STATUS OF THE OAK RIDGE NATIONAL LABORATORY NEW HYDROFRACTURE FACILITY: IMPLICATIONS FOR THE DISPOSAL OF LIQUID LOW-LEVEL RADIOACTIVE WASTES BY UNDERGROUND INJECTION[a]

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ABSTRACT

From 1982 to 1984, Oak Ridge National Laboratory (ORNL) disposed of approximately 2.8 x 10^{16} Bq (7.5 x 10^5 Ci) of liquid low-level radioactive wastes by underground injection at its new hydrofracture facility. This paper summarizes the regulatory and operational status of that ORNL facility and discusses its future outlook.

Operational developments and regulatory changes that have raised major questions about the continued operation of the new hydrofracture facility include: (1) significant ^{90}Sr contamination of some groundwater in the injection formation; (2) questions about the design of the injection well, completed prior to the application of the underground injection control (UIC) regulations to the ORNL facility; (3) questions about the integrity of the reconfigured injection well put into service following the loss of the initial injection well; and (4) implementation of UIC regulations.

Ultimately, consideration of the regulatory and operational factors led to the decision in early 1986 not to proceed with a UIC permit application for the ORNL facility. There are no plans to reactivate the hydrofracture process. Subsequent to the decision not to proceed with a UIC permit application, closure activities were initiated for the ORNL hydrofracture facility. Closure of the facility will occur under both state of Tennessee and federal UIC regulations and under provision 3004(u) of the Resource Conservation and Recovery Act.

Nationally, there is an uncertain outlook for the disposal of wastes by underground injection. All wells used for the injection of hazardous wastes (Class I wells) are being reviewed, and a possible outcome of that review is that such wells would be banned or severely restricted in their operation. If such a ban or restriction were enacted, it would also have major implications for the injection of radioactive wastes, even though such wastes may not be classified as hazardous.

INTRODUCTION

During the past two decades, Oak Ridge National Laboratory (ORNL) has disposed of over 5.2 x 10^{16} Bq (1.4 x 10^6 Ci) of liquid low-level radioactive waste by underground injection using the hydrofracture process. In this process, liquid radioactive wastes are mixed with solids to form a cementitious slurry that is pumped underground through a cased injection well. The slurry spreads out into hydraulically fractured intervals in a low permeability host rock through slots at the bottom of the injection well casing (Fig. 1). It forms irregularly shaped, pancake-like sheets and solidifies into a grout that encapsulates the wastes. The principal radionuclides disposed of are ^{90}Sr and ^{137}Cs, although others, including ^{3}H, ^{60}Co, and ^{106}Ru, also occur in the wastes. Approximately 0.1% of the total activity disposed of consists of transuranic elements, with Cm being the most abundant. This process represents the only permanent geological disposal of nuclear wastes in the United States.

The hydrofracture process has been developed at ORNL over the last quarter century (1, 2). Initial developmental work was performed at three test facilities; in the mid-1960's, the process became operational, and approximately 2.4 x 10^{16} Bq (6.4 x 10^5 Ci) of radioactive wastes were disposed of at the modified third test facility from 1965 through 1980. A new injection facility, which is the main focus of this paper, was put into operation in 1982, and a total of over 2.8 x 10^{16} Bq (7.5 x 10^5 Ci) of radionuclides has been disposed of since 1982 (3).

Details of the ORNL process and a summary of operations at the new hydrofracture facility through 1984 have been presented previously (3, 4, 5, 6). The pupose of this paper is to review recent operational developments at the new hydrofracture facility, to summarize its regulatory status, and to discuss the future outlook and implications for the disposal of radioactive wastes by underground injection.

