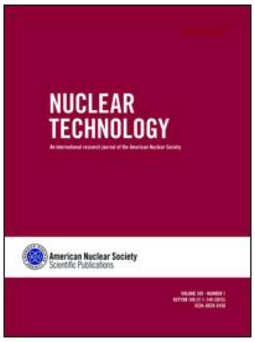
Nuclear Technology



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RETRIEVABLE SURFACE STORAGE FACILITY FOR COMMERCIAL HIGH-LEVEL WASTE

RADIOACTIVE WASTE

KEYWORDS: *casks, radioactive waste storage, cooling, design, containers, radioactive waste facilities*

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At the request of the U.S. Atomic Energy Commission (USAEC), the Atlantic Richfield Hanford Company has completed engineering studies that will lead to the construction of a retrievable surface storage facility (RSSF), capable of receiving all high-level radioactive wastes generated by commercial reactor fuel reprocessing plants through the year 2000 and storing these wastes for at least 100 years. There will be approximately 75 000 canisters (1 ft diam × 10 ft long) of dry solid waste containing a total of about 200 MW of heat. These wastes must be safely stored in a manner that will have minimum adverse impact on man's environment and the ecology, and not cause undue risk to the health and safety of the public. General design criteria for the RSSF were developed and the technical feasibility of each of the following concepts was determined: (a) storage in water basins where the decay heat is rejected to the atmosphere by the use of heat exchangers and cooling towers, (b) storage in air-cooled vaults where the heat removal is by natural convection, and (c) storage in rugged thick-wall casks placed outdoors. Selection of the concept to be developed for RSSF construction will be made by the USAEC.

INTRODUCTION

The policy of the U.S. Atomic Energy Commission (USAEC) is to assume permanent custody of all commercial high-level radioactive wastes. This policy, set forth in the Code of Federal Regulations, Title 10, Part 50, requires that these "wastes shall be transferred to a Federal repository no later than ten years following separation." Ultimate disposal methods are being evaluated but are not expected to be available when waste deliveries from commercial fuel reprocessing plants begin in about 1984. The USAEC, therefore, plans to build an interim storage facility called the retrievable surface storage facility (RSSF).

The Atlantic Richfield Hanford Company was selected by the USAEC Division of Waste Management and Transportation to perform engineering studies for the RSSF, with Kaiser Engineers providing design support. These studies were performed to evaluate the technical feasibility of several storage concepts and the detailed study results[1] are published in ARH-2888 REV.

SUMMARY

This paper summarizes the results of engineering studies performed to evaluate methods for the storage of high-level radioactive wastes. A design basis for any acceptable storage concept was that it be capable of safely storing, for at least 100 years, all the commercial high-level waste generated by the year 2000. The three basic storage concepts evaluated—(a) water basin storage, (b) air-cooled vault storage, and (c) air-cooled steel cask storage—included both active and passive cooling systems for radioactive decay heat removal. Other features investigated included radiation shielding requirements, materials compatibility, and safety and environmental effects.

DISCUSSION

Principal design bases used in evaluating alternative RSSF concepts are as follows:

1. Store all high-level wastes generated by the nuclear power economy through the year 2000 A.D.
2. Store these wastes for at least 100 years.
3. Assure the health and safety of the public and the protection of the environment.
4. Design, construct, and operate in accordance with USAEC, federal, state, and local regulations.
5. Provide the ability to withstand credible natural phenomena.
6. Limit maximum waste temperature by continuous heat removal.
7. Assure retrievability of stored waste at all times.
8. Use existing technology.

Initially, the waste will be accepted at the RSSF as a dry, inert, stable calcine. The primary container will be a metal canister. The criteria for canister size, material, and features have not been established, but for conceptual design purposes a typical canister as shown in Fig. 1 has been assumed.

Assuming the typical waste canister and 10-yr reprocessor storage before shipment, the load buildup for the RSSF (Ref. 2) would be as shown in Fig. 2. In 1990, about 20 canisters per week would be received; the rate would increase to about 20 per day in 2010. The radioactive decay heat load associated with the waste would reach a maximum of 195 MW in the year 2010 and, if no additional waste were added to the RSSF, it would decrease to about 30 MW after 100 years.

