saline County where peat deposits are known to mark an area of subsidence activity. Approximately three 6-in.-diam cores of the peat and overlying and underlying clays (containing shell fossils), which lie about 150 ft below the surface, to be obtained for ^{14}C (peat) and species identification (fossils) analyses (1972). [I-E-1-a, I-E-1-b, I-E-1-c]
- c. Establish the configuration of an apparent vertical displacement in the bedrock above the salt to determine the rate of late Pleistocene dissolutioning along a part of the salt face in northeast Saline County. Approximately nine test holes 50 to 100 ft in depth to be drilled within the area (1972).
- d. Determine any acceleration and/or retardation in the rates of dissolutioning due to: increased circulation of groundwater in the salt zone resulting from such things as river channel dredging; increased groundwater withdrawals; improved surface drainage; disposal of fluids into shallow aquifers near the salt rocks; and cross circulation of groundwaters in the many

boreholes that penetrate the salt. Measurements of the effects of these activities on dissolutioning to be made initially by establishing a series of monitoring wells in and around selected areas of increased water circulation. Preliminary findings will be reported prior to construction (1972-1975).

- e. Determine and define the irregularities in thickness and configuration of the salt body along its eastern and northeastern boundaries and relate the dissolutioning (or the absence of it) to geomorphic and structural features. This will be accomplished primarily through studies of logs from recently drilled boreholes within the area. Preliminary findings will be reported prior to start of construction (1972-1975).

1.2 Rock Fracturing

1.2.1 Geology and Hydrology of Surficial Deposits

Establish the thickness, composition and water-bearing characteristics of the unconsolidated surficial materials at the site and in the immediate area surrounding it to evaluate the potential effects of these waters on the underlying salt deposits and the wastes contained therein should the existing borings and shafts and any future breaches in the rock overlying the salt serve as channels for the downward movement of these waters. [I-A-1, I-A-2, I-B-1, I-B-3, I-B-7]

- a. Drill, test, and recover samples from a series of 40 borings up to about 200 ft deep in an area of about 10 miles by 12 miles and centered on the site. Incorporate the significant findings of prior investigations within the area (1971).*
- b. Determine the nature and extent of the thicker water-bearing sediments in the immediate vicinity of the site by drilling, testing, and recovering samples of water and sediments from 20 holes that will range up to 100 ft in depth (1972-1973).

1.2.2 Geology and Hydrology of Water-Bearing Rocks Above Salt

Establish the rates and directions of movement, the potentiometric relationships, and the quantity and quality of the Stone Corral and Kiowa aquifers above the salt. In the event of a breach of the shales which overlie and protect the salt formation, these waters would provide the means for dissolving the salt and the enclosed wastes. [I-A-1, I-B-1, I-B-4, I-B-5, I-B-6, I-B-7]

- a. Drill, test, and recover samples from 12 boreholes located: (1) at the four corners of the site; (2) at 1/2 mile distances from the boundaries; and (3) four additional holes at the southeast corner of the site (1971-73). [I-C-4, I-C-6]

- b. Interpret these data for use in: (1) plugging and sealing oil and gas wells; (2) design of shaft sinking and lining operations; (3) evaluation of penetration dissolution phenomena; (4) thermal and mechanical deformation analysis; and (5) establishing baseline conditions for the hydrologic monitoring program. Preliminary interpretation of these data for use in (2), (3), and (4) above will be made before the start of construction (1972-1975).

1.2.3 Geology and Hydrology of Rocks Below the Freshwater Aquifers

Establish the water-bearing properties and continuity of the salt and the overlying and underlying rocks to: (1) determine those features of the salt disposal beds which influence the detailed design of the mine; (2) provide samples for rock property testing needed for the heat flow and rock mechanics studies; (3) determine the potential effects of the water in the rocks on the salt body; and (4) assess the stability of the site as to faults, folds, and other geologic structures. [I-A-1, I-B-1, I-B-2, I-B-6]

- a. Drill, test, and recover rock and fluid samples from four boreholes located at the corners of the site. The first two holes to extend to depths of approximately 1300 ft; the third holes to extend to a depth of approximately 1700 ft or to the first aquifer below the salt; the fourth hole to provide data on the deeper portions of the rock column at the site (1971-1973). [I-C-1, I-C-2, I-C-3, I-C-5, I-C-7]
- b. Interpret these data for use in salt mining operations, plugging and sealing boreholes, evaluating the deformation of the rocks due to heat, radiation and subsidence, and tectonic stability of the site. Preliminary interpretation of these data will be made prior to the start of construction (1971-1975).

1.2.4 Diapirism

Establish that the integrity of the salt deposit will not be impaired by mass movements of salt during the effective lifetime of the wastes. [I-B-1, II-10]

- a. Examine through borehole geophysical logs and other subsurface data the structure of the Hutchinson salt formation to ascertain whether the local thickening and thinning represents incipient diapirism. Preliminary findings will be reported prior to start of construction (1972-1973).
- b. Evaluate the potential for development of diapiric structures at the Repository site as influenced by the elevated temperatures and induced deformations resulting from Repository operations. Preliminary findings will be reported prior to start of construction (1972-1973).

1.2.5 Rock Property Testing

Determine the various properties of the several rock types at the Repository site for use in (a) the thermal analysis program, (b) the rock mechanics analysis program, and (c) the analysis and evaluation of the combined effects of the Repository operation on the surrounding rocks.

