Demonstration of Disposal of High-Level Radioactive Solids in Salt[1]

F. M. Empson, W. J. Boegly, Jr.,
R. L. Bradshaw, W. C. McClain,
F. L. Parker, W. F. Schaffer, Jr.[2]
Oak Ridge National Laboratory

ABSTRACT

A major problem in the development of a nuclear power industry is the disposal of the high-level solid radioactive wastes which will be produced in the processing of spent reactor fuels for recovery of unconsumed fissionable material. Use of salt formations as a disposal site has been under investigation since 1956. A demonstration of the disposal of these solid wastes is to be carried out in salt of the Hutchinson member of the Wellington formation using the inactive mine of The Carey Salt Company at Lyons, Kansas. The objectives of the demonstration are: (1) the demonstration of required waste-handling equipment and techniques, (2) the determination of the stability of salt under the influence of heat and radiation, and (3) the collection of information on creep and plastic flow of salt which is needed for the design of an actual disposal facility.

In the demonstration 14 irradiated fuel assemblies from the Engineering Test Reactor at the National Reactor Test Site will serve as a source of radiation in lieu of actual solidified wastes. The fuel assemblies will be contained in seven cans placed in a circular array of holes in the floor with one can in the center and six cans located peripherally, spaced 5 ft. on centers. Four sets of assemblies will be used during a 2-year test to achieve a peak dose to the salt of about 8 x 10^8 rad. Additional heat (over that produced by radioactive decay) will be added by electric heaters to maintain the adjacent salt at 200°C. A control array, consisting only of heaters, will be operated to determine those effects due solely to heat. In addition to the radioactive and control arrays, a rib-pillar will be heated electrically around its base to produce information on salt flow characteristics at elevated temperatures.

Mine renovations and mining of a new area for the test are complete. The start of the test is scheduled for July 1965.

INTRODUCTION

The development of a new industry usually creates a waste disposal problem. The major waste problem in the expanding nuclear power industry is the disposition of the high-level radioactive wastes which are produced in the processing of spent reactor fuels for the recovery of unconsumed fissionable material. The fission products which constitute radioactive wastes are unique in that they are not destroyed or modified except by radioactive decay, and that they remain hazardous for very long periods of time. Since they cannot be released to the environment, safe disposal consists of placing the wastes in such a form in such a location that neither catastrophic

[1] Research sponsored by the U. S. Atomic Energy Commission under contract with the Union Carbide Corporation.

[2] Member of Chemical Technology Division.

acts of nature nor inadvertent or malicious actions of this or future generations will cause the material to enter the living environment.

The use of salt structures for the disposal of radioactive waste was first suggested by a committee appointed by the National Academy of Science-National Research Council, Earth Sciences Group, at the request of the USAEC. The properties of salt upon which this recommendation was based are:

1. Wide distribution and large reserves.
2. Good structural properties -- Salt has the strength of concrete.
3. Relatively low cost of developing space in salt.
4. Thermal conductivity -- Salt has a high thermal conductivity compared with most geologic materials.
5. Salt deposits are located in areas of low seismicity.
6. Salt is essentially impermeable to the passage of water and other fluids.

Investigation of salt as a medium for radioactive waste disposal began in 1956. Early studies were directed toward the disposal of the liquid wastes which were the product of fuel reprocessing systems at that time (1, 2). Fuel reprocessing technology has changed, however, and future high-level wastes most likely will consist of calcined or glassy solids contained in sealed canisters or pots (3).

The study of disposal of solidified radioactive waste in salt has therefore been directed toward the study of heat flow through salt and the movement (plastic flow) of salt at elevated temperatures. Results of these investigations make it possible to define a practical technique for the disposal of these highly radioactive solids in a salt structure.

OBJECTIVES

This paper is a description of Project Salt Vault, a demonstration of the disposal of high-level radioactive solids in salt using irradiated fuel assemblies from the Engineering Test Reactor (ETR) in lieu of the actual calcined waste which will not be available even on an experimental basis in sufficient quantities before 1967. The ETR assemblies were chosen because of their availability on a dependable schedule and their relatively high radioactivity levels. Using four sets of the ETR assemblies (changing each six months) a maximum radiation dose of 8×10^8 rad will be delivered to the hole in two years. In a two-year period an actual six-inch diameter, ten-foot long, calciner pot containing material 2.3 years out of the reactor would give a dose to the salt of 3×10^9 rad.

The demonstration is to be carried out in the inactive mine of the Carey Salt Company at Lyons, Kansas. This mine operated from 1890 to 1948, exploiting salt of Permian age from the Hutchinson member of the Wellington Formation at a depth of 1,020 feet. Since 1948 the mine has been kept open for possible future use. The mine workings required extensive cleanup. Topside, a new shaft collar and head frame were installed and extensive rehabilitation of the hoist house and machinery were carried out.

The engineering and scientific objectives of Project Salt Vault are:

1. The demonstration of required waste handling equipment and techniques;
2. The determination of the stability of salt under the combined effects of heat (at 100° to 200°C) and radiation (up to 10^9 rad);
3. The collection of information on creep and plastic flow of salt which is needed for the design of an actual disposal facility.

The disposal site will also be monitored for the products of radiolytic chemical reactions, if such should occur.

DESCRIPTION

The operating plan of Project Salt Vault is relatively simple. Irradiated fuel elements from the Engineering Test Reactor at the National Reactor Testing Station will be placed in canisters and sealed. The seven canisters will be transported by truck in a lead-shielded carrier to the experiment site at Lyons, Kansas. The canisters will be lowered, one at a time, into the mine through a 19-inch diameter charging shaft. In the mine they will enter a lead-shielded vessel on a trailer drawn by a diesel-powered tractor which will deliver them, one at a time, to an array of lined holes drilled in the floor. The same machine, designated the Waste Transporter, will be used to recover the canisters at the end of their period of use and also to make transfers underground.

A general plan of part of the Lyons Mine is shown in Fig. 1. This location for the site of the demonstration was chosen because: (1) it was located at the periphery of the mine; (2) The Carey Salt Company owned this area in fee; and (3) the area was readily accessible through old workings which are in relatively good condition.

