THE BURIAL OF RADIOACTIVE WASTE IN SALT*

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The use of natural salt formations for the long-term storage of radioactive waste has been actively studied at ORNL since 1957. Results of these studies, which included Project Salt Vault, a field-scale experiment, confirmed the feasibility of this concept and provided data for the design of an actual waste repository. A conceptual design of a repository for demonstrating storage of both solidified high-level fuel reprocessing wastes and alpha-contaminated solid wastes was completed in April 1971. This paper discusses the rationale of using salt deposits for storage of radioactive waste, siting considerations in locating a repository, the operating concepts developed during the conceptual design for the handling and burial of the solidified high-level wastes, and the long-term geological effects on the area surrounding a repository.

MASTER

INTRODUCTION

One important problem associated with an expanding nuclear power industry is the management of the radioactive wastes that are generated in the fabrication and reprocessing of reactor fuels. The fabrication wastes are principally solid materials contaminated with plutonium, whereas the reprocessing wastes are liquids containing a high concentration of fission products. Both contain radioactive nuclides that decay so slowly that they require containment outside man's biological environment for hundreds of thousands of years.

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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; further, in consultation with the National Academy of Sciences and members of the geologic community, the AEC has sponsored work over the past 15 years to examine the suitability of bedded salt formations as a final repository for these materials. As a first step in implementing an overall waste management policy, the AEC has published an appendix to 10CFR50 in the Federal Register. This appendix requires high-level liquid wastes produced in industrial operations to be solidified and shipped to a federal repository.

RATIONALE FOR THE USE OF SALT DEPOSITS

In 1955, an advisory committee of geologists and geophysicists was established by the National Academy of Sciences — National Research Council (NAS-NRC) to consider the possibilities for disposal of high-level radioactive wastes in geologic formations within the United States. This committee proposed storage in natural salt formations as the most promising method for the near future. Three subsequent NAS-NRC committees have endorsed this recommendation following reviews of on-going research and development work. Laboratory and field studies of the feasibility of using salt formations for this purpose were conducted by ORNL during 1957-1962, and during 1963-1967 we performed extensive studies with high levels of radioactivity in the Carey Salt Company mine in Lyons, Kansas.¹ These

studies, designated Project Salt Vault, yielded highly satisfactory results.

The NAS recommendation was based on a number of characteristics which make salt particularly attractive for storage of radioactive wastes. It is widespread and abundant, underlying about 500,000 square miles in portions of 24 states (see Fig. 1); it has good structural properties, with a compressive strength and radiation-shielding properties 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. This situation tends to be preserved because any fractures that might develop are healed by plastic deformation and recrystallization of the salt.

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 to only those sites having the 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 more than the use of salt formations, and would result in an undesirable proliferation of surface disposal sites. And, finally, the practical application of such advanced techniques as transmutation or disposal in space is dependent on the development of

sophisticated and expensive technologies in the distant future which can be justified only for reasons other than waste disposal.

PROJECT SALT VAULT

A field-scale experiment called Project Salt Vault¹ was performed in the Carey salt mine at Lyons, Kansas in the mid-1960s to demonstrate the feasibility and safety of the 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 waste repository. Fourteen irradiated fuel assemblies from the ETR, two each in 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 structural properties.

A total of about 4 million curies of fission-product activity, in 21 containers, was transferred into and removed from 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 rather high doses, there was 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.

SITING CONSIDERATIONS

In selecting the site for the initial waste repository, certain geologic criteria, given below, were established consistent with considerations of long-term isolation and efficiency of operations. These requirements should not necessarily be considered applicable to the siting of future repositories. 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.

1. The thickness of the salt formation shall be greater than 200 ft.
2. The thickness of the salt formation above the disposal horizon shall be greater than 150 ft.
3. The purity of the salt formation shall be such that the equivalent thickness of pure NaCl is greater than 150 ft.
4. The disposal horizon shall be at least 12 ft thick, having a purity greater than 95% NaCl and containing no "partings" of impurities larger than 1/4 in.
5. The stratigraphy in the mining horizon above the waste disposal section must be "minable."
6. The depth to the top of the salt formation shall be greater than 700 ft.
7. The total depth to the mining horizon should not exceed 2500 ft.
8. Relief of the salt formation at the mining horizon shall be less than 100 ft/mile.
9. Topographic relief of the site area and environs shall be less than 100 ft/mile.

10. The site shall be located in the U.S. Coast and Geodetic Survey Seismic Risk Zone 0 or 1, as confirmed by examination of the detailed seismic history of the region.
11. The site shall be located at least 10 miles from the nearest boundary of the salt formation.
12. The site shall be located at least 20 miles from the nearest boundary of the salt formation which is currently undergoing active dissolutioning.
13. The site should be located at least 5 miles from the nearest salt production facilities of any type.

The salt deposits shown in Fig. 1 are presently being evaluated according to these criteria. The more promising sites will be the subject of on-site investigations which ultimately will lead to the selection of an optimum site for the Repository.