- a. Thermal Properties. - Testing and comparison with values used in preliminary calculations will be completed prior to the start of construction (1972-1974).
 - (1) Establish the thermal properties required for the thermal analysis calculations. These properties to include conductivity, specific heat (or diffusivity), density, and coefficient of expansion, as a function of temperature, and direction for the various rock types encountered at the site.
 - (2) Define the specimen characteristics required for the thermal property testing (size, number, manner of preservation, etc.) for use in designing subsurface drilling program.
 - (3) Obtain samples for thermal property testing from subsurface drilling.
 - (4) Provide thermal property parameters by carrying out appropriate laboratory tests on the specimens.
- b. Mechanical Properties. - Testing and comparison with values used in preliminary calculations will be completed prior to the start of construction (1972-1974). [I-D-1]
 - (1) Establish the mechanical properties required in both the semiempirical and the finite-element rock deformation calculations. These properties to include elastic moduli, Poisson's ratio, strengths, and creep parameters.
 - (2) Define the specimen characteristics required for the thermal property testing (size, number, location, manner of presentation, etc.) for use in designing the subsurface drilling program.
 - (3) Obtain specimens for mechanical property testing from subsurface drilling (hole No. 3).
 - (4) Provide mechanical property values by carrying out appropriate laboratory tests.
 - (5) If necessary and possible, confirm the laboratory values of the mechanical property by suitable in-situ tests at the Lyons site.

c. Mineralogical and Geochemical Properties (1972-1975)
[I-D-1, II-1, II-2, II-3, II-5, II-10]

- (1) Establish the range of thermal and rock deformation conditions to which the rocks at various locations will be subjected by the operation of the Repository from the preliminary results of the thermal and rock mechanics analysis programs.
- (2) Using specimens from the subsurface drilling (hole No. 3), investigate the potential for mineralogic alterations (changes in mineral species, phase, or hydrational states) and geochemical effects (type, volume, and fate and consequences of any fluids driven off) resulting from the imposed conditions.

1.2.6 Rock Mechanics Analysis

Establish that the transient and permanent rock deformations (displacements, strains, and stresses) induced in the rocks over and around the portion of the salt formation containing the wastes will not produce conditions leading to a breach of the integrity of the long-term confinement. These deformations are produced by both the designed closure of the mine openings and the thermal expansion of the entire rock column. [II-1, II-2, II-3, II-4, II-5, II-9, II-10]

a. Semiempirical Model

- (1) Salt Vault using an analysis similar to that described in Chapter 13 of ORNL-4555 and a new computer program developed for the purpose and incorporating three-dimensional geometry (1972).
- (2) Extrapolate this computer model to obtain mine closures as a function of time for the entire Repository and including the resistance of the consolidating room backfill salt (1972).
- (3) Based on the predicted mine closures and the thermal expansion effects obtained from the results of the thermal analysis--task 1.2.7, predict the total deformations of the rocks at the site due to Repository operation effects (1972).

b. Finite-element Model

- (1) Develop a sophisticated finite-element computer model of the entire geologic regime influenced by the operation of the Repository and incorporating: (a) internally coupled calculation of thermal expansion effects, (b) viscous behavior in the high-temperature zones, and (c) elastic-plastic deformational behavior throughout the geologic section (1972-1973).

- (2) Using mechanical properties obtained from the rock property testing program, predict the total deformations at all points as a function of time (1973-1975).
- (3) Compare the predictions from the two calculational methods for ascertaining the best (most realistic) and the probable range of error (1973-1975).

1.2.7 Thermal Analysis

Establish the transient thermal condition within and surrounding the Repository which will result from the heat generation characteristics of the anticipated wastes (1972-1976). [II-1, II-2, II-3, II-4, II-5, II-10]

- a. Develop improved calculational models and numerical solutions to the heat conduction equation as indicated by sensitivity studies.
- b. Using values for the thermal properties as obtained from the rock property testing program and a geometrical-geological model of the site and the planned schedule of waste deliveries, establish the predicted temperature history at any point.
- c. Establish the suitability of the proposed heat loading in the Repository by comparison of predicted temperatures with thermal criteria and by analysis and interpretation of the purely thermal consequences (that is, heat flux at the surface, temperature rises in waters flowing through various aquifers at the site, etc.).

1.3 Effects of Boreholes and Hydraulically Mined Cavities on Containment

1.3.1 Cavity Development in Boreholes

There are several documented cases of salt dissolution in and around oil and gas borings in central Kansas. It is thus necessary to establish that dissolution of the salt body at or near the site by this phenomenon will not occur during the effective lifetime of the wastes, as follows: [I-B-2, I-E-3-e]

- a. Assemble a catalog of pertinent facts (locations, depths, casing and plugging materials, etc.) of all borings (presently known and unknown) in the immediate vicinity of the site (1972). [I-E-3-a, I-E-3-d]

- b. Determine the rates and conditions fostering dissolution through studies of the known instances of cavity development and through investigations of planned hydraulically mined cavities in salt (that is, salt jugs and LPG storage cavities). Preliminary findings will be reported prior to the start of construction (1972-1975).
- c. Determine the nature and extent of dissolution in at least four of the existing borings (those where dissolution might be most likely to occur) in the immediate vicinity of the Repository through reentry operations (1972).
- d. Develop through laboratory and field investigations a satisfactory well sealing method (1972-1975). [I-E-3-b, I-E-3-c]

1.3.2 Migration and Collapse of Hydraulically Mined Cavities

Numerous hydraulically mined cavities have been made in the central Kansas salt deposits. These cavities may measure up to several hundred feet in diameter. Subsidence of the land surface has occurred above some of them, and water may circulate between closely spaced cavities, especially when fractures are purposely developed between them to enhance circulation. The salt at the Repository and its contained wastes must be found to be secure from this type of dissolution, as determined by the following studies:

- a. Determine the configuration and other characteristics of specifically hydraulically mined cavities in areas of similar geology to that of the proposed Repository site (1972).
- b. Determine the fate of the cavities after they have been abandoned, especially to ascertain the rates of cavity migration or growths over a wide range of geologic and hydrologic conditions. Preliminary findings will be reported prior to the start of construction (1972-1975). [I-E-3-e]

2. OPERATIONAL SAFETY

The objectives of these investigations are as follows: (1) determine those characteristics of the waste and the salt strata which can influence a dispersion of radioisotopes and other noxious materials within the mine, to the atmosphere adjacent to the Repository and to the soil and groundwater in the vicinity during and after emplacement of the waste; and (2) evaluate the fate of chronic or acute releases of radioactivity from the operation of the Repository on surface biological environment and develop an overall monitoring program for continued surveillance of the environment at and surrounding the Repository site.