The plan shown in Fig. 2 has been chosen for the Experimental Area. Mining of this area has been completed at a level approximately 14 feet above the existing mine floor in order to do the test in pure salt. Four experimental rooms have been driven off a 300-foot-long entry. Rooms 1 and 4 are approximately 60 feet deep by 32 feet wide and separated from the adjoining rooms by 30-foot pillars. The two center rooms are nominally 44 feet wide and are separated by a 23-foot pillar. In addition a room has been driven to the Waste Shaft from a point near the entrance of the entry. The Waste Shaft is a drilled hole from the surface to the mine level. The

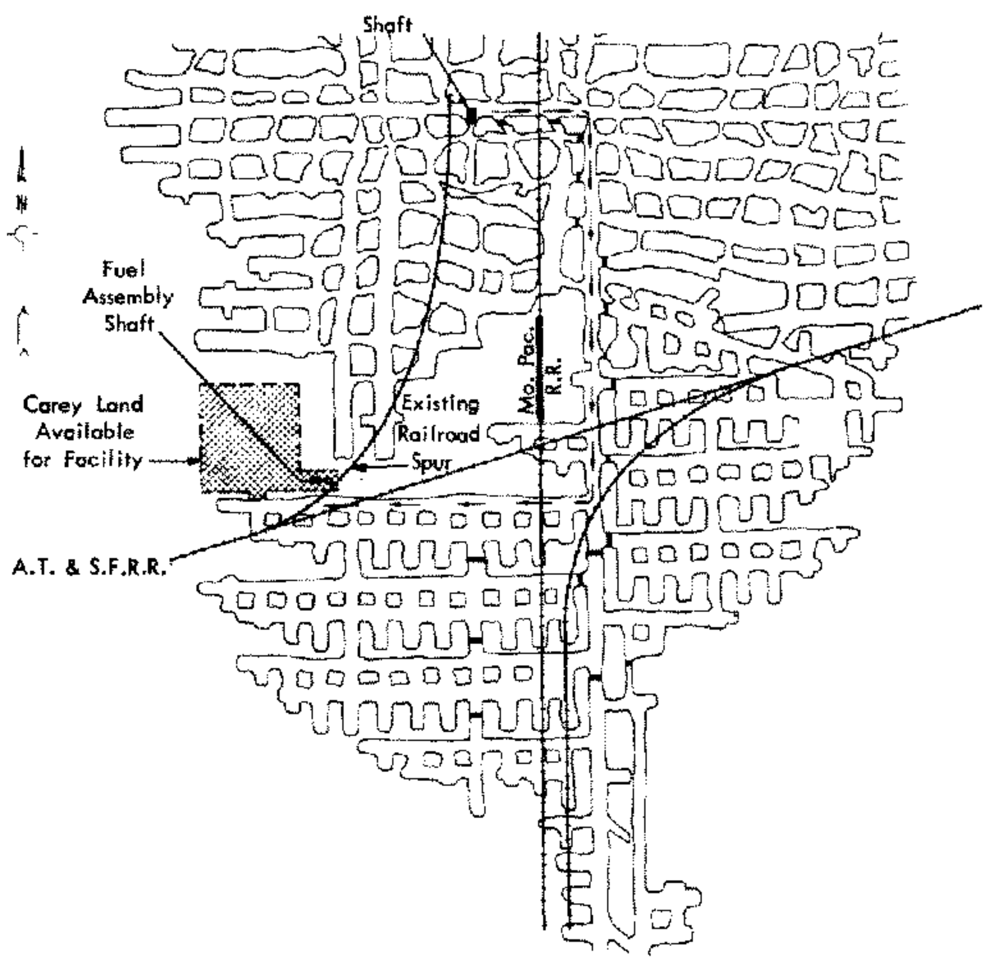


Figure 1. General plan of Lyons Mine.

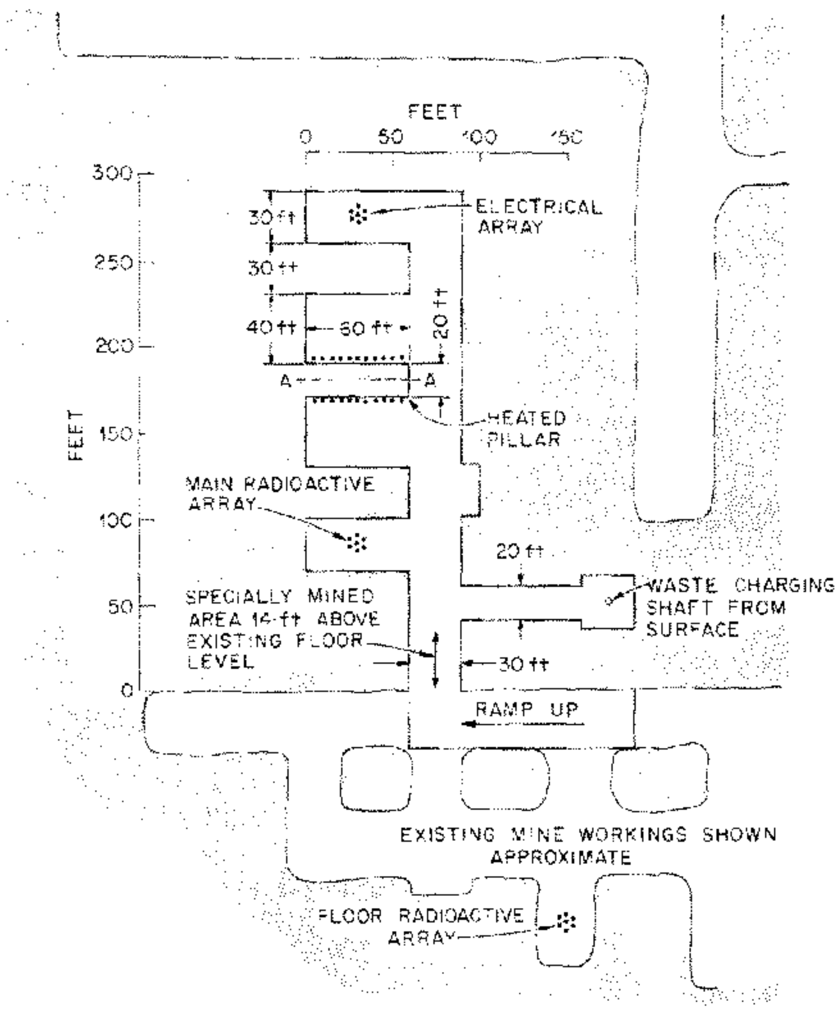


Figure 2. Experimental Area.

upper 300 feet of the shaft is double-cased with an outer casing 26 inches in diameter cemented into the formation. Twenty-inch o.d. casing is cemented inside the surface casing down to the mine level.

