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WASTE DISPOSAL BY HYDROFRACTURE AND APPLICATION OF THE TECHNOLOGY TO THE MANAGEMENT OF HAZARDOUS WASTES

by

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A unique disposal method, involving hydrofracturing, has been used for management of liquid low-level radioactive wastes at Oak Ridge National Laboratory (ORNL). Wastes are mixed with cement and other solids and injected along bedding plane fractures into highly impermeable shale at a depth of 300 m forming a grout sheet. The process has operated successfully for 20 years and may be applicable to disposal of hazardous wastes. The cement grout represents the primary barrier for immobilization of the wastes; the hydrologically isolated injection horizon represents a secondary barrier. At ORNL work has been conducted to characterize the geology of the disposal site and to determine its relationship to the injection process. The site is structurally quite complex. Research has also been conducted on the development of methods for monitoring the extent and orientation of the grout sheets; these methods include gamma-ray logging of cased observation wells, leveling surveys of benchmarks, tiltmeter surveys, and microseismic arrays. These methods, some of which need further development, offer promise for real-time and post-injection monitoring. Initial suggestions are offered for possible application of the technology to hazardous waste management and technical and regulatory areas needing attention are addressed.

INTRODUCTION AND PURPOSE

At Oak Ridge National Laboratory (ORNL), low-level radioactive wastes are routinely disposed of by a process termed "hydrofracture." The liquid wastes are mixed with cement and other solids to form a slurry that is pumped under pressure through an injection well into underlying strata. The slurry follows fractures in the strata and sets to form a solid grout, which contains and immobilizes the radioelements.

This process has been successfully developed at ORNL over the last quarter century. Initial development work was performed at test facilities; in the mid-1960s, the process became operational. A new injection facility was put into operation in 1982. A total of over 1.5 million curies of radioelements has been disposed of; the principal nuclides are Sr^{90} and Cs^{137}, although others, including H^3, Co^{60}, Ru^{106}, and isotopes of U, Am, and Pu, also occur in the wastes. This process represents the only permanent geologic disposal of nuclear wastes in the United States.

The disposal operation is unique and is based on the common practice of hydrofracturing, which is routinely used by the petroleum industry to increase porosity and permeability in reservoir rocks by fracturing the rocks with water injected under pressure. It appears that this technique may have potential application

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to the management of some kinds of hazardous wastes, especially if alternative methods to shallow land burial are sought. Thus, our purpose is to discuss the basic principles of the hydrofracture program at ORNL and to offer initial thoughts on the application of the technique to hazardous waste management.

THE HYDROFRACTURE PROCESS

A complete review of the history of the hydrofracture operation and a description of the process can be found in previously published works (1-3). The process is a large-scale batch operation (Fig. 1). Liquid wastes are stored in underground tanks and disposed of typically every one to two years. The waste solutions, which are alkaline and 1-2 M $NaNO_3$, are blended with cement and other additives to form a slurry, which is pumped under approximately 20-MPa pressure into the cased injection well. The casing is slotted at a depth of approximately 300 m. Fractures in the host rock, a shale of low permeability, are initiated along bedding planes by pumping a few thousand liters of water into the well; this is followed immediately by the slurry, which spreads radially from the injection well along the fractures. The slurry sets to form a thin (less than a few cm) grout sheet that extends up to several hundred meters from the well. No grout sheet has been detected more than 220 m from the injection point. Later injections are made through slots cut at shallower depths in the well, thus allowing maximum use of the host injection strata.