SCHEDULE OF TASK MILESTONES AND PRIORITIES
(SECTION I)

1A Gross rate due to natural processes established
 2A Natural process studies completed
 3A Preliminary estimate of impact of Repository operations completed
 4B All investigations completed
 5A Gross rate during Pleistocene Epoch established (last 1 million years)
 6A Rate during late Pleistocene Epoch determined
 7A Preliminary estimate of impact of man-made activities and geologic irregularities completed
 8B Studies completed
 9A Sediments and their water-bearing potentials characterized
 10A Areas of special interest defined
 11A General characteristics determined and areas of potential or suspected instabilities located
 12A Instabilities evaluated

13A Preliminary interpretation of data completed
 14B Studies completed
 15A Continuity of salt established
 16A Deep aquifers defined and determined
 17A Preliminary interpretation of data completed
 18B Structural integrity of deeper rocks confirmed and baseline data investigations completed
 19A Gross potential for deformation determined
 20A Mechanisms for abnormal salt thicknesses determined
 21A Preliminary evaluation of effects of added heat completed
 22B Studies completed
 23A Input for thermal analysis established
 24A Samples obtained and tested
 25A Comparison of test values with preliminary calculated values completed
 26B Program concluded

27A Gross deformation patterns established
 28A Semi-empirical model developed
 29B Finite-element model developed
 30A Gross transient thermal condition established
 31B Predicted temperature history at any point established
 32B Predictions confirmed and suitability of heat loading established
 33A Gross rates of dissolutioning established
 34A Nature and extent of dissolutioning at site determined
 35A Preliminary estimate of rates determined
 36B Well plugging procedures established
 37B Studies completed
 38A Locations and characteristics of nearby cavities determined
 39A Preliminary rates of cavity migration established
 40B Investigations completed

*Subject to Congressional Action

Several factors could contribute to the possible dispersion of radioisotopes and noxious gases and these will be investigated. The list includes the stability of the wastes and the integrity of the packages in which the wastes are buried as a breach of this initial containment is first required in order to disperse these materials; isotopic migration through the salt by gas phase transport and diffusion could then disperse the materials; radiation effects on the crystal structure of the salt and on the solidified wastes themselves could aid this migration by opening up channels for the escape of the radionuclides or altering the strength of the overlying and underlying rocks; and finally, accidents and malfunctions of equipment occurring during the handling of the wastes within the Repository could disperse the material.

In order to evaluate the factors listed above, it is necessary to obtain information on the following:

- a. Thermal stability of alpha wastes and physical integrity of alpha waste packages.
- b. Isotopic migration by gas phase transport, surface and grain boundary diffusion, and diffusion within the body of the salt.
- c. Effects of radiation on the structures of the salt and the solidified wastes.
- d. Thermal and radiation chemistries of the salt and brines near the buried wastes.
- e. Ecosystem processes and radionuclide behavior in the environment.
- f. An environmental monitoring program during the operational and postoperational periods.
- g. Design confirmation studies during the demonstrational phase of operation.

2.1 Packaging and Acceptance Criteria

Establish packaging and acceptance criteria for wastes to be received at the Repository during the demonstrational phase (1971).*

2.2 Isotope Migration

Ascertain the extent to which the radioactive species within the container can be transported after a breach of the container occurs.

2.2.1 Gas Phase Transport

- a. Make thermodynamic study to determine which of the radioactive waste materials can undergo chemical reaction in the expected environment of the Repository to yield either volatile species or chemical forms which are soluble in water (1972-1973).
- b. Introduce steam into the base of a simulated bed at a realistic rate, and under the anticipated temperature conditions. Both the gas and heat transport characteristics to be monitored as a function of time to confirm the thermodynamic studies (1972-1973).
- c. Define the means of achieving the desired reconsolidation of the crushed salt by controlling the structure of the crushed-salt beds (1973).
- d. Continue work on this subtask as required, leading to the design of in-situ experiments in the salt mine during the design confirmation studies (Ref. Task 2.6) (1974-1976).

2.2.2 Diffusion

- a. Establish the magnitude of diffusion rate through the salt crystal (1971).
- b. Establish the magnitude of the diffusion rate by surface and grain boundary mechanisms by literature search and through experimental means (1972-1974).

(1) Surface only.

(2) Grain boundary only.

(3) Net effect in 3 to 5 in. diam by 1 to 3 ft long columns.

2.3 Radiation Effects

Establish identity and magnitude of those effects of radiation on the salt and the solidified waste which bear on the operational safety of the Repository.