Three basic storage concepts were evaluated for the RSSF. These were as follows:

1. storage in cooled water basins [water basin concept (WBC)]
2. storage in air-cooled concrete vaults [air-cooled vault concept (ACVC)]
3. storage in air-cooled steel casks [sealed storage cask concept (SSCC)].

In the WBC, the waste canisters would be stored in water-filled, stainless-steel-lined basins. Each basin would contain 500 typical canisters, with each canister generating up to 5 kW of decay heat. By the year 2010, 165 basins would be required assuming 10% spare capacity. The water in the basins would be a good heat sink, a transparent, flexible radiation shield, and would provide an additional radioactive material confinement barrier.

Radioactive decay heat would be transferred from the waste to the basin water and then rejected to the atmosphere via primary and secondary cooling loops, a heat exchanger, and a cooling tower as shown in Fig. 3. The basin water would be maintained at <120°F under normal operating conditions. Pumps, heat exchangers, and associated systems would be designed for quick replacement since the water would reach its boiling temperature in 12 to 16 h if the cooling system were inoperative. Emergency water make-up systems would be provided as an additional backup feature.

Water purity would be maintained at <10 ppm chloride by passing a portion of the recirculated cooling water through a filtration and demineralizer system. The high purity water would be required to minimize corrosion of the stainless-steel canister and basin liner during long-term storage. A portable high-capacity water cleanup system would be provided for use in the event a canister should fail and the water become contaminated.

Some canister failures would be expected during the 100-yr storage period. Technology is

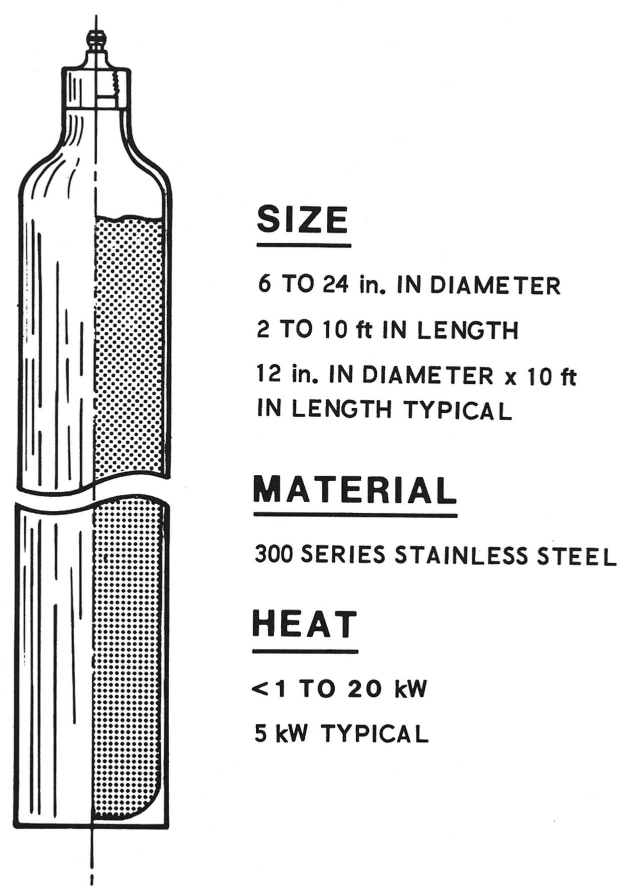

Fig. 1. High-level waste canister.

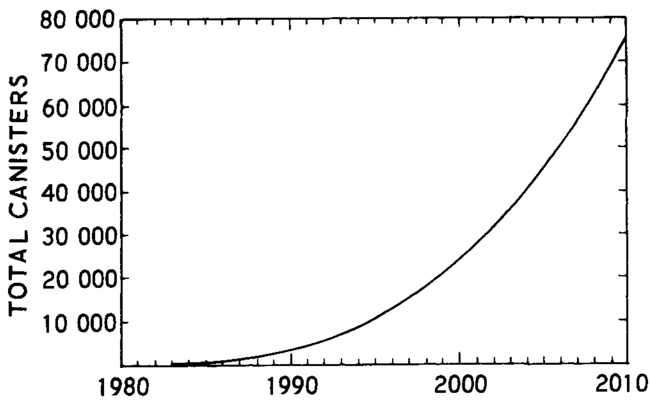

Fig. 2. Canisters in storage.

available to engineer systems to handle these situations as storage of highly radioactive heat-emitting materials in water basins has been successfully accomplished for three decades.