The main unit of the Demonstration will be an array of seven canisters placed in the center of the floor of Room No. 1. The array has a hexagonal pattern with one hole in the center and six holes around it, arranged on five-foot centers. This is the smallest unit of an infinite repeating pattern of holes on triangular spacing.

Fig. 3 shows the construction of each of the array holes. A 16-inch diameter hole, five feet three inches deep, is drilled and then deepened to 12 feet 10 inches with a diameter of 12 inches. A two-part liner is placed in this hole. The upper portion, made of 14-inch carbon steel well casing, is grouted into the upper section of the hole. The lower liner, made of six-inch o.d., 0.25-inch wall, stainless steel tubing, hangs in the 12-inch section of the hole from a flange at the lower end of the upper liner.

Electric heaters are attached to the lower liner to furnish supplemental heat in the radioactive array and all of the heat in the nonradioactive array. The heaters will be used to compensate for the somewhat lower heat release rate of the fuel elements compared with actual waste. To secure the maximum radiation dose to the surrounding salt, the canned fuel elements will be exchanged at six-month intervals.

The drawing shows the canister containing two Engineering Test Reactor fuel elements in place in the liner. The canister is made of 4 3/4-inch tubing, and is topped by an integral, depleted-uranium, shield plug of slightly greater diameter. The uranium shield plug prevents radiation from shining directly up the hole. Radiation around the uranium plug is controlled by the annular shield of steel shot.

Figure 4 is a photograph of the canister showing the depleted-uranium shield plug, dummy fuel assemblies, the tubular body of the canister, and the bottom closure of the canister. The canister closure is threaded into the body and then welded.

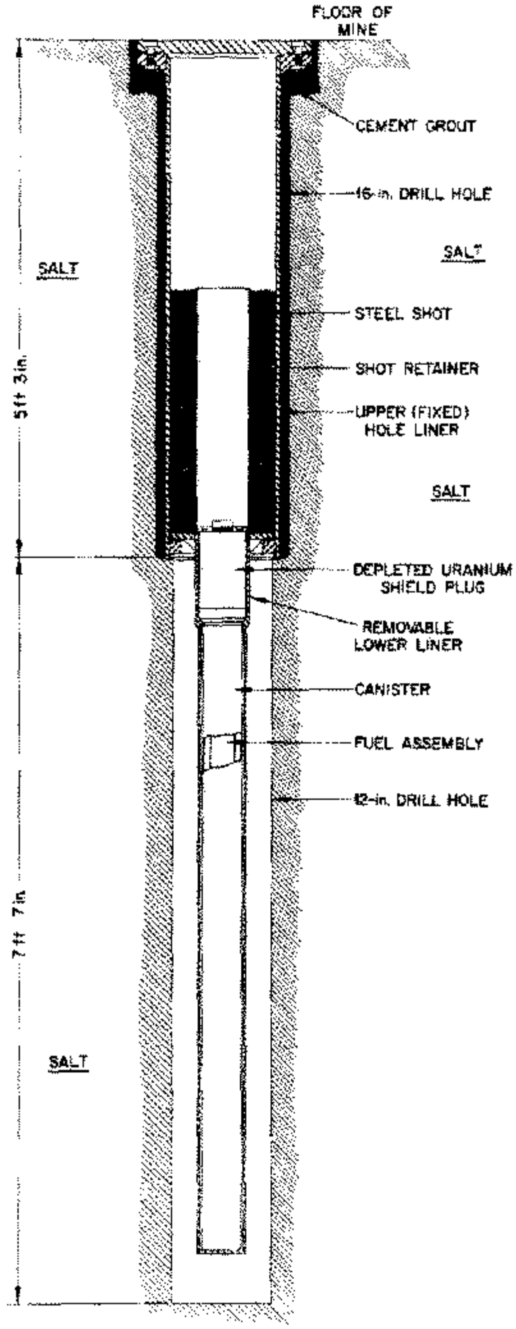


Figure 3. Simplified cross section through demonstration hole.

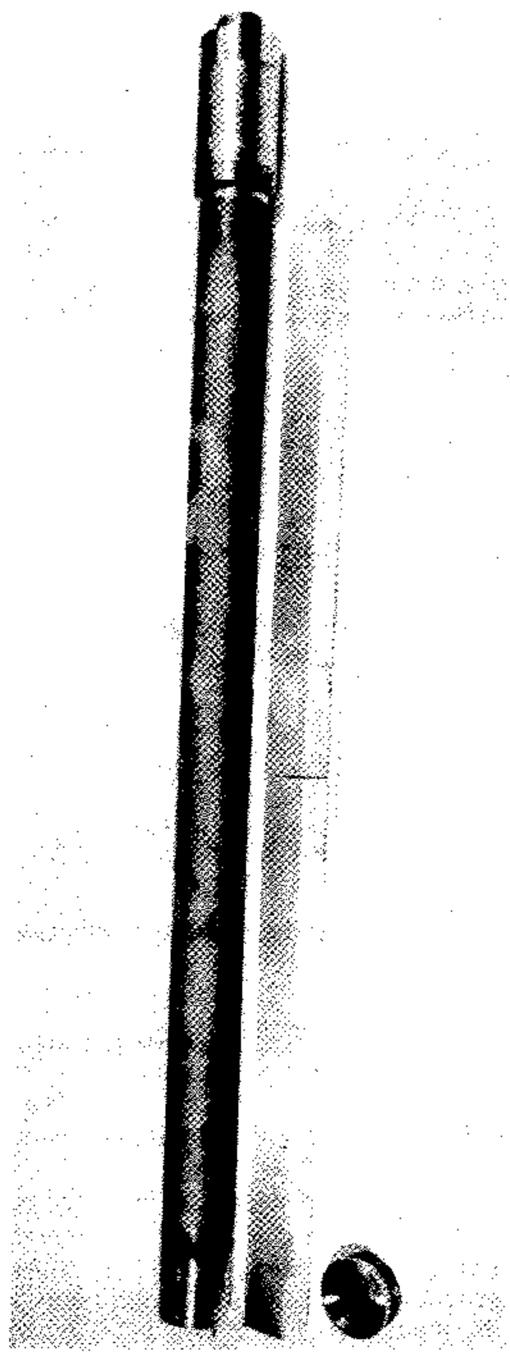


Figure 4. Canister and dummy fuel assemblies.