2.3.1 Energy Storage

Establish the thermal and mechanical effects of the greatest possible energy release from the waste and salt containment by the following studies: [III-1, III-2, III-3, III-4]

- a. Perform experiments to establish maximum energy storage in salt as a function of temperature, dose rate, and impurities using gamma and proton radiation (1972).
- b. Perform experiments to establish maximum energy storage in simulated fluidized bed, calcined oxide and glassy solid wastes using proton radiation (1972-1974).
- c. Calculate the consequences of energy release (1972-1974).
 - (1) Establish that the temperature of the waste is maintained below the melting point of the container.
 - (2) Establish that the melting temperature of the salt is not exceeded.
 - (3) Establish that the temperature between containers is maintained within acceptable limits as established under Task 1.2.7.
 - (4) Establish that the instantaneous release of energy is within acceptable mechanical shock limits as established under Task 1.2.6.
- d. Confirm energy storage during the demonstration phase.

2.3.2 Effects on Physical Properties

Determine the effects on physical properties of the materials in and around the high-level waste cans. Specifically establish the variation of thermal conductivity and creep rate for use in temperature calculations and evaluations of the rate of reconsolidation of crushed salt around the container (1972-1973).

2.3.3 Radiation and Thermal Chemistry

Establish the identities and amounts of radiolytic and thermal reaction products in the environment around the waste can for use in assessing the effects of container life and waste stability.

- a. Establish the composition of the brines by examining the literature and experimentally with salt from the mine (1972).
- b. Investigate brine migration, theoretically and experimentally (1972).
- c. Make literature search to establish that potentially explosive accumulations of hydrogen and oxygen can be prevented (1972-1973).
- d. Establish the identities and yields of radiolytic products of the brines and salt by experimental means (1973-1974).
- e. Design in-mine demonstration tests (1975).

2.4 Ecological Site Investigation

The objective of this task is to develop the information on ecosystem processes and related radionuclide behavior for the rational assessment of the fate of either chronic or acute releases of radioactivity from the Repository operation and for the evaluation of thermal effects on the surface biota. Research will focus on three different ecosystems: (a) aquatic, a variable flow-rate stream (Cow Creek); (b) a grassland pasture, the projected community for the Repository site; and (c) a wheat agroecosystem, the most predominant crop of the area. For each of these ecosystems the investigation will consist of: [VIII-3]

2.4.1 Assessment and Model Development

Perform maximum credible assessments to identify critical problem areas, and use this information as guidelines for on-site ecological research. Refine model design and use in the prediction of ^{90}Sr and transuranics behavior in the environment in order to assess long-term impact and fate of chronically or accidentally released radionuclides (1972-1973).

2.4.2 Definition of Processes

Determine the structure and function of the ecosystems and the ecological processes which influence radionuclide fluxes in the vicinity of the Repository. This to include: (a) determination of the species composition and abundance; (b) verification of principal food chains; (c) determination of seasonal population fluctuations; and (d) analysis of environmental and biotic phenomena which may influence the behavior of stable forms of plutonium, strontium, cesium, and nutrient elements for use in specific activity models (1973-1974).

2.4.3 Establishment of Base Lines

Establish ecological base line references for evaluating real or alleged thermal or radioecological effects (this subtask is somewhat different from and broader than the establishment of routine monitoring base line - Task 2.6) (1972-1975).

2.5 Monitoring

Develop and establish an overall monitoring program for all aspects except on-site radiological health and including: (a) off-site and environs radiological and public health through routine monitoring of air, soil, water, particulate fallout, etc.; (b) surveillance of off-site and on-site geological (thermal probes), hydrological (well water levels and water chemistry), and geophysical (surface levelings, seismometry)

characteristics which bear on the geologic containment; and (c) periodic sampling of key biological indicators. [I-E-3-b, I-E-3-c, IV-1, IV-2, IV-3, IV-4, IV-5, V-2]

2.5.1 Monitoring Program Requirements

Establish the requirement of the monitoring program (both objectives and instrumentation) by consideration of the preliminary results of the various investigation programs (1972).

2.5.2 Long Lead Time Base-Line Data

Identify those portions of the overall monitoring program which require several years of base-line data for proper interpretation and establish instruments for collecting that background information (1972-1973).

2.5.3 Monitoring Program Establishment

Establish entire monitoring program, including all remaining instrumentation, mechanisms for reading and servicing instruments, and arrangements for compilation, interpretation, and distribution of data (1973-1976).

2.5.4 Operational Monitoring

Continue the monitoring program through Repository operation and, with some modification, after decommissioning.

2.6 Design Confirmation Studies

Design and perform experiments in the mine to refine certain design factors and the "worst case" hazard analysis. Obtain data regarding temperature distributions, rock deformations, radiation effects in the salt, brine migration rates, and waste container integrity and failure mechanisms (1972-~1985). Preliminary design of demonstration experiments developed before the start of construction (1972-1985).

SCHEDULE OF TASK MILESTONES AND PRIORITIES
(SECTION 2)

1A Preliminary acceptance criteria established
 2B Magnitude of gas transport through crushed salt established
 3B Rates of isotope migration by gas phase transport confirmed
 4B In-mine demonstration of gas phase transport designed
 5B Magnitude of solid state diffusion rates established
 6B Magnitude of grain boundary and surface diffusion established
 7B In-mine demonstration of diffusion rates designed
 8A Magnitude of energy storage problem established
 9B Saturation values of stored energy in salt determined
 10B Quantities of energy stored in waste and salt and consequences of its release established

11B Magnitude of radiation effect on k in salt established
 12B Effects of radiation on physical properties of wastes and salt established
 13B Composition of brines established, brine migration rates confirmed
 14B Identities and yields of radiolytic and thermal reaction products established
 15B In-mine demonstration test designed
 16B Model to predict behavior of key radioisotopes in environment designed

17B Ecosystems and processes that influence radionuclide fluxes in vicinity of site determined
 18B Ecological reference baseline established
 19B Monitoring requirements established
 20B Acquisition of long lead-time baseline data started
 21B Radiological baseline established
 22A Preliminary design of demonstration experiments developed
 23B Design of all demonstration experiments completed

3. PROGRAM MANAGEMENT AND DESIGN

The objective of these efforts is to provide overall technical direction, planning, evaluation, and coordination of the Repository project, including all investigative tasks outlined in this document; to maintain technical direction of the architect-engineer (A-E) during all phases of design and development; to maintain technical liaison with the operating contractor during design, procurement, construction and facility startup; to provide detailed engineering and procurement services for certain specialized facility equipment items; to establish and maintain an overall project schedule for activities funded under both capital and operating; to provide two design concepts for waste retrieval; to direct and approve the preparation of project documentation and funding schedules; to prepare a preliminary safety analysis and subsequent revisions; and to assist the operating contractor during operator training, startup, and during the demonstrational phase of operations.