A variation of this concept that was considered would be to place the waste canister in a secondary stainless-steel container (overpack). This would provide an additional barrier between the waste and the basin water.

Storage of high-level wastes in an air-cooled system is attractive because air is normally less corrosive than water and it is possible to utilize a passive cooling system to remove the heat by radiation and natural convection, thus eliminating reliance on mechanical systems.

In the ACVC, the waste canisters would be sealed inside $\frac{1}{2}$-in.-thick wall carbon steel overpacks which would be stored in concrete vaults as shown in Fig. 4. Each vault would contain 500 canisters, and by the year 2010, a total of 150 vaults would be required. The thick concrete walls of the vault structure would serve as a radiation shield and provide physical protection for the canisters and overpacks. Overpack corrosion rates would be expected to be low, <0.002 in./yr. The heat would be removed by the air entering the bottom of the vault, flowing up past the overpacked waste canisters, and then out an exhaust port. The system heat transfer analysis was based on three extreme assumptions that probably would never occur simultaneously—a no-wind condition, an atmospheric pressure of 28 in. of mercury, and an ambient air temperature of 110°F. Under these conditions, a draft of 0.06 in. of water would be developed. This would provide an air flow of ~180 CFM/canister. Waste and canister temperatures would naturally be higher in an air-cooled system than in a water-cooled system, as the temperature differential provides the motivating force to initiate the natural draft air flow.

As an aid to heat transfer, each overpacked

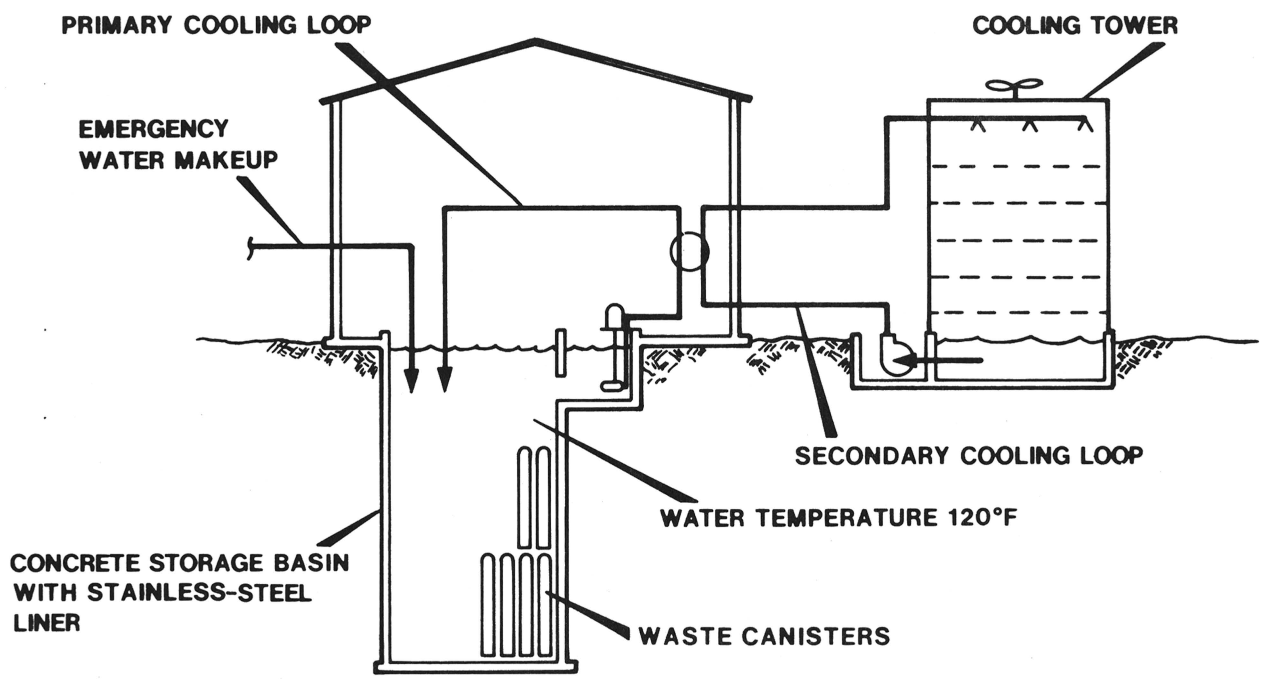

Fig. 3. Water basin concept.