The radioactive material is contained by multiple barriers at all times during the demonstration. When the canister is in the array liner, there are three positive containment barriers. They are the aluminum cladding of the fuel element, the welded and pressure tested canister, and the liner closed by gasketed flanged joints.

In Room No. 4 there is an electric duplicate of the array in Room No. 1 which serves as a control. This array will be operated to duplicate the Room No. 1 array with respect to heat but without radioactivity present.

The Demonstration is designed, as would be a facility for disposing of actual waste, to limit temperatures of the salt to safe levels. The maximum temperature for the salt at the hole surface is 200°C. This is a safe margin below 250°C, the temperature at which the Kansas salt can be expected to begin to decrepitate because of the occluded moisture. The temperature of the fuel elements will be approximately 470°C, safely below the melting point of aluminum which is about 660°C.

Computed temperature rise isotherms around the main array are shown in Fig. 5. These are, of course, expected to be the same for both of the arrays. The ambient temperature of the salt structure is about 26°C. A significant portion of the structure will be 100°C or above.

A third array using the fuel assembly canisters from the radioactive array is planned for the original mine floor. After being in place for six months in the Radioactive Array, the canisters will be moved to the floor array for an additional six-month period. This array will provide data on the behavior of the original mine floor which contains large amounts of shale.

NONRADIOACTIVE TESTS

A "rib pillar" test will be operated to observe the behavior when a large mass of salt beneath a pillar is heated to a temperature of 100°C and above. Rooms 2 and 3 of the Experimental Area are separated by a column 23 feet thick. Along each side of this pillar a row of 11 heaters will be placed. These heater assemblies are approximately 13 feet long and are heated in the bottom six feet. They will be installed so that the center of the heated section is nine feet below the floor. They will be operated at a power input of about 1,500 watts.

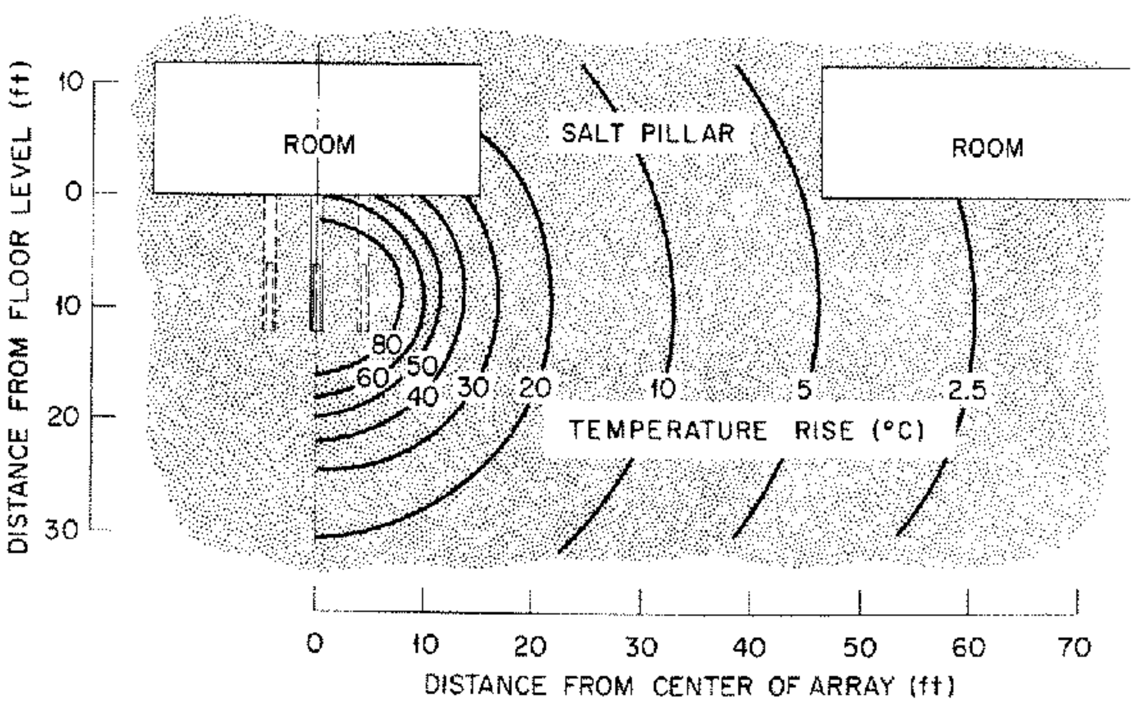
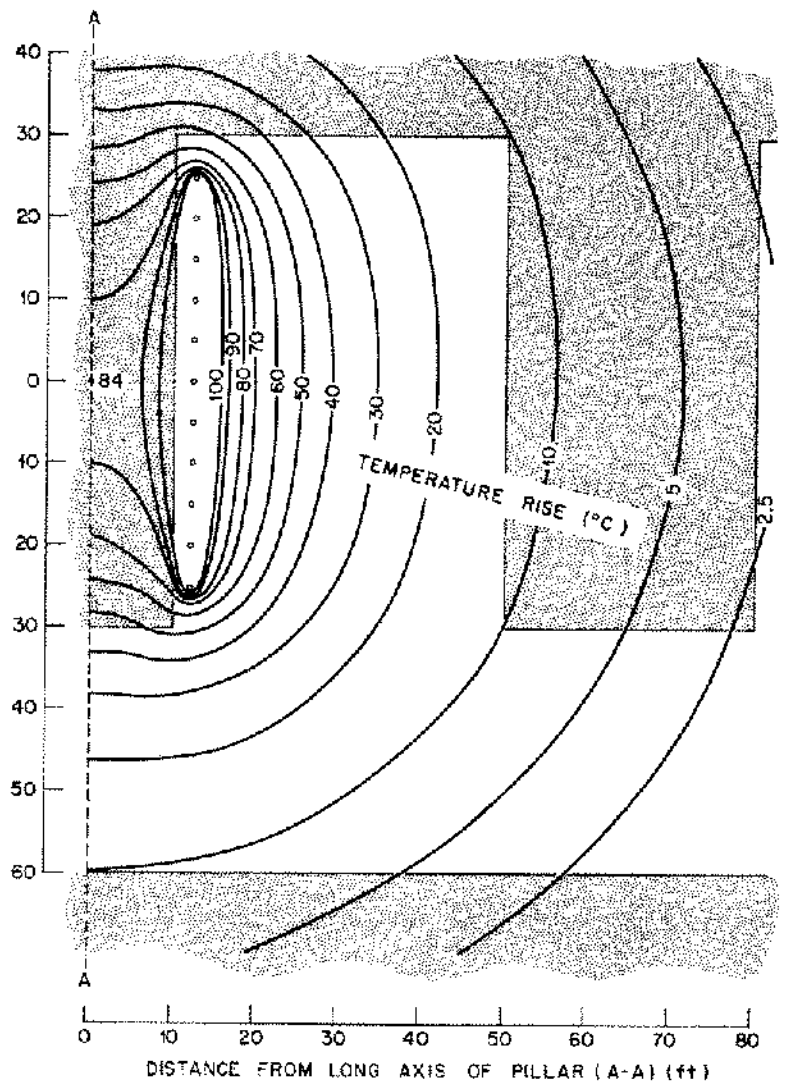