To achieve the stated objectives, the following major tasks and subtasks will be undertaken as indicated.

3.1 Program Management and Design Review

3.1.1 Design Reports

- a. Prepare a Conceptual Design and Safety Report (CDSR) in conjunction with Kaiser Engineers, Inc., the architect-engineer (A-E). The CDSR to include the essential features of a conceptual systems design description (CSDD), a preliminary safety analysis report (PSAR), and a conceptual design report, as well as a preliminary project schedule and a conceptual design cost estimate (1971-1972). [V-1, V-2]
- b. Assist the A-E in preparation of a Title I design report (1972). [II-8]
- c. Update the safety analysis portions of the CDSR, in conjunction with the operating contractor (1973). [VIII-2, VIII-7]

3.1.2 Facility Design and Construction

- a. Provide technical direction to the A-E during Title I design of the Repository (1972).
- b. Provide technical direction to the A-E during Title II design (1973).
- c. Assist A-E and AEC in construction and inspection activities (1973-1976).

- d. Assist in procurement of certain special and long-lead-time equipment (1973-1976).

3.1.3 Assistance to Operating Contractor

Provide assistance to the operating contractor during the design, construction, facility startup, and the demonstrational phases of the Repository (1973-1985).

3.2 Design Participation

3.2.1 Process Design Studies

Conduct process design studies, in conjunction with the A-E, to establish process flowsheets and variables and equipment sizes for special facility processes such as the cooling system for the high-level waste cans and cask internals and the collection, concentration, decontamination, and solidification systems for liquid wastes generated at the Repository (1971-1972).

3.2.2 Mechanical Design

- a. Develop and test a suitable connector for remote handling of high-level waste cans within the surface-level transfer cell, the mine-level receiving station, and the high-level waste transporter (1971-1972).
- b. Develop the mechanical modifications to the existing Project Salt Vault (PSV) waste transporter as required to make it suitable for the initial burial of the high level waste cans (1972-1973).
- c. Prepare conceptual designs of future models of the high level waste transporter, in conjunction with the A-E (1973).
- d. Design, in conjunction with the A-E, the high-level shipping cask components which interface with the Repository facilities and establish the basic features so that the cask designers can include these considerations in the development of shipping casks (1972-1973).
- e. Assist the A-E in study of handling methods used for existing heavy shielding casks and development of methods for handling casks at the Repository (1972).

3.2.3 Alternate Shielding Materials

Investigate availability and relative cost of alternate aggregates for shielding concrete and conduct early discussions with shielding window manufacturers to establish the most economical and efficient configuration for shielded cell facilities at the Repository (1972).

3.2.4 Site Investigations

In cooperation with the A-E, arrange for certain engineering evaluations of the Repository site in advance of Title I design, including a civil survey of the site and preparation of an acquisition map; investigation of the soil characteristics for foundations design; and liaison with the public utilities of the Lyons, Kansas, area to confirm availability and need for relocation of services (1972).

3.3 Waste Retrieval Concepts

Prepare two concepts for future retrieval of wastes buried in the Repository: (1) a concept for retrieval during the demonstration phase; and (2) a concept for retrieval thereafter (1972-1974). [VIII-1]

3.3.1 Method for Retrieval During Demonstration

Establish a method for emplacing high-level wastes in the mine that will ensure container integrity and ease of retrievability during the demonstrational phase of Repository operations.

- a. Investigate materials (both metallic and ceramic) for use as sleeves around cans, from the standpoints of their structural, thermal, and corrosion-resistant properties.
- b. Investigate methods and materials for increasing heat transfer in the annular space between the waste container and the sleeve, and for sealing the top of the burial hole.
- c. Investigate alternate concepts, as required, for emplacing containers without sleeves; e.g., by use of a scavenger material such as CaO in the burial hole.

3.3.2 Concept for Retrieval Following Demonstrational Phase

Establish a concept for retrieval of waste to be buried after the demonstrational aspects have been completed.

3.4 Safety Analysis and Reviews

Prepare a preliminary safety analysis and subsequent revisions as may be required by ongoing reviews and design changes. Pertinent results from all other tasks to be used as input data for these analyses to arrive at a final assessment of operational and long-term safety. Preliminary safety analysis contingency plans will be completed before the start of construction.

3.4.1 Analysis of Long-Term Geologic Containment

- a. Continue to analyze integrity of the salt formation from various natural effects alone, using information gathered from tasks in Section 1 and extrapolating it to several hundred thousand years (1971-1976).
- b. Continue to analyze possible disturbance of the geologic regime created by operation of the Repository itself and the possible influence these effects may have on the integrity of the containment, again using input data from tasks in Section 1 (1971-1976).

3.4.2 Analysis of Routine Operations

Continue analysis of health and safety criteria and possibilities of routine releases of radioactive and noxious materials from the Repository during operation; analysis to continue through design, construction, and startup phases of the project (1971-1976).