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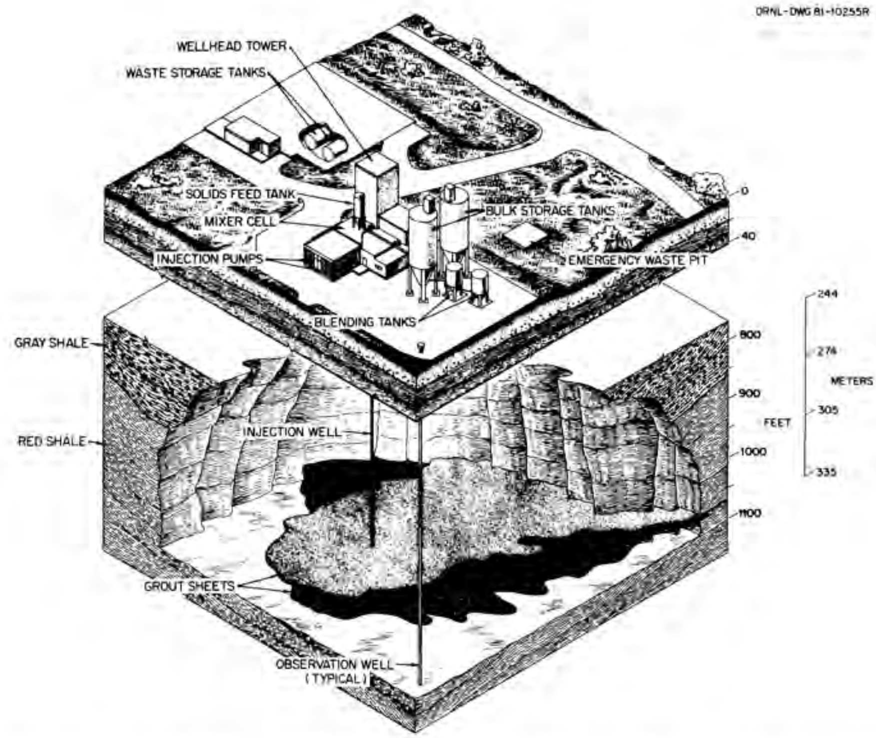
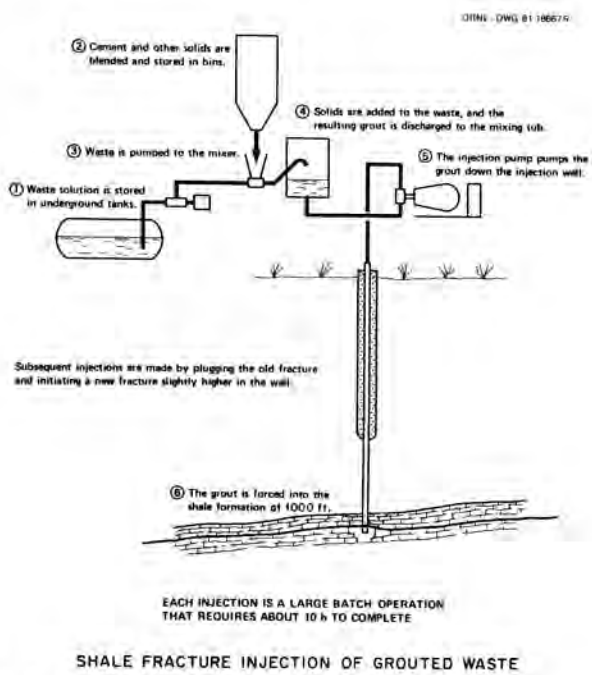


Fig. 1. Conceptual diagram illustrating major features of the ORNL new hydrofracture facility. Wastes are held prior to injection in storage tanks. Solids used to mix the slurry are held in bulk storage tanks. Slurry is mixed at wellhead and pumped underground through injection well. Observation wells are used to determine location of injected slurries. Scale is approximate.

The Hydrofracture Process

The hydrofracture process is a large scale batch process (Fig. 2) that makes use of standard operating and engineering practices from hydraulic fracturing technology as applied in the petroleum industry. Liquid radioactive wastes were stored in underground storage tanks and disposed of typically every one to two years. The waste solutions, which were alkaline and nitrate-rich (1 to 2 M $NaNO_3$), were blended with cement and other additives to form a slurry, which was pumped under approximately 20- to 25-MPa (2,800- to 3,500-psi) pressure into a cased injection well. The casing was slotted at a depth of approximately 300 m (1000 ft). Hydraulic fractures in the host rock, a shale of low porosity and permeability, were initiated along bedding planes by pumping several thousand liters of water into the well; this was followed immediately by the waste-bearing slurry, which spread radially from the injection well along the hydraulic fractures. The slurry set to form thin (less than a few centimeters) grout sheets that extend up to several hundred meters from the well. No grout sheet has been detected more than 210 m (700 ft) from the injection point. Later injections were made through slots cut at shallower depths in the well, thus allowing maximum use of the host injection strata.