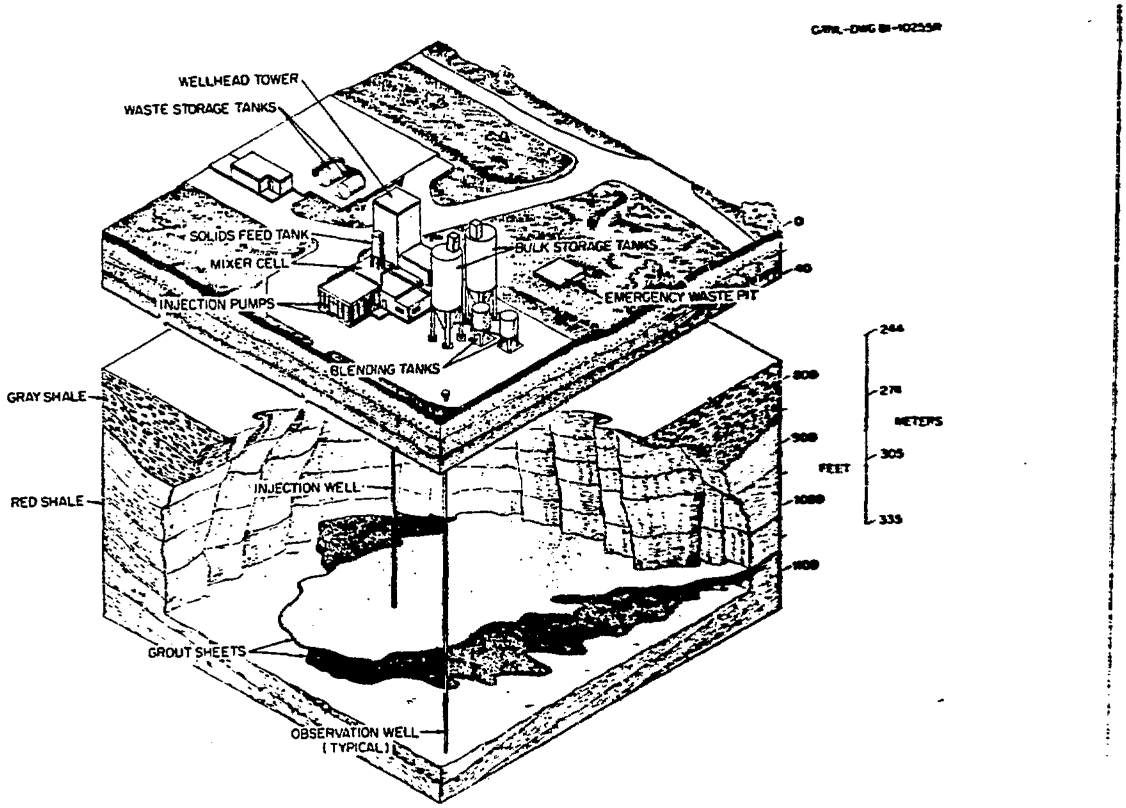

Figure 1. Conceptual drawing of the Hydrofracture Facility at Oak Ridge National Laboratory. Surface facilities, the injection well, one cased observation well, and grout sheets are depicted.

Disposal is normally done over a two-day period in two eight- to ten-hour shifts. The total volume disposed of ranges from 350,000 to 700,000 l. Although some operational problems have arisen over the years, the technique has been highly successful. A major reason for this success is that the engineering and operational aspects of this technique are not unique but rather are standard practice in the petroleum industry.

The costs for disposal at ORNL are approximately \$0.30/l. About half of this is operational cost, including dry solids and personnel. The other half represents amortization of the capital cost (\$5.4 million) of the facility prorated for disposal of 40 x 10^6l of waste. The costs are sensitive to process parameters (batch size, injection rate, etc.), which were chosen to fit ORNL requirements.

PRINCIPLE OF WASTE ISOLATION

The basic objective of the ORNL hydrofracture program is to effectively isolate the wastes from the accessible environment. This is achieved through immobilization of the wastes in a variety of ways. The cementitious waste carrier is the primary barrier and is tailored to retard the two principal isotopes that occur in the wastes, Sr^{90} and Cs^{137}. Highly sorbing illitic clay is added to help retain the Cs^{137}. Most of the Sr^{90} occurs as a find-grained precipitate in the waste; this precipitate is physically entrapped in the cement and Sr^{90} is largely immobilized in this fashion. The secondary barrier is the shale, which has a high content of illite. If isotopes such as Cs^{137} should escape the grout, they should readily be sorbed by the shale. Equally important is the fact that the 100-m-thick host shale formation is of low permeability, contains small amounts of groundwater, and is removed from any fresh-water aquifer by over 100 m of intervening strata.

One of the most significant aspects of the waste isolation operation at ORNL is the generation of bedding plane fractures. It is critical that the radioactive slurry remain in the impervious host horizon and not travel through vertical fractures into strata that might have hydrologic communication with the environment. As noted later, the great mechanical anisotropy of the shale and the fact that the injections are apparently shallow enough so that the least principal stress is vertical are factors that cause the nearly horizontal bedding plane fractures. The production of fractures with this orientation represents one of the most significant differences with the standard hydrofracture methods used in industry, where the fracturing is done at much greater depths with the intent of producing vertical fractures that cross many strata.

SITE SELECTION CRITERIA

Idealized Criteria

A set of idealized geologic criteria that should be considered in selecting a site for a hydrofracture facility has been developed (2,3). The criteria are similar to many used in the selection of repository sites for high-level commercial nuclear wastes (4). For instance, a properly located hydrofracture site should be in an area that is tectonically stable (low frequency of earthquakes, no volcanic activity or recent faulting, low rates of uplift) and has few, if any, natural resources that might be sought in the future. The injection horizon should be thick and laterally extensive enough to contain and to help isolate the wastes, and it should be hydrologically isolated from the accessible environment. The host strata and waters contained within should have geochemical characteristics that enhance immobility of the wastes through retardation, precipitation, or formation of colloids, and should produce horizontal (or nearly horizontal) bedding plane fractures.

