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WASTE DISPOSAL BY SHALE FRACTURING AT ORNL*

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The shale fracturing process is a method of waste disposal currently in use at Oak Ridge National Laboratory for the permanent disposal of certain locally generated radioactive waste solutions. In this process, the waste solution is mixed with a solids blend of cement and other additives; the resulting grout is then injected into an impermeable shale formation at a depth of 200 to 300 m. The grout sets a few hours after completion of the injection, fixing the radioactive waste in the shale formation. The operational experience with this process since 1966 and the monitoring techniques that have been developed are discussed. A description of a new facility being built and the preliminary-site proof test that was required are given.

Shale fracturing is a process currently being used at Oak Ridge National Laboratory (ORNL) for the permanent disposal of locally generated intermediate-level waste solutions. These solutions are alkaline, about 1 M in $NaNO_3$, and have a radionuclide content (predominantly ^{137}Cs) of about 0.2 Ci/ltr. In this process, the waste is mixed with a solids blend of cement and other additives; the resulting grout is then injected into an impermeable shale formation at a depth of 200 to 300 m, well below the level at which groundwater is encountered. During the course of the injection, the injected grout forms a thin, approximately horizontal grout sheet 100 to 200 m in width. The grout sets a few hours after completion of the injection, permanently fixing the radioactive waste in the shale formation.

The essential feature of the shale fracturing process is the fixation of the radionuclides in a geological formation that is known to be isolated from contact with the surface environment. The process has additional features that would provide continued containment of the radionuclides even if the isolation of the disposal formation should be lost. For example, the leach rates of significant radionuclides from the set grout are quite low. In addition, any radionuclides that might be leached from a grout sheet would be retained in the disposal zone by the high ion-exchange capacity of the shale; therefore, this process offers an exceptionally favorable approach to permanent disposal of radioactive wastes.

The mix developed for this process consists of Portland cement, fly ash, drilling clay, pottery clay, and a retarder. The retarder delays the setting time of the mix, the pottery clay fixes cesium, the drilling clay retains excess water, the fly ash fixes strontium, and the cement is the overall binder. These various solids are blended and stored just before each injection. This blend is subsequently mixed with the waste solution in a ratio of about 0.8 kg of solids per liter of waste solution. The resulting grout has a density of about 1.5 g/cm^3 and an apparent viscosity of about 40 cP. The grout remains fluid for about 24 h, if kept in motion. The compressive strength of the set grout is low (about 1.5 MPa). The rates at which radionuclides can be leached from the set grout are also quite low (i.e., approximately equivalent to those from a borosilicate glass). The cesium leach rate is 7 μg/(cm^2·d), the strontium is 32 μg/(cm^2·d), and curium and plutonium are about 0.15 μg/(cm^2·d). These rates were determined for specimens aged 28 and 100 d [1].

Each injection disposes of an annual accumulation of waste solution of about 300,000 ltr. Prior to the injection, the waste solution is pumped to the waste storage tanks at the injection site. The dry solids are blended and stored in bins at the injection facility. A standby injection pump is rented for each injection; its function is to clean grout from the injection well in the event of failure of the main injection pump. During the injection, the waste solution is pumped to the mixer, continuously mixed with the preblended solids, and then discharged into the surge tank. From the surge tank, the grout is pumped down the tubing string in the injection well and out into the shale formation. A schematic of the process is shown in Fig. 1. The injection pressure is about 200 atm. The normal grout injection rate is about 1000 ltr/min; an injection requires about 8 h to complete. The grout sheet formed during the injection is approximately 1 cm thick and up to 200 m wide. The fracture orientation generally follows the bedding planes in the shale, which are inclined about 10 to 15° to the horizontal. At the end of the injection, the well is flushed with water so that the slot in the injection well will be free of grout and can be reused for the next injection. Then a valve shuts the well until the grout has set. Subsequent injections are made through the same slot, forming grout sheets that are generally parallel to the first. After four injections have been made through the one slot, the bottom of the well is plugged and a new slot is cut in the casing of the well 3 m above the old slot. The surrounding shale formation is fractured at this new depth by pressurizing the well until a sudden drop in pressure signals the creation of a fracture.