Figure 5. Temperature rise isotherms in vertical cross section through main array.

After one and a half years of operation (12, 800 hours), the temperature profiles around the center line of this pillar will be as shown in Fig. 6. Loading on this pillar is relatively high, with a wide room on each side. The test should give a clear indication of the effect of heating a large volume of salt on the behavior of a supporting column.

INSTRUMENTATION

Experimental measurements which will be made during the test include the magnitude of the radiation dose received by the salt structure around the Radioactive Array, the energy supplied by the electric heaters, the temperature in the liners and canisters as well as out in the salt structure, and the movement of salt in the structure surrounding the radioactive material and the heat sources as well as throughout the general area in the mine. Electrical power measurements do not require elaboration. The measurement techniques for temperatures, radiation, and salt movement are outlined in the following paragraphs.



Nine Feet Below Floor Level; Temperature Rise Isotherms After 12,800 hr Operation of 22 Heaters at Base of Pillar (1546 w/heater).

Figure 6. Temperature rise profiles for center pillar.

Radiation Dosimetry

Radiation will be measured by both chemical dosimeters and glass rod dosimeters installed at the mid-point of two of the Radioactive Array holes. These dosimeters will be installed in holes drilled from the floor tangent to the array hole at a point midway of the lower section, that is, at the point of highest radiation dose to the salt. Radiation readings will be taken periodically by exposing a dosimeter assembly to the radiation field. The chemical dosimeter system planned is a deoxygenated solution of $FeSO_4$ which is oxidized to $Fe_2(SO_4)_3$ by the radiation field.

Plastic Flow Measurement

A total of approximately 700 gages have been installed for the measurement of flow of the salt. These include about 60 simple convergence gages fabricated of two pieces of pipe anchored in the ribs or in the floor and ceiling as shown in Fig. 7. A dial gage inserted between the ends of the pipe makes it possible to measure changes in room dimensions. The remainder of the gages are based on the extensometers developed by Prof. E.L.J. Potts of the University of Newcastle, England, for the measurement of internal strain and convergence. This instrument consists basically of a wire anchored in a hole at some known distance from the mouth of the hole (shown in Fig. 7). A fixture anchored in the mouth of the hole serves as a mount for the extensometer which is used to apply a standard tension to the wire. A scale and micrometer screw give a reading which is a measure of the change in the distance between the anchor at the back of the hole and the anchor at the mouth of the hole. When several wires are installed at varying distances from the mouth of the hole, relative movements can be determined. Installations of this type are being made in the rib, floor, and roof. The mouth of the hole anchors may be used with a similar instrument to measure convergence.