3.4.3 Accident Analysis and Contingency Planning

- a. Continue to evaluate the history of natural events, such as earthquakes, tornadoes, flooding, etc., in the Kansas area, using information obtained from various sources, and the possible effects of these events on the integrity and safety of the critical Repository structures, systems, and equipment (1971-1976). [V-1, V-2, VIII-4]
- b. Develop contingency plans to be put into effect in the event of an operational accident (1971-1974). [VII-2, VIII-4, VIII-5, VIII-6, VIII-8]

SCHEDULE OF TASK MILESTONES AND PRIORITIES
(SECTION 3)

- 1A Preliminary draft of CDSR completed
- 2A CDSR update completed
- 3A Waste can connector developed and tested
- 4B Design modifications for waste transporter developed, conceptual design of future transporter completed, design interfacing features of shipping cask completed

- 5A Optimal shielding materials specified
- 6A Construction features of site evaluated
- 7A Method established for emplacement and retrieval of high level waste during demonstrational phase, concept established for long-term retrieval

- 8B Concept developed for long-term retrieval
- 9A Preliminary safety analysis and contingency plans completed
- 10B Analysis of long-term containment, safety of routine operations, and consequences of accidents completed

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4. PROJECT RELATED ACTIVITIES

The tasks listed in this section are not within the purview of the salt mine repository activity at ORNL, but will be performed either at ORNL under different funding or at other AEC sites.

4.1 Mine Management

Establish optimum mine geometry, burial pattern, and pricing schedules, within previously established safety criteria.

4.1.1 Parametric Studies

Perform parametric studies to determine most sensitive features of burial costs. Parameters to include such things as waste composition, thermal power, age, and thermal properties; container dimensions; waste package pitch and array in the mine; room and pillar dimensions; and time and location of package burial relative to previous burials in the mine (1972-1973).

4.1.2 Pricing Schedules

- a. Establish preliminary pricing schedules for burial of both alpha and high-level wastes, based upon results obtained in 4.1.1 above, and furnish same to industry (1972-1973).
- b. Periodically revise pricing schedule as warranted by availability of new information and better estimates (1974-1976).

4.1.3 Mine Management Computer Program

Develop a computer program to calculate optimal mine geometry and maintain inventory records of material buried within the mine (1974-1976).

4.2 Miscellaneous Studies

A series of studies and analyses must be conducted as a corollary to the principal project effort, but outside the responsibility of ORNL, including the following.

4.2.1 Waste Transport Analysis

- a. Analyze the adequacy of the existing railway systems to carry waste shipments as projected for the Repository, including the availability of ATMX-600 rail cars hauling alpha waste; availability and design limitations of rail cars for hauling 100-ton

shipping casks; and the conditions of existing rails, ties, and road beds over which waste is likely to be transported to the Repository (1972).

- b. Make an appropriate evaluation of the safety aspects of the ATMX-600 rail cars for shipping alpha wastes and prepare a report; the analysis to specifically include the possible effects of earthquakes, tornadoes, and wind-driven missiles, as well as fire, collision, derailment, and other accidents (1971-1972).

4.2.2 Thermal Stability of Alpha Wastes and Development of Packaging Criteria

Investigate the thermal stability of alpha wastes and develop packaging and acceptance criteria for alpha wastes at the Repository in order to facilitate safe and economical operation of the Repository.

Perform experimental work as follows to broaden criteria for the alpha waste packages that are to be received during the demonstrational phase of the Repository:

- a. Characterize typical wastes from the standpoint of spontaneous combustion, ignition temperatures, rates of combustion and pyrolysis as a function of temperature, and chemical heat generation rate as a function of time and temperature.

Continue heating tests with small steel drums and combustible mixtures to provide additional information on the rates of pressure buildup with temperature and the quantities and identities of noxious gases that are produced. Initiate calorimetric measurements to help interpret the results and enable them to be used to predict the behavior of other combustible mixtures (1972-1973).

- b. Develop a few types of standard burial units that can be certified as specification containers by the Department of Transportation (1972-1973).
- c. Determine containment capability of these burial units when subjected to an internal fire, external fire or heat source, dropping, puncture, internal pressure, and external pressure (1973).
- d. Investigate low-weight materials such as foams to render reactive materials inert, fix contamination, and provide internal support (1972-1974).
- e. Investigate gasket and coating materials (1972-1974).
- f. Establish firm criteria for alpha wastes and their packaging (1974).

4.2.3 Decommissioning

Prepare and continue to develop a conceptual plan for decommissioning of the Repository at conclusion of operations; ultimately, the procedures to accomplish the decommissioning to be prepared by the operating contractor, during the early years of Repository operation (1972-1977).

4.2.4 Nondestructive Assay

Develop and test a fully operational system for nondestructive assay of waste burial packages ready for immediate use at the Repository (1973-1975).

4.2.5 High-Level Waste and Container Evaluation and Testing

Test decontamination methods for high-level waste cans; resistance of these cans to thermal and mechanical shock and to internal buildup of pressure; corrosion of pots during interim storage; evidence of stored energy in solidified wastes; stability of bare, solidified wastes in presence of salt and brine (1972-1976).

4.2.6 Surplus Salt Disposal

Develop a fully operational plan for off-site disposal of mined surplus salt as an alternate to storage in the alpha mine (1973-1974).