canister, when stored, would be positioned inside a steel sleeve with a $1\frac{1}{2}$-in.-wide air flow annulus between the overpack and the sleeve (Fig. 5). As a result of heat transfer by radiation from the overpack to the sleeve, the overall heat transfer surface would be essentially double that of the overpack. For this system, the canister surface temperature would be 620°F, the overpack surface temperature 400°F, the concrete surface temperature 200°F, and the exhaust air temperature 210°F. Elimination of the sleeves would increase the overpack surface temperatures by ~100°F.

Sufficient natural draft cannot be effectively developed in the ACVC to overcome the pressure drop across high efficiency particulate air (HEPA) filters; therefore, HEPA filters would not be utilized for confinement. Reliance would be placed on the overpack to contain any leakage of radioactive material from the waste canister. It would also be possible to monitor the gap between the waste canister and the overpack to determine their integrity.

The principles of natural draft air cooling are well established, although this particular application may be somewhat unique. The PIVER waste storage facility in France is designed for natural draft cooling in the event the forced draft system should fail.

An analysis of total air flow stoppage in the ACVC indicates that because of high waste density, canister temperatures would initially rise quite rapidly, 50 to 100°F/h. Features can be designed into this type of system to minimize the potential of complete air flow stoppage by providing large protected air inlets and outlets, and various types of surveillance and inspection devices.

In the SSCC, the waste canister would be sealed in a cask or overpack and stored outdoors. Cooling would be by natural convection. The cask