The radiation exposure of the operating crew and the injection pressure are regularly monitored during each injection. A few days after the injection, the orientation of the grout sheet is determined by logging the network of observation wells that surrounds the facility. (These are cased wells that extend to the bottom of the disposal formation.) A gamma-sensitive probe lowered in these wells detects the presence of the grout sheet at a particular depth, thereby verifying the orientation of the grout sheet. A representative series of logs is shown in Fig. 2. After several injections have been completed, the cumulative surface uplift around the injection well is determined by measuring the change in elevation of a network of bench marks. This uplift averages 0.03 cm per injection at the injection well and decreases regularly to near zero at about 400 m from the well. The significance of this measurement is dubious, and it will probably be discontinued. The permeability of the shale overlying the disposal zone is also periodically measured to verify that it has not been increased by the stresses generated by repeated injections. No change in the cover rock permeability has been observed to date.

The process was developed in a series of experiments between 1959 and 1965. The experimental facility was modified in 1966 for the routine disposal of intermediate-level waste solutions generated at ORNL. Since 1966, this facility has been used for 17 operational injections. More than 8 Mltr of waste grout containing over 600,000 Ci of radionuclides have been injected. Although operational problems have been experienced, most have been comparatively minor and none has been severe; the general experience has been quite good. With the exception of four injections (discussed below), the difficulties have not been serious enough to force the termination or major delay of an injection; they have required, at most, a relatively short shutdown of the injection while repairs were being made. These difficulties included (1) eroded check valves in the injection pump, (2) a plugged drain line from the injection pump sump, (3) a ruptured solids supply-line connection, (4) loss of prime in the waste pump, (5) jamming of the clutch on the injection pump, (6) bridging of solids in the feed hopper, and (7) a leak past the sealing ring in one of the high-pressure valves. Each incident was an isolated occurrence and none caused serious difficulty.

One delayed injection resulted from a failure of a packing seal in the injection pump. In this case, the facility and well were washed free of grout with the standby pump; repairs were made, and the injection was resumed 2 d later. In another injection, the drain valves on the high-pressure valve rack were eroded by leakage of grout through the valves. The valves would no longer hold pressure; therefore, the injection was halted, the facility and well were washed free of grout, repairs were made, and the injection was resumed 2 d later.

One injection that was terminated resulted from an attempt to use blended solids that had been stored for several months. The flowability of these solids was poor, and the injection was quickly shut down. Another injection was terminated when the diesel drive of the injection pump threw a connecting rod through the block. The facility and well were washed with the standby pump.

General experience with the shale fracturing facility in 7 experimental and 17 operating injections has been quite good. Large volumes of waste solution have been continuously mixed with dry solids, in the desired proportions, and injected into the isolated shale bed. Cleanup of small waste spills is feasible, as is the direct maintenance of mechanical equipment.

The operational cost of an injection is approximately $50,000 (US). About $10,000 of this is the cost of the dry solids, about $25,000 is the service charge of an oil well cementing company for making the injection, and the remaining $15,000 is for various maintenance and operations charges.

A new shale fracturing facility is being designed and built at a site about 250 m south of the existing facility. At this location, the disposal zone is about 60 m deeper than at the existing facility; the geology is similar in other respects. A site proof test was made at the new site to verify that the site was suitable for waste disposal by shale fracturing. This test consisted of drilling an injection well and four observation wells at the site and making a test injection of grout tagged with a radioactive tracer. The injected grout was detected in three of the observation wells at depths that indicate that bedding-plane fractures were formed. Subsequently, a water injection was made to obtain pressure decay data. This test indicated that no extensive interconnected fractures and joints exist at the disposal site and that the shale permeability is very low at the injection depth. The results of these tests indicate that the site is suitable for shale fracturing disposal operations.

An environmental impact statement has been written to cover the operations of the facility [2]. The statement concludes that the overall impact would be beneficial. The facility would remove large volumes of potentially hazardous radioactive wastes from the existing surface storage facilities and would fix these wastes in impermeable shale formations (well removed from the biosphere). All major incident situations postulated are considered quite improbable, and the analysis of each case indicates that the ultimate release of radionuclides to the environment would be small.