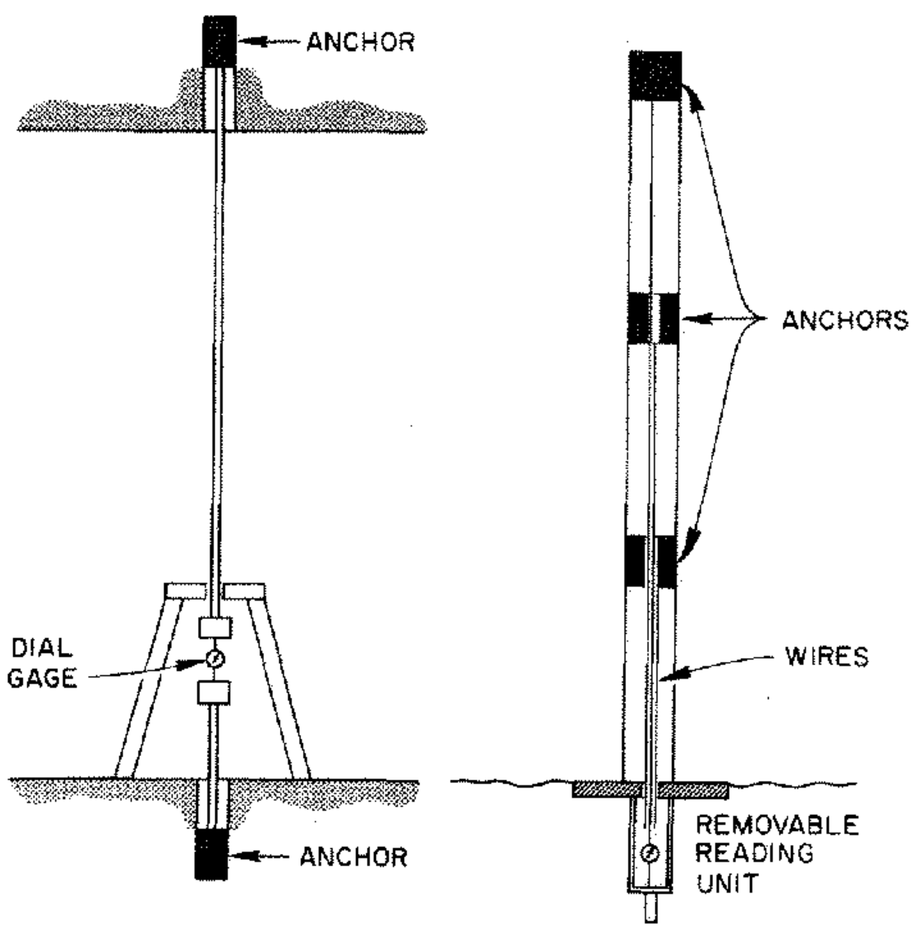
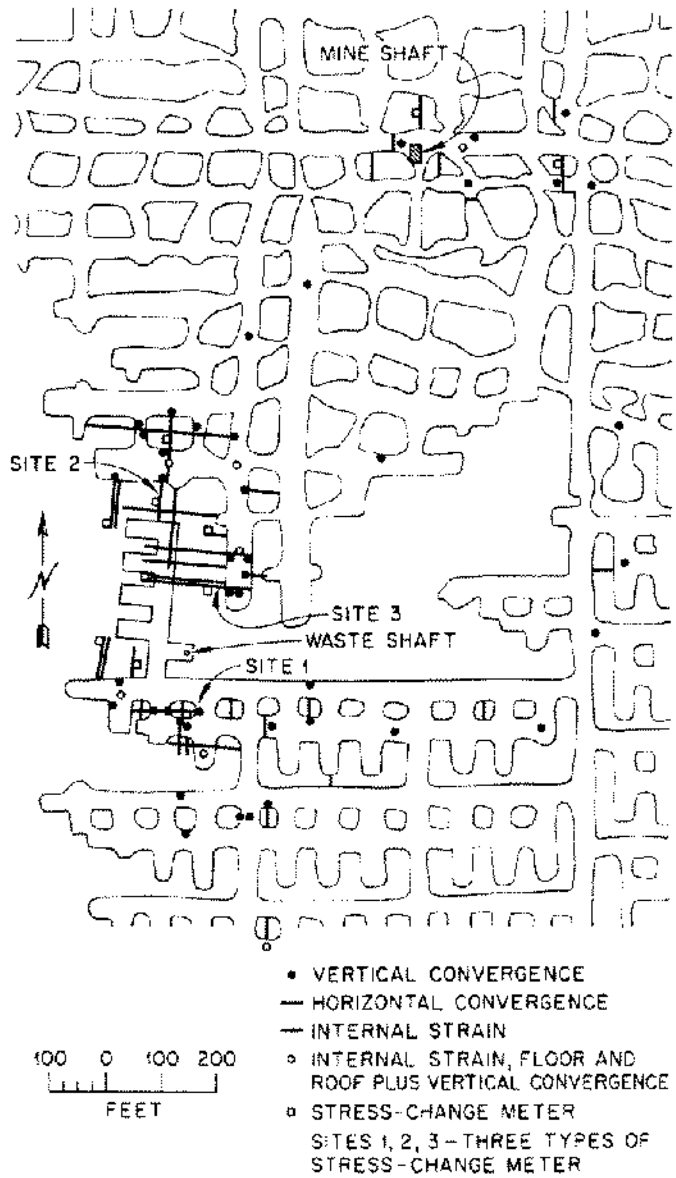


Figure 7. Plastic flow gages.

Figure 8 is a partial plan of the Lyons Mine showing installation of plastic flow gages in the area outside the Experimental Area. They extend to the mine shaft area, more than 1,000 feet from the Experimental Area, and considerably farther to the south off the plan. Figure 9 shows the location of gages installed within the Experimental Area. There are a limited number of stress-change gages installed, both of the type designed by Prof. Potts and by the Applied Physics Laboratory, U.S. Bureau of Mines.

Temperature Measurement

Heat transfer through the salt will be studied through temperature measurements made with a large number of thermocouples installed in the floor of the Experimental Area and in the walls of the rooms. Temperatures will be recorded continuously or read intermittently, depending on



Partial Plan of Lyons Mine Showing Locations of Stress and Strain Gages External to Experimental Area.

Figure 8. Location of plastic flow gages outside of experimental area.