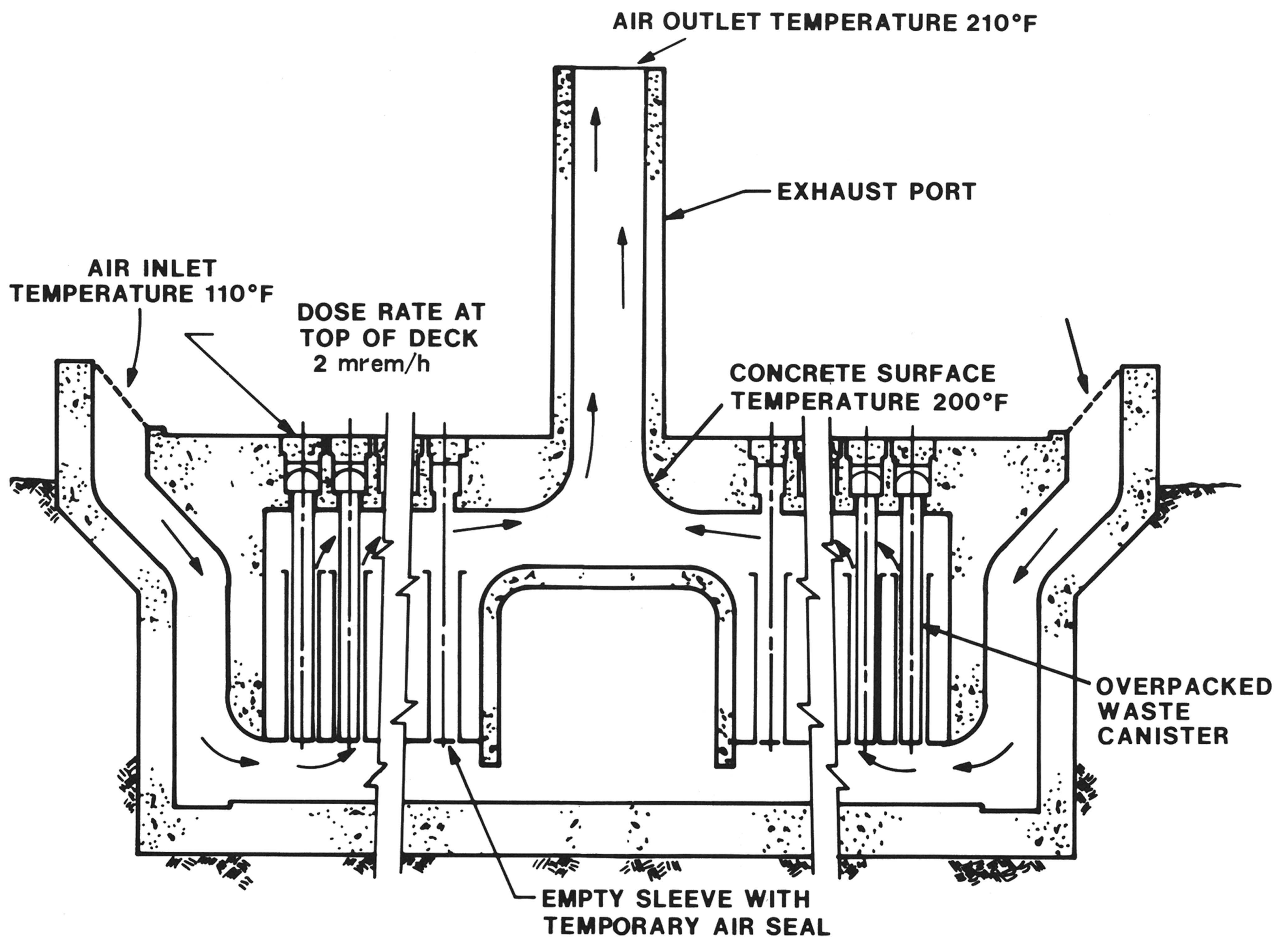

Fig. 4. Air-cooled vault concept.

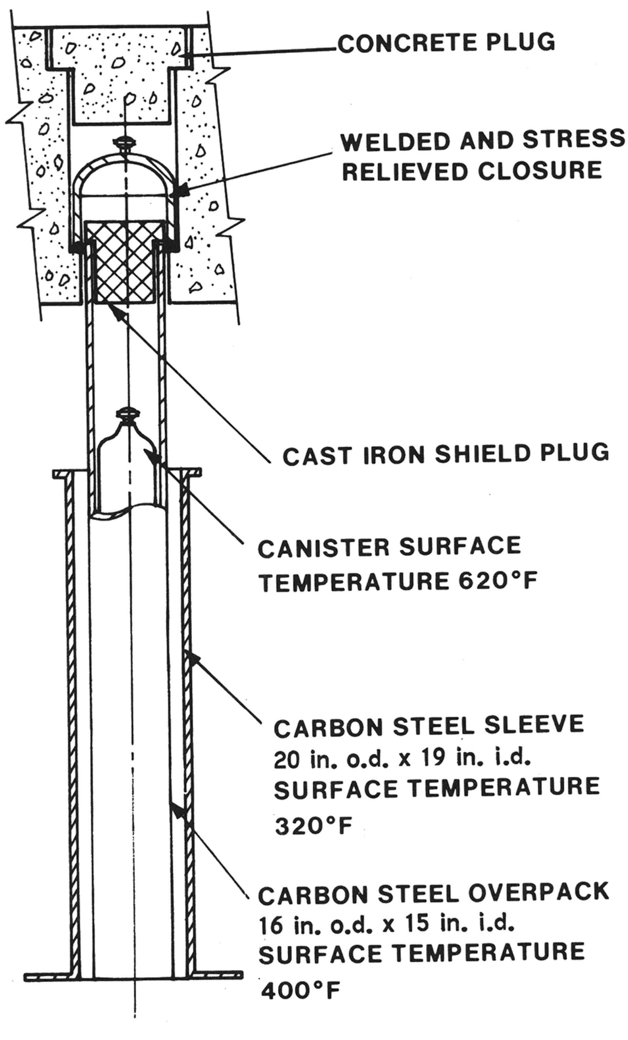

Fig. 5. Air-cooled vault concept storage unit in cell.

would be sufficiently thick to provide necessary physical protection. Radiation protection would be provided by additional cask wall thickness, concrete shielding, distance, or any combination thereof. Advantages of the SSCC are as follows:

1. natural convection cooling
2. high integrity containment
3. minimum surveillance
4. service life of more than 100 years
5. little interaction between waste cannisters.