SCHEDULE OF TASK MILESTONES AND PRIORITIES
(SECTION 4)

*Subject to Congressional Action

5. STUDIES AND INVESTIGATIONS RELATED TO THE PROPOSED REPOSITORY AT LYONS, KANSAS, THAT HAVE BEEN RECOMMENDED BY THE NAS COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (NAS), THE KANSAS GEOLOGICAL SURVEY (KGS), AND THE U.S. DEPARTMENT OF THE INTERIOR (DI)

I. Geologic Site Investigation

A. Regional Studies

1. Review and summarize all available information on geology and hydrology of area (KGS). [1.2.1, 1.2.2, 1.2.3]
2. Study surface geology and hydrology within a 50-mile radius of the site from available information (KGS). [1.2.1]

B. Local Surface Geology and Hydrology

1. Study in detail geology of 9-square-mile area centered on site (KGS). [1.]
2. The geology of the area should be examined in greater detail. Particular attention should be paid to faults and sink holes (NAS). [1.3.1, 1.2.3]
3. Drill at least 30 holes to a depth of 100 ft through Pleistocene material to bedrock (KGS). [1.2.1]
4. At least 12 cores should be obtained to a depth of about 300 ft through the stone corral formation (KGS). [1.2.2]
5. Sufficient borings should be carried out to determine the geology of the area and the quantity and quality of the aquifers (NAS). [1.2.2]
6. The extent, magnitude and nature of all regional fresh and saline aquifers and their associated strata from the surface to the crystalline basement rocks should be defined and characterized. The main emphasis should be directed toward determining the regional groundwater flow patterns and how effectively the salt will remain isolated from groundwater (KGS). [1.2.2, 1.2.3]
7. Take water samples from all aquifers (KGS). [1.2.1, 1.2.2]

C. Local Subsurface Geology

1. At least four borings, about 1100 ft deep, should be cored and logged from the stone corral formation through the entire salt section to a depth of a few hundred feet below the Hutchinson Salt at the corners of the site. One of these holes should be cored and logged from the limestone corral to the Precambrian basement rock, approximately 4500 ft deep (KGS). [1.2.3]
2. Four cored and logged drill holes through the salt should be sunk at the corners of the proposed site (NAS) [1.2.3]
3. The original plan for investigating the hydrology of the deeper formations called for the drilling of four test holes. This should be regarded as a minimum number to determine the general hydrologic characteristics of the formations at the site. This information is vital for an appraisal of the stability of future hydrologic conditions, particularly those having to do with the possible downward movement of groundwater to the salt formation (DI). [1.2.3]
4. The original plan for the study of the shallow formations (from the Kiowa to the Stone Corral) involved the drilling and testing of about 12 holes rather than four in the nine-square-mile area including the site. This study should be completed immediately (DI) [1.2.2]
5. The possible injection into the Arbuckle Formation of brine made from mined salt requires studies of the hydrology of this formation (NAS). [1.2.3]
6. Additional tests may be desirable to determine the flow of water in the aquifers (NAS). [1.2.2]
7. We strongly recommend that...we must have a continuous core and geophysical logs to the Precambrian (KGS). [1.2.3]

D. Rock Property Testing

1. The physical properties of the mixed salt bed materials should be determined (NAS). [1.2.5-b,c]

E. Solution of Salt Beds

1. Boundary Dissolution
 - a. More work needed on rate of western migration of the eastern edge of the salt where it crops out on the surface about 25 miles east of the site (DI). [1.1.2]

- b. Study solutional history and regime of the eastern edge of the Hutchinson salt bed (KGS). [1.1.2]
- c. The solutional history and regime of the eastern edge of the Hutchinson salt should be investigated (NAS). [1.1.2]

2. Erosion and Denudation

- a. Determine the nature and extent of erosion that may take place in central Kansas during the next 500,000 to 1 million years (KGS). [1.1.1]
- b. The extent of land erosion that may take place in central Kansas during the next 500,000 to 1 million years should be investigated (NAS). [1.1.1]

3. Penetration Dissolution - This item concerns the possibility of salt dissolution occurring as the result of freshwater migration down the numerous oil wells and other penetration of the salt formation. A few examples of this phenomena are known in the region where sufficient salt has been removed to result in the development of a sinkhole on the surface.

- a. A survey should be made at neighboring oil and gas wells (NAS). [1.3.1-a]
- b. We also strongly recommend that the monitoring system include plans to relocate and recement old abandoned holes in the area at least every 10 years (KGS). [1.3.1-d, 2.5]
- c. Provisions for installing radiation monitoring equipment and/or sealing of all existing oil, gas, and water wells within or surrounding the Repository site (DI). [1.3.1-d, 2.5]
- d. A surrounding peripheral zone must be protected from accidental drilling (NAS). [1.3.1-a]
- e. Hydrologic studies being made should determine the need to control man's activities on the surface...that may precipitate unintentional changes in the groundwater regime above the salt bed...this could adversely affect salt storage areas (DI). [1.3.1, 1.1.1-b, 1.3.2-b]

II. Geothermal

1. With reference to heat transfer, the problem of modeling heat flow and subsidence during and following waste storage is of paramount importance. The crucial problem is not the transient heat flow problem, but rather the interaction of subsidence, thermal expansion, and heat-flow effects as they occur over the life of the disposal facility. It is this interaction...that could be responsible, potentially, for breaking the seal of overlying beds permitting entry of surface or subterranean waters (KGS). [1.2.5-c, 1.2.6, 1.2.7]
2. With reference to problems relating to heat flow and surface subsidence, the interaction of subsidence, thermal expansion and heat flow could be responsible for breaking the seal of overlying rocks, and permitting entry of surface and sub-surface waters. The State Geological Survey regards solution of this problem as crucial to the safety of the Repository site (KGS). [1.2.5-c, 1.2.6, 1.2.7]
3. A study should be made of the effects of thermal stress on the stability of the salt and the rocks and their contained fluid above and below the salt (KGS). [1.2.5-c, 1.2.6, 1.2.7]
4. Further analysis of the thermal and other stresses on the heterogeneous rocks in the Hutchinson Salt Member at the site are warranted, these stresses (prolonged heating and exposure to radiation and subsidence and deformation associated with the mining and flow of salt) could result in fracturing of the rocks above the salt. If the system of induced fractures extends upward through the 500-ft-thick section of the shales...groundwater might move down to the salt (DI). [1.2.6, 1.2.7]
5. The effects on the shales interbedded with and overlying the salt, of prolonged exposure to heat and radiation. Along with possible subsidence effects, any shear stresses that would result from heating the shales could increase the vertical permeability of the rocks between the salt formation and the aquifers and permit groundwater to move down and dissolve the salt; circulation would result from convection produced by heat from the wastes. An analysis of all aspects of the problem would involve several other disciplines including mining engineering, rock mechanics, thermodynamics, hydrology, etc. (DI). [1.2.5-c, 1.2.6, 1.2.7]
6. An investigation should be made of various methods of mining and backfilling as they relate to possible subsidence above the Repository (NAS).