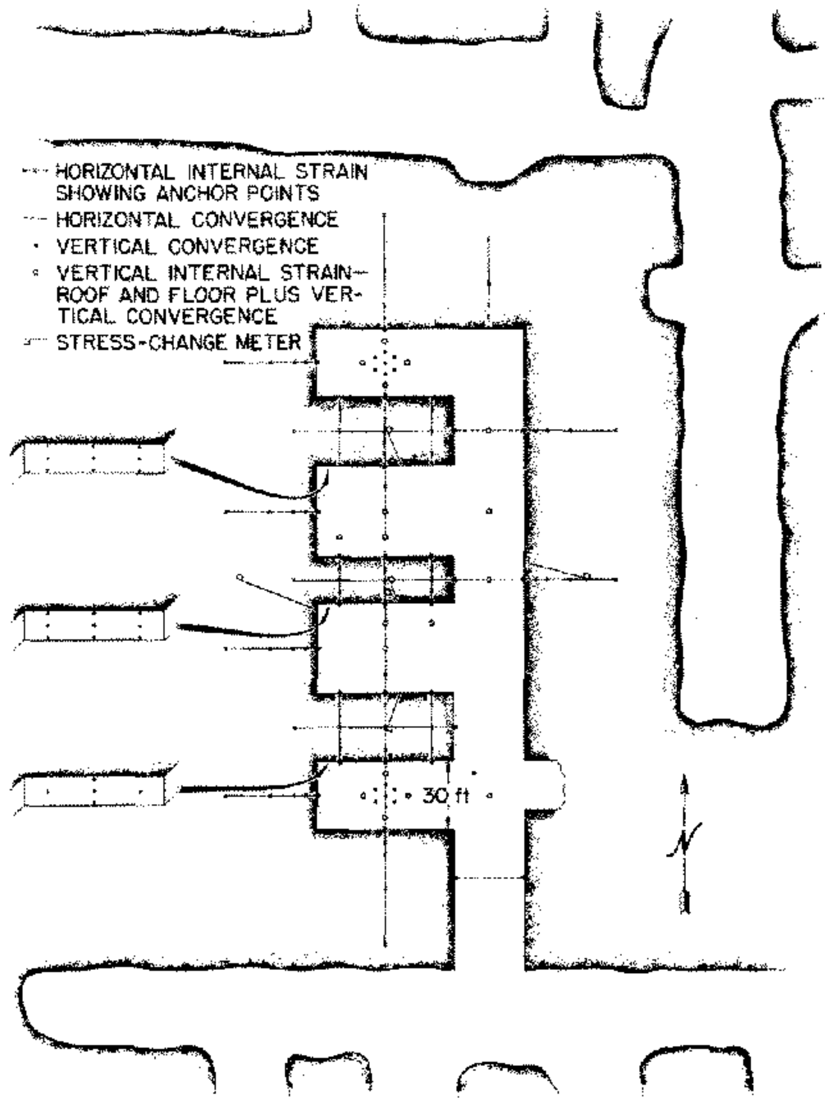


Figure 9. Location of plastic flow gages inside experimental area.

the magnitude and rate of changes expected. There are to be a total of more than 500 thermocouples installed in 140 holes drilled for this purpose and in the array holes themselves. A total of 43 thermocouples are to be installed in the off gas systems. Both iron-constantan and chromel-alumel thermocouples are being used.

OPERATION OF THE EXPERIMENT

The first step in the Demonstration, canning of the ETR fuel assemblies, two to the canister, will take place at the National Reactor Testing Station near Idaho Falls, Idaho. This operation will be a completely remote operation carried out in a "hot cell." The heat generation rate will have decreased sufficiently in 60 days following removal of elements from the reactor to allow canning to begin, and shipment is expected to take place at approximately 75 days out of the reactor.

The canisters will be shipped in the shielded and water-cooled carrier shown in Fig. 10. The weight of this piece of equipment is approximately 30 tons. Its shielding is equivalent to ten

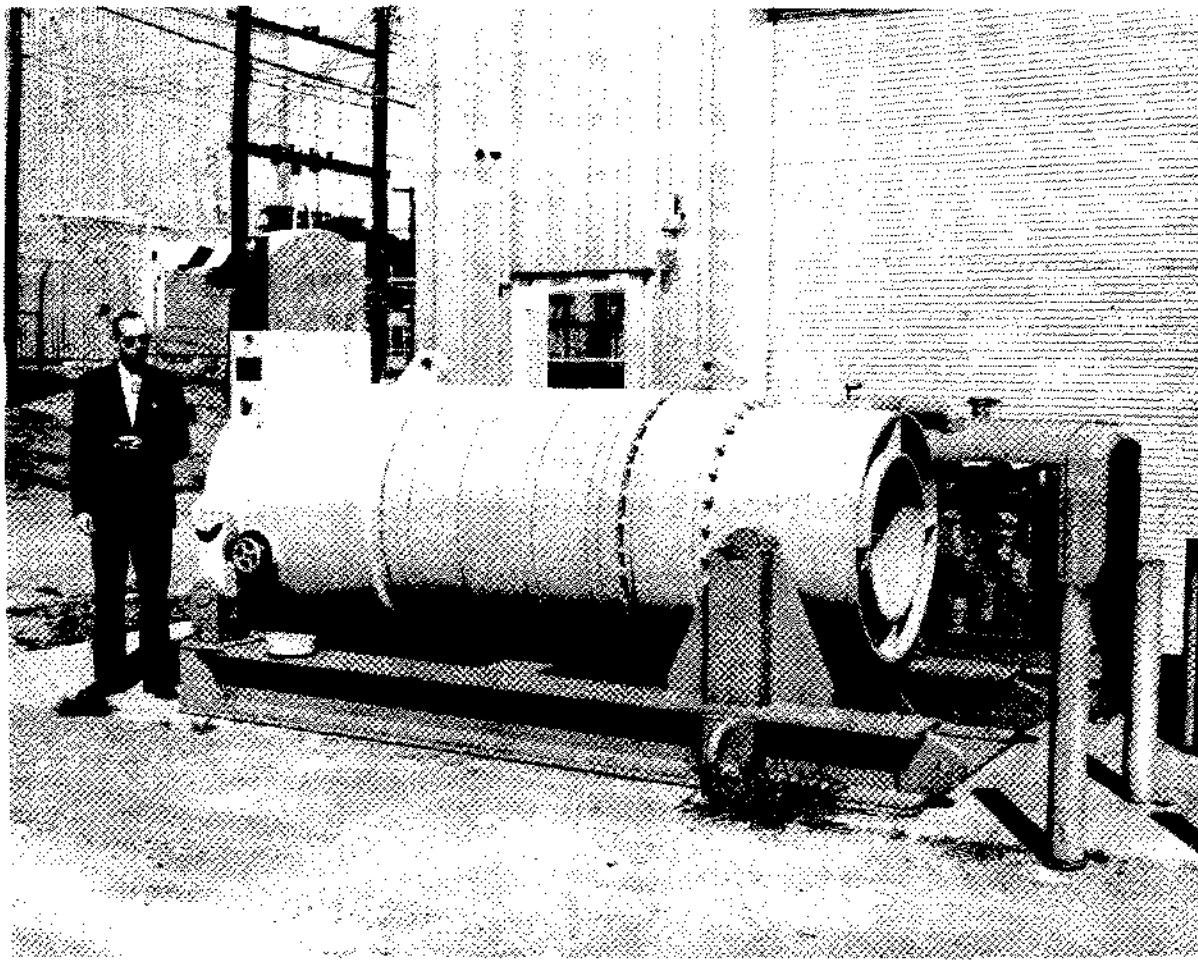


Figure 10. Shipping carrier.

inches of lead. Cooling of the canisters during shipment is accomplished by pumping cooling water through channels in the carrier adjacent to the canisters. The water is cooled to 100°F by passing through an oversized radiator on the same diesel engine which drives the pump. The carrier will be secured to a shipping frame and together with the diesel engine cooling system will be mounted on a special heavy-duty, five-axle trailer for truck shipment. The shipment will be under constant surveillance by specially trained truck drivers. Temperature and diesel control alarms will be installed in the tractor cab for constant monitoring, and the load will be checked routinely every hour.