The new facility will have improved shielding and containment so that wastes of higher specific activity can be handled. These wastes are expected to include currently generated intermediate-level wastes, resuspended sludges that have accumulated in waste storage tanks over the past thirty-five years, and pilot-plant wastes with a specific activity of up to 8 Ci/ltr. Very little of this latter waste is expected, but it was made the design-basis waste for the new facility. The operating pressures and flow rates for the new facility will be similar to those of the existing facility. The dry-solids handling equipment, which has been a source of chronic difficulty in the existing facility, will be improved so that the flow of solids to the mixer will be smooth and controlled. The process instrumentation will be improved by the incorporation of a weigh-belt feeder to measure the flow of solids more precisely. Improved mix ratio indicators will be installed to determine and display the ratio of the weight of solids and the volume of liquid going to the mixer. This ratio should be kept within rather narrow limits for good process control. A check on this ratio will be provided by the ratio of grout volume to liquid volume, a ratio that is directly proportional to the mix ratio. Completion of construction of the new facility is scheduled for early 1981, and the first injections will be made at the new facility shortly thereafter.

REFERENCES

[1] MOORE, J. G., et al., Development of Cementitious Grouts for the Incorporation of Radioactive Wastes, Oak Ridge National Laboratory Rep. ORNL-4962 (1965).

[2] Final Environmental Impact Statement, Management of Intermediate Level Radioactive Waste, ERDA-1553 (1977).

FIGURES

ORNL-DWG 63-3830

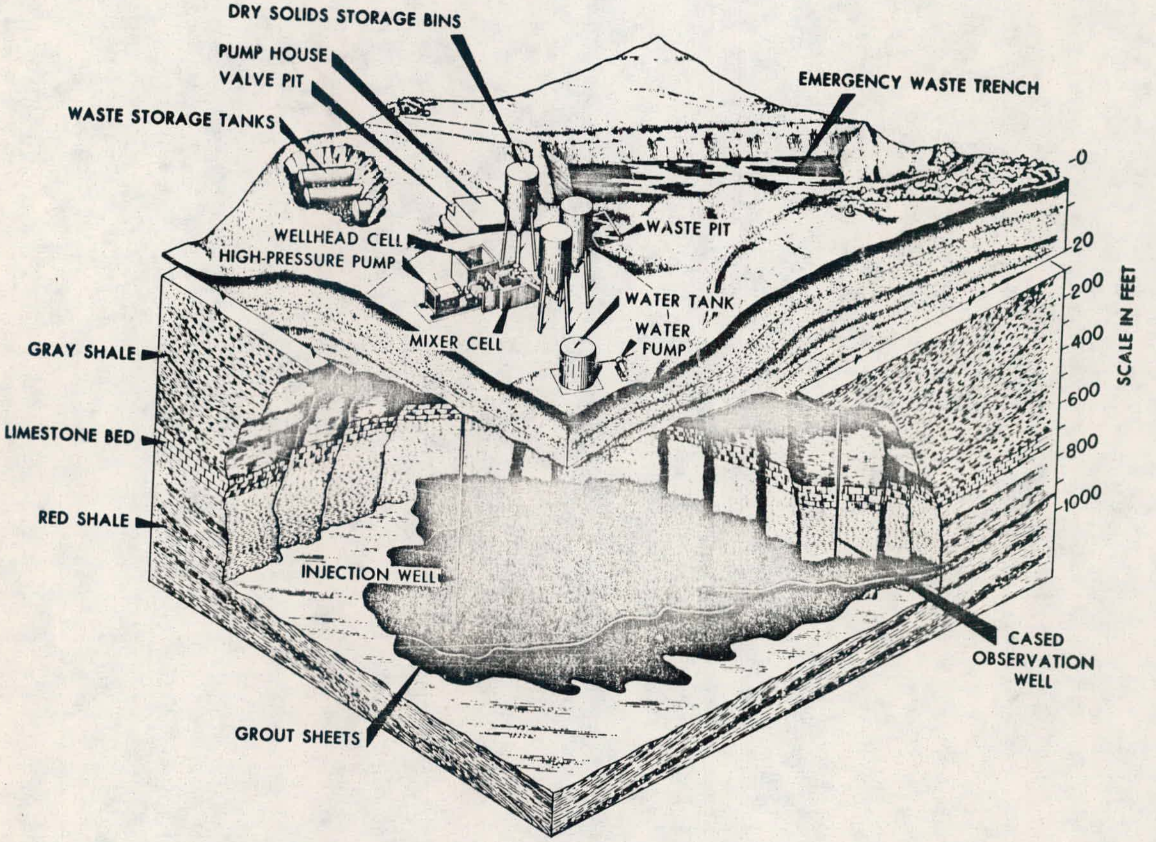

Fig. 1. ORNL Fracturing Disposal Pilot Plant Process Schematic.