In one SSCC evaluated, the waste canister would be sealed in a cask having an 8-in.-thick wall. The cask would be stored outdoors as shown in Fig. 6, and cooling would be by radiation and natural convection. The thick steel wall of the cask would attenuate much of the gamma radiation; however, it would have little effect on the neutron radiation. Additional shielding requirements would be provided by isolation and distance. Access into the storage area would be via a shielded vehicle. The high radiation level and its possible adverse environmental effects may not be acceptable.

In another variation of the SSCC, the canister would be sealed in a 14-in.-thick steel cask. This would be positioned inside a concrete neutron shield and stored outdoors as shown in Fig. 7. Cooling would be by natural convection with air entering at the bottom and flowing upward in the annulus between the cask and the concrete. The outside surface temperatures of the canister and cask would be 450 and 170°F, respectively. With 14 in. of steel and 11 in. of concrete, the radiation dose rate on the outside of the concrete would be <2 mrem/h. Although the technical features of this concept are attractive, the steel requirements for casks would be quite excessive, ~30 tons per cask or ~2 million tons of steel by the year 2010. This is equivalent to one week of steel production in the United States at current production rates.

By reducing the cask wall thickness and increasing the concrete shield thickness as shown in Fig. 8, a more optimized version of the SSCC is achieved which would retain all the attractive features while reducing the steel requirements extensively. In this concept, the waste canister would be placed in a steel cask with a 2-in.-thick wall. The cask would be sealed by welding, provided with a concrete radiation shield, and stored outdoors. The cask would provide containment and structural strength, while the concrete would provide shielding and additional physical protection.

Heat removal from the waste would be accomplished by a combination of radiation and natural convection. Air would flow through the annulus between the storage cask and the concrete shield by entering at the bottom and leaving at the top. The heat transfer principles are well known.

Under normal operating conditions, that is with the air flowing through the annulus between the cask and the concrete, the canister and cask surface temperatures would be 500 and 360°F, respectively. The temperature of the outer concrete surface would be 150°F. Limiting material temperatures below which the integrity of the storage unit components would not be compromised were established as 800°F for the stainless-steel canister, 550°F for the steel cask, and 500°F for the concrete. An attractive feature of this concept is that, even with no air flow through the annulus, the limiting temperatures would not be exceeded.

The fabrication of heavy steel casks for at least a 100-yr life can be accomplished with

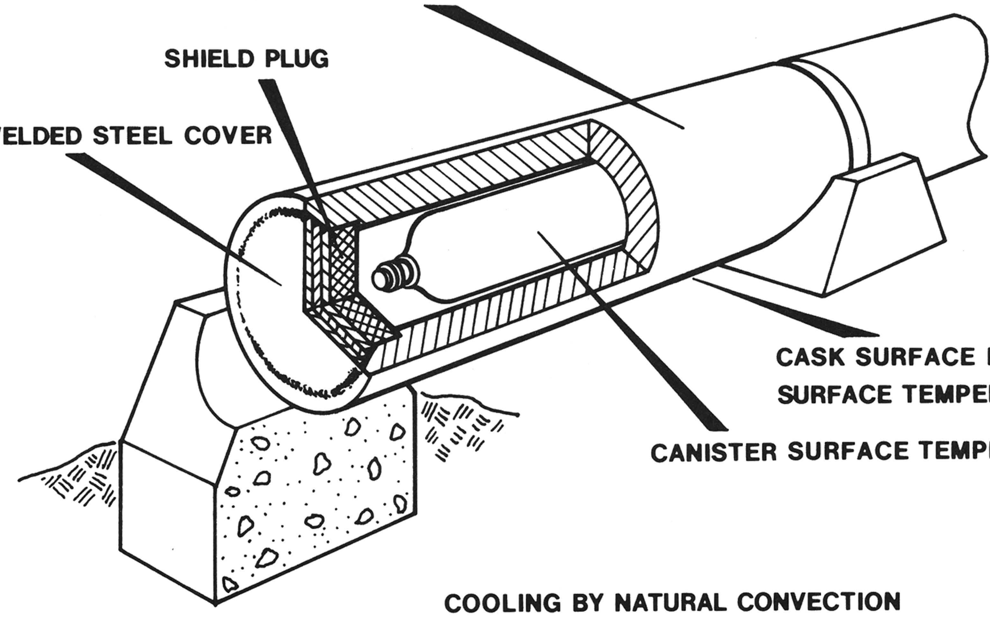

Fig. 6. Sealed storage cask concept—unshielded.