At Lyons the carrier will be delivered to a handling facility at the surface end of the drilled shaft. The carrier will be upended over the shaft in a building designed for the purpose and the canisters lowered to the mine level where they will be received, one at a time, by the machine shown in Fig. 11.

This machine is designed to transfer the canisters containing fuel elements from the Waste Shaft to the holes of the Radioactive Array and to make transfers between the arrays. In addition it will be used to remove the canisters from the array holes at the conclusion of their usefulness and return them to the Waste Shaft for delivery to the surface and return to Idaho Falls.

The machine consists of a standard Caterpillar 619C two-wheeled tractor pulling a "one of a kind" trailer incorporating a cylindrical shield having 8 3/4 inches of lead shielding. This shield can be positioned in three dimensions by hydraulically actuated mechanisms. Hydraulically operated doors, top and bottom, and a hydraulically driven winch, all controlled remotely, make possible transfer of the canisters from the bottom of the waste shaft to the Arrays.

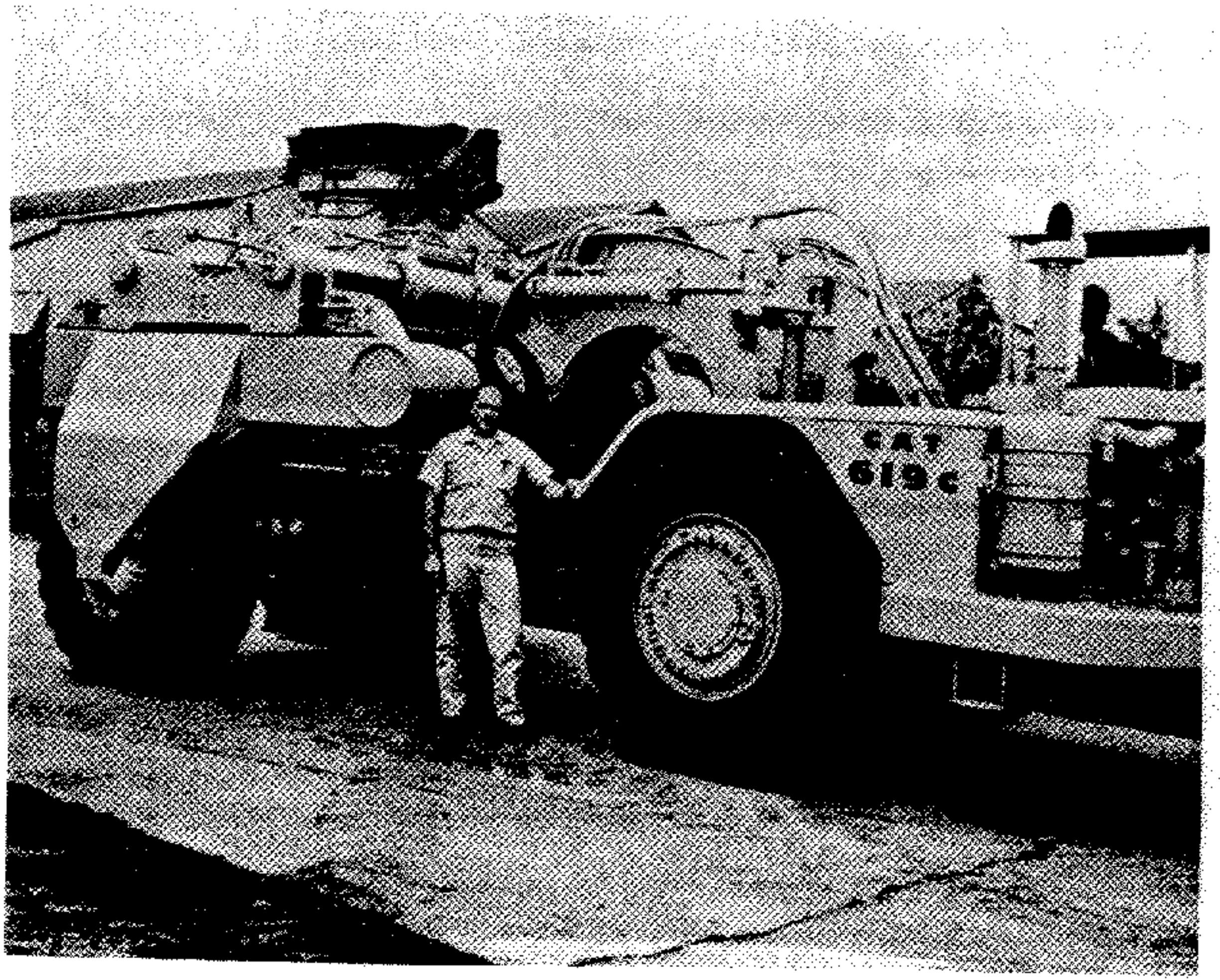


Figure 11. Underground transporter.

STATUS

This paper must end with a statement of the status of Project Salt Vault rather than with the results of the Demonstration. Both heavy mining and the installation of plastic flow instrumentation are complete. Installation of other experimental equipment has begun and will be complete in time for November startup of the Demonstration.

REFERENCES

1. R.L. Bradshaw, F.M. Empson, W.J. Boegly, Jr., H. Kubota, F.L. Parker, J.J. Perona, and E.G. Struxness, "Ultimate Storage of High-Level Waste Solids and Liquids in Salt Formations," Treatment and Storage of High-Level Radioactive Wastes, International Atomic Energy Agency, Vienna, 1963, pp. 153-175.

2. R.L. Bradshaw, W.J. Boegly, Jr., F.M. Empson, H. Kubota, F.L. Parker, J.J. Perona, and E.G. Struxness, "Ultimate Storage of High-Level Waste Solids and Liquids in Salt Formations," Retention and Migration of Radioactive Ions in Soils, French University Press, Paris, 1963, pp. 257-268.

3. W.J. Boegly, Jr., et al., in Health Phys. Div. Ann. Progr. Report, July 31, 1964, ORNL-3697, K.Z. Morgan, Editor (October 1964), pp. 19-31.