Characteristics of the ORNL Site

The site at ORNL, although selected prior to systematic identification of these idealized siting parameters, conforms to them fairly well. A detailed description of the site geology has been published by Haase et al. (5). The injection horizon is the Pumpkin Valley Shale, which is a formation in the Lower Paleozoic Conasauga Group. The shale is highly impermeable (0.01 - 0.001 millidarcy [1,2]), approximately 100 m thick, highly sorbing for some nuclides, well bedded, and can be easily fractured along bedding planes. The area is tectonically stable and does not contain known mineral or energy resources.

Structurally, the site is quite complex. It lies on the leading edge of the Copper Creek fault, a major thrust fault in the Valley and Ridge Province; a number of inactive cross-strike tear faults occur within hundreds of meters of the facility. The Pumpkin Valley Shale dips at 15 to 20° and contains common small tight folds; it is well jointed, and bedding plane slippage has occurred during deformation. The joints appear to be the controlling factor in groundwater movement. In spite of the complexity of the site geology, it does not appear to have had any detrimental effect on the successful disposal operations at the site.

A program is currently under way to more fully clarify the subsurface hydrology of the site. Deep (500-m) monitoring wells have been drilled, and hydrologic testing of the injection horizon and other strata is under way. Recent work (6) shows that groundwaters from the injection horizon and surrounding strata are highly saline, containing up to 190,000 ppm total dissolved solids. The dominant constituents are Na, Mg, Ca, and Cl. The salinity decreases upward in the wells. No age data are yet available on the groundwater.

DEVELOPMENT OF MONITORING PROCEDURES

Monitoring Methods

It appears certain that if the hydrofracture technique is to be considered for future disposal operations, including disposal of hazardous wastes, sensitive and accurate monitoring schemes must be developed and applied so that the distribution and fate of the wastes can be understood. When the ORNL injection facilities were constructed, cased observation wells were installed between 30 and 100 m from the injection well. These observation wells intersect the injection zone and are logged with a gamma-ray detector after each injection. By comparing the gamma-ray profiles between injections, it is possible to determine the depth and orientation of a grout sheet and get some general information on its extent (1-3).

During a series of recent bimonthly injections, research was conducted on the development and application of ground deformation and microseismic surveys as monitoring techniques. Recent articles (7,8) describe these techniques. The ground deformation approach is based on the principle that subsurface fractures produced by hydrofracturing create a measurable deformation at the surface. The shape of this deformation reflects the orientation of the fracture (9,10). Two methods have been examined for measurement of ground deformation at ORNL: (1) precise leveling of benchmarks and (2) tiltmeter surveys.

Precise Leveling

Leveling surveys have been conducted for eight recent injections. A total of 75 benchmarks up to 700 m from the injection well were surveyed before and after each injection. For the October 1983 injection, a fairly representative one, deformation is characterized by uplift of up to 2.5 cm; the area of maximum uplift is slightly south of the well. Such a configuration indicates that the fracture rises to the north along the dip of the shale. This orientation is expected, as it is in the direction of least lithostatic pressure and along bedding planes. The orientation can be confirmed by the gamma-ray logs from the observation wells. A leveling survey taken 30 days later showed that the uplift had decayed to approximately 50 percent of its initial value and had shifted slightly to the north. Surveys from other injections are similar, but the shape of the surface deformation may vary.

Tiltmeter Surveys

A series of eight tiltmeters was installed in shallow wells 125 and 200 m laterally from the injection point to measure ground deformation during the October and November 1983 injections. The instruments are capable of detecting injection of the first few thousand l of water, and they accurately recorded the uplift and deformation throughout the injections. During the 30-day period after the October injection, a subsidence of the uplift was recorded, corresponding closely with the leveling data. Modeling of the tiltmeter data, in an effort to determine the orientation of the subsurface fracture, however, has not produced an orientation that corresponds with actual measurements from the gamma-ray logging. Currently used models are for homogeneous, isotropic media; the stratigraphy at the ORNL site is highly heterogeneous and anisotropic. Work is continuing to more fully refine the models.