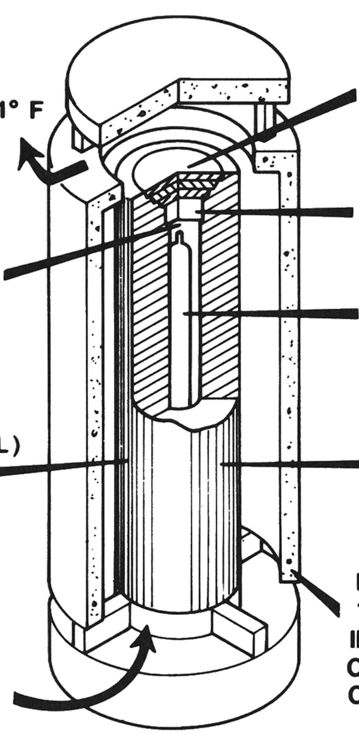

Fig. 7. Sealed storage cask concept—thick wall.

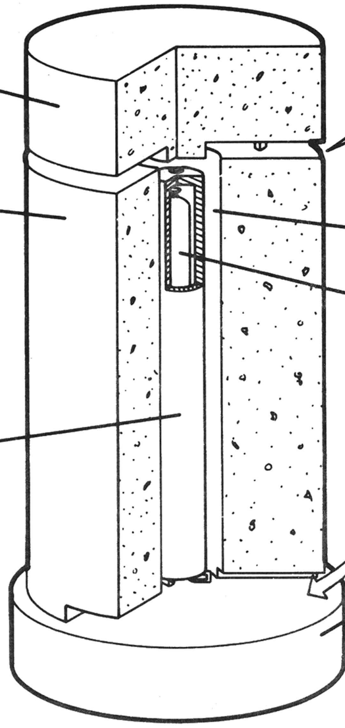

Fig. 8. Sealed storage cask concept.

adaptation of existing technology and high quality assurance standards. A cask wall thickness of 1 in. would provide adequate protection against natural force phenomena such as design basis earthquake or a tornado-generated missile. This would also allow for an average corrosion rate of 0.003 in./yr as could be expected in a relatively arid, non-industrial atmosphere. The additional inch of wall thickness would provide a 100% excess for additional safety. The thickness of the concrete is calculated such that the radiation dose rates on the outside of the storage unit would be maintained at <2 mrem/h.

Each cask would weigh about $2\frac{1}{2}$ tons and the concrete shield would weigh about 55 tons. By the year 2010, about 180 000 tons of steel for casks and 2 000 000 yd^3 of concrete for shields would be required. Put into perspective, this would represent less than one day of steel production in the United States at current capacities and $\sim\frac{1}{5}$ of the concrete in Grand Coulee Dam. Approximately 1100 acres of land including the receiving facilities would be required to store all the wastes received at the RSSF through the year 2010.

The concept would be amenable to further optimization to improve the waste to steel and concrete ratios. This could be done by increasing the capacity of the casks to store larger waste canisters or by storing more than one canister per cask. The key to increasing the amount of waste in a cask is removal of the decay heat. With improved thermal conductivity within the waste product itself and in the air gap between the canister and the cask, it should be possible to accommodate heat loads greater than the 5 kW currently being used as a design basis.

The probable environmental effects of the RSSF concepts have been evaluated and are considered acceptable. As an example, the induced radionuclides formed in soil and other materials by neutron activation for the ACVC and the SSCC will contribute <0.2 mrem/yr exposure to individuals in the vicinity of the RSSF.

The RSSF concept eventually selected for construction can be engineered to safely store all the commercial high-level radioactive waste for the interim time period required for this nation's scientists and engineers to develop the necessary technology for ultimate disposal.

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