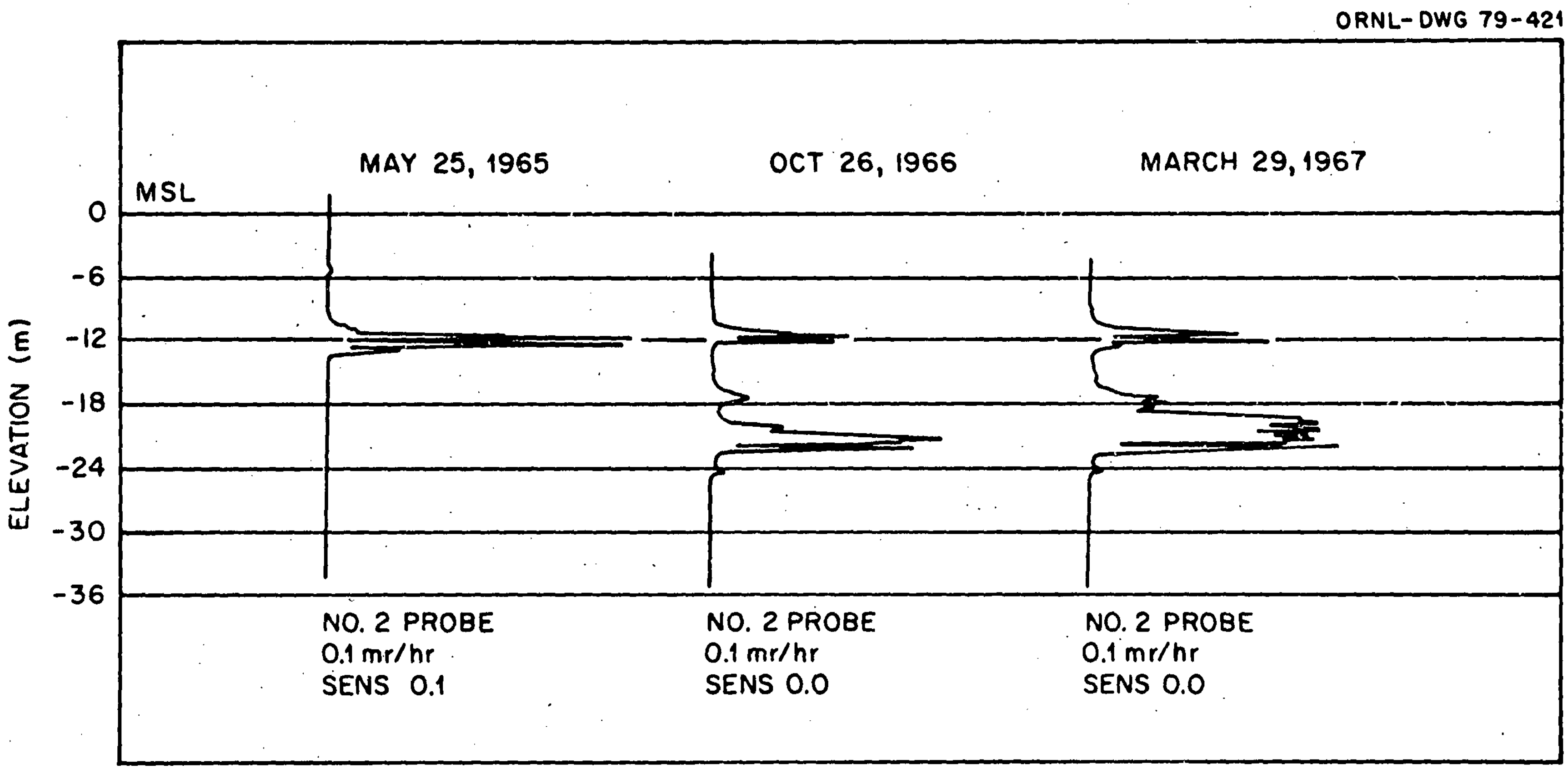

Fig. 2. Representative Series of Logs of Grout Sheet.