Microseismic Arrays

A third method of instrumental monitoring involves detection of microseismic signals associated with the injection. This approach is based on the principle that the fracturing process should produce seismic signals; with properly placed geophones, it should be possible to monitor the fracture as it propagates. Thus far, this effort has provided useful information on the mechanisms of fracture formation and has shown that seismic activity continues for weeks after an injection. These data indicate that the strata overlying the injection zone undergo mechanical relaxation after the induced stress of an injection. The microseismic method has not yet been developed at ORNL for determination of the extent and orientation of the fractures.

Overview

There is considerable work yet to be done on development of monitoring techniques, especially those that provide real-time data during an injection. The two methods that do provide such data (tiltmeter, microseismic) show promise; of the two, the tiltmeter method appears to be better developed at present. Stow et al. (7) provide a relative evaluation of the techniques. While it is anticipated that future hydrofracture disposal operations may require installation of real-time monitoring systems, absolute techniques, such as gamma-ray logging, will probably also be required.

CONSIDERATION OF HYDROFRACTURING FOR HAZARDOUS WASTE MANAGEMENT

In this final section, two general topics will be addressed: (1) ways in which the hydrofracture method might be used for some types of hazardous waste management, and (2) technical and regulatory aspects that need to be addressed if the method is applied to hazardous waste.

Use of the Technique for Hazardous Wastes

It is felt that the hydrofracture technique may have significant potential for disposal of certain types of hazardous wastes. Because the operational aspects of the disposal operation are fairly routine, attention is directed here toward waste forms and carriers that are compatible with the injection process and the host formations.

It may be possible to use the method for disposal of certain heavy metals. For instance, chromium could be precipitated as the ~~highly~~ insoluble sulfate, or other transition metals might be fixed by chelating agents. The insoluble salts or chelated metals could then be mixed with a cementitious carrier and injected. Cement might also be useful as a carrier for PCBs.

There is no reason why materials other than cement might not be considered as waste carriers. Polyacrylamide grouts might prove to be chemically compatible with certain wastes and thus offer sufficient isolation potential. Alternatively, phenol or amine polymers might be developed as waste forms and carriers that could be pumped into an injection zone before polymerization.

For certain wastes, it might be feasible to produce a microencapsulated waste form that could be mixed with cement or an organic-based carrier for disposal. The costs of microencapsulation would probably dictate use of such a method for only a limited number of very toxic wastes. Particle size should probably be kept below 1 mm.

Technical and Regulatory Considerations and Needs

If the ORNL hydrofracture technique is considered for permanent disposal of hazardous waste, the existing technical data base is inadequate to provide assurance that the process is environmentally safe, as determined by current statutes. There are a number of technical areas that must be pursued to provide the data that will be required for use of the technology. Because one of the principal factors in waste isolation by this method is the creation of (nearly) horizontal bedding plane fractures and because little is known of the behavior of such fractures in rocks, research must be directed toward fracture behavior in anisotropic media. This and other critical rock mechanics issues relative to hydrofracturing are discussed by Doe and McClain (11). A related issue is the determination of the maximum volume that can be injected into a single well.

Work must also be continued on development and refinement of real-time monitoring techniques. Such monitoring is critical to ensure that fractures that form during disposal do not break a containment horizon and intersect horizons that are connected to the accessible environment.

Finally, research should be directed toward study of the long-term stability of the injected hazardous waste. Groundwaters at injection depths may be highly saline and have corrosion and complexation potential. The long-term interaction of such waters and wastes should be understood.

It is also appropriate to note the need for consideration of the regulatory status of injection wells. Certainly many regulations could apply to a hydrofracture site, including its surface and subsurface facilities. At present, federal underground injection regulations (EPA regulations for the Underground Injection Control Program, 40 CFR 144) and similar statutes at the state level may be applied to the process because the technology involves subsurface injection of wastes. Underground injection regulations are written for disposal of liquids, including hazardous wastes, into porous and permeable aquifers; the wastes mix with nonpotable groundwater and slowly disperse. The concept of waste isolation by hydrofracturing, as noted previously, is totally different from the disposal method envisioned by existing legislation. Thus, it may be necessary to formulate legislation that specifically addresses the hydrofracture process.

SUMMARY

The hydrofracture process has been shown to be a viable method for disposal of radioactive wastes at ORNL. The operational aspects are routine and could rather easily be adapted for hazardous waste disposal. Because the process appears to have applicability for hazardous waste disposal, research needs to be conducted on the development of stable waste forms and carriers, as well as on the rock mechanical and monitoring aspects. Site selection considerations are of prime importance in future applications of the technology. There may be a need to more fully explore the regulatory picture because of the fact that existing regulations for deep well injection were not formulated with the concepts of waste isolation that characterize the hydrofracture process.

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