7. Evaluate the feasibility of block mining of salt (KGS).
8. It would be advisable to describe in more detail how the mined salt will be processed and utilized to increase its density for backfill to reduce subsidence...criteria for backfilling...are especially desirable, since salt flowage and other deformations are presently occurring in the Carey Salt Mine (DI). [3.1.1-b]
9. The statement does not provide an adequate specific description or analysis of the contemplated design of the "high-level mine" from which the effects of mining subsidence can be evaluated even in a general qualitative manner (DI). [1.2.6]
10. Theoretical and experimental work should be carried out to determine the possible establishment of thermally initiated flow patterns that may dissolve and transfer salt (NAS). [1.2.5-c, 1.2.6, 1.2.7, 1.2.4]

III. Radiation Effects

1. Experimental determination of the metamict effect in salt should be made (NAS). [2.3.1]
2. Evaluate metamict processes in the materials that surround the radioactive waste products (KGS). [2.3.1]
3. With reference to studies of radiation damage, the State Geological Survey regards this problem as extremely critical to safe storage of radioactive waste at the Lyons site (KGS). [2.3.1]
4. With reference to Energy Storage in Salt Resulting from Radiation Damage: We consider additional investigation...to be necessary part of the safety evaluation of the Lyons site, tests should be performed on artificially irradiated salt so that practical limits for energy storage capability can be established...until such studies are completed, energy storage in salt must be classified as a potential and incompletely evaluated hazard.

It is possible to envisage a number of hazardous phenomena that might occur at or near the individual waste container sites...We feel these potential hazards cannot be dismissed without careful research and documentation (KGS). [2.3.1]

IV. Ecology and Monitoring

1. Provisions for continuous air monitoring to detect dangerous levels of radioactive gases and airborne particulate matter within the mine and at the mine ventilation exhaust port both before and after filtration (DI). [2.5]
2. Design monitoring system for surveillance of water quality and temperature, radiation levels, seismic activity, surface subsidence, plugged wells, and change in biota (KGS). [2.5]
3. Continuous ecological and other environmental monitoring within and immediately surrounding the site (DI). [2.5]
4. Adequate plans for a monitoring system for environmental surveillance must be developed (NAS). [2.5]
5. Provisions for drilling and instrumenting deep wells about the perimeter of the disposal site to monitor temperature and radiation levels in the Hutchinson and adjacent formations, and overlying aquifers (DI). [2.5]

V. Earthquakes

1. The statement should derive and specify the expected earthquake, and a definition of the potential hazards to mines and surface structures (DI). [3.1.1-a, 3.4.3-a]
2. Evaluate briefly the earthquake history of the region. It would be desirable to establish seismograph stations (KGS). [3.1.1, 3.4.3-a, 2.5]

VI. Transportation

1. With reference to plans for safe transportation of radioactive materials, the element is critical and crucial to the safe storage of radioactive materials at the Lyons site (KGS).

VII. Retrieval of Waste

1. A system for retrieving the waste from the Repository, should it ever be necessary, must be developed (NAS). [3.3]
2. The AEC should undertake contingency planning for "worst possible case" conditions that might develop in the storage site (KGS). [3.4.3-b]

VIII. Miscellaneous Recommendations

1. Studies to determine the rupture strength of these canisters from internal gas and temperature buildup during the decay of the contained radioactive materials (DI). [3.3]
2. The waste handling procedures and emplacement of wastes into the mine should be further described. The terms used for waste containers (casks, waste packages, high-level waste containers, etc.) should be defined to give a better perspective of the operation (DI). [3.1.1-c]
3. Regardless of possible industrial or other uses, the area should be revegetated to the natural state as soon as possible in order to maintain the actual ecological niche of the general area (DI). [2.4]
4. Planned means for cleaning up radioactive waste spillage within the mine, receiving facilities, and along principal access routes (DI). [3.4.3-a,b]
5. Provision for strategically located mine safety areas and/or shelters to which personnel could retreat in the event of a caving or radiation accident, and from which they can be rescued without bringing radioactive contaminants to the surface (DI). [3.4.3-b]
6. Provisions for rapid and automatic sealing of all mine openings in the event of a radiation accident, atmospheric contamination, destruction of support facilities (receiving buildings and hoisting), and loss of power (ventilation and monitoring) (DI). [3.4.3-b]
7. Construction and posting of a personnel barricade around the perimeter of the Repository (DI). [3.1.1-c]
8. Provisions for removal, storage and treatment of water that may accidentally enter storage areas in the mine and become contaminated (DI). [3.4.3-b]
9. Studies to determine the deterioration rate of the stainless steel and high carbon steel canisters to be used for storing radioactive wastes in the salt environment of the mine (DI). [2.1.2-a,b,c]

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