DESCRIPTION OF THE REPOSITORY

The conceptual design of a repository with the capability of subsequent expansion to provide storage capacity for all of the high-level wastes and most of the alpha waste generated in the United States through the remainder of the century was initiated by Kaiser Engineers in September 1970 under the direction of ORNL, and completed in April 1971. The facilities and general layout are shown pictorially in the cutaway section of the repository in Fig. 2. After the conceptual design had been completed, it was decided that alpha waste should not be buried in the initial repository. Accordingly, the alpha-related facilities will not be constructed.

The high-level facility will provide the space and equipment necessary to receive and handle 300 cans of solidified high-level waste per week. Virtually all the high-level wastes will be generated by the reprocessing plants that recover the uranium and plutonium from spent reactor fuels. These wastes are initially in the form of nitric acid solutions containing fission products and smaller quantities of uranium, plutonium, and other heavy elements.

Four processes have been developed for converting these liquid wastes to solids which, we believe, can be shipped and stored safely in salt. The volumes of these wastes average about 3 ft³ per ton of fuel processed. The products can be described as calcine cake for the pot calcination process, microcrystalline ceramic for the spray solidifier, glass for the phosphate glass ^{process} ~~products~~, and a powder for the fluidized-bed calciner.

The acceptance criteria for the Repository specify that the dry, solid high-level waste shall be chemically, thermally, and radiolytically stable, and shall be packaged in containers that will maintain their integrity for at least 90 days after they have been buried in salt. Typically, these wastes will be received in sealed cans up to 14 in. in diameter, up to 10 ft long, weighing up to 4000 lb, and generating 1 to 4 kW of waste heat. The waste cans will be shipped to the repository in casks weighing as much as 100 tons.

The sequence of operations required for the burial of the high-level waste cans is shown in Fig. 3. Upon arrival at the repository each cask will be unloaded and moved to a cooling station where the cask will be vented, the cavity purged, the purge gas sampled and analyzed, and the waste cans cooled. The casks will then be moved into a transfer gallery, positioned on a motorized dolly, moved laterally to a location under the cask port in the shielded

transfer cell, and raised pneumatically to make a seal with the bottom of the cell. The cask port cover and the shipping cask shield plug will be removed, exposing the cans and the cask interior to the cell. The cans will be lifted from the cask individually, placed into a protective cage, and lowered to mine level approximately 1000 ft below.

At mine level the shaft will open into a shielded transfer station. The cage containing the waste can will be lowered into the station, placed in a transfer car, and moved to a position under a port in the top of the station, through which the waste can will be hoisted into the shielded transporter. The existing Project Salt Vault transporter, with necessary modifications, will be used for initial high-level burial operations. This transporter will receive the can at the receiving station, transport it to the burial room, deposit it in a hole that has previously been drilled in the floor, and backfill the hole with crushed salt. The spacing between containers will be such that the radioactive decay heat will be dissipated without causing excessive temperatures in the salt or in the neighboring geological formations. After the burial area of a room has been utilized, the room will be backfilled with crushed salt and sealed from the remainder of the mine.

The master plan developed for the high-level mine provides for the burial of the cans containing high-level waste in accordance with projected rates of shipment to the Repository. The mine layout and the sequence of salt bed utilization consider the requirements of mine ventilation, mine opening stability, heat effects, efficient use of mining and hauling equipment, and efficient use of mine space that is created. The master plan utilizes a conventional room-and-pillar layout in which the waste cans are buried in

vertical holes drilled in the mine floor. The bed of salt in which the cans will be buried is the most uniform and of the best quality of the entire sequence of rock salt deposits.

We have assumed that any wastes buried in the mine will be fully retrievable during the life of the mine. "Retrieval" is defined as the removal of the wastes from the salt, transfer of the suitably-contained waste to the surface, and loading it into a shielded cask for transport off-site. Concepts for retrieval of these wastes are now being developed as part of a postconceptual design study.

Long-Term Geological Effect

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. Fracturing, bed separation, localized crushing, and other extreme effects, will occur in the immediate vicinity of the mined rooms, out to a distance of perhaps 10 to 20 ft from the walls and ceiling. At distances greater than about 20 ft, plastic deformation of the salt will accommodate imposed motions without any of these effects. Closure of the mine will represent a net decrease in the volume of the geologic system; however, the temperature of the rocks will increase as the result of heat from radioactive decay, and the subsequent thermal

expansion will represent 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, of course, in and immediately around the openings. 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. These deformations and motions will be only slightly greater than those occurring 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. 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 that would lead to fracturing or other adverse effects. 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 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 and, furthermore, that 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 Fig. 4.

Reference

1. Bradshaw, R. L., and McClain, W. C. (eds.), Project Salt Vault: Demonstration of the Disposal of High-Activity Solidified Wastes in Underground Salt Mines, USAEC Report ORNL-4555 (March 1971).

Fig. 1. Rock Salt Deposits in the United States and Those Portions Suitable for the Initial Demonstration Repository

Fig. 2. Waste Repository

Fig. 3. High Level Receiving, Handling, and Burial System

Fig. 4. Effects 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