Disposal was normally done over a two-day period in two 8- to 10-hour shifts. The total volume of radioactive waste-bearing slurry disposed of in a single injection was approximately 760,000 L (200,00 gal).



SHALE FRACTURE INJECTION OF GROUTED WASTE

Fig. 2. Schematic flow diagram for the ORNL hydrofracture process [from Weeren et. al. (3)].

Operational History of the New Hydrofracture Facility

Construction of the new hydrofracture facility began in November 1979 and was completed in February 1982. A preoperational test was conducted in March 1982, and the facility became operational in June 1982. The last waste injection was completed in January 1984 (3).

During the life span of the new facility, a total of 13 injections were made (3,7). In contrast to operations at the previous hydrofracture facility, where injections were made on a 18- to 24-month period, injections at the new facility were made typically on a 4- to 6-week basis.

The radionuclide contents and waste volumes for the 13 injections are summarized in Table I. Additional specific data on individual injections are presented elsewhere (7). Of the 13 injections, three involved disposal of wastes generated by current, normal laboratory operations (injections ILW-19, ILW-20, and ILW-21). The remaining ten injections involved the disposal of historically-generated wastes. Total volumes of grout slurry disposed of during any one injection ranged from 580,000 L to 1,190,000 L (150,000 to 314,000 gal), and the total amount of waste-bearing grout slurry injected during the 13 injections was 10,874,000 L (2,900,000 gal).

Comparison of the ORNL Process to Other Underground Injection Operations

It has recently been determined that ORNL's hydrofracture facility is regulated by federal and state underground injection control (UIC) regulations. It is important to compare and contrast the ORNL process with those for which the UIC legistation was written because there are significant similarities and differences (Table II). Such aspects as the intent to prevent contamination of potable groundwater, the desire for high integrity of the injection well, and monitoring of the injection operations represent facets *where* the legislation is in full concert with the ORNL process. However, a number of the characteristics of the ORNL process make it apparent that the legislation was written for injection operations radically different from those at ORNL. The principle of waste isolation through creation of a solid waste form (cement) and the injection into a low permeability, rather than a high permeability, host formation represent primary differences. In other injection operations mixing of the liquid waste with groundwater occurs and causes eventual dilution; the ORNL process is directed toward retardation of wastes and isolation from groundwater in the injection formation. Most hazardous waste injection operations do not operate at pressures sufficient to hydraulically fracture the host strata because the strata have inherent high porosity and permeability. At ORNL, porosity necessary to accommodate the wastes must be created by fracturing the host strata with high injection pressures. Although strictly a site-specific difference, the ORNL process involves the injection into dipping strata that crop out within 1.6 km (1 mi) of the injection well; other injection wells involve relatively horizontal strata so that the surface outcrops do not occur within the area of review for the particular faciltity. Finally, at ORNL, relatively small volumes of waste-bearing slurry [averaging about 760,000 L (200,00 gal)] have been injected in discrete batch operations; other underground waste injection operations involve continuous injection of many millions of liters of waste solutions.

RECENT OPERATIONAL DEVELOPMENTS

Operations at the new hydrofracture facility were characterized by two significant deviations from the experience at previous hydrofracture sites. The first of these was the loss of the injection well, and the second was the discovery of radioactively-contaminated groundwater in strata surrounding the grout sheets.

TABLE I

Summary of Injections at the New Hydrofracture Facility [data from Weeren et al. (3)]

Injection	Date	Waste Volume (L)	Grout Volume (L)	Activity Injected (Ci*) ^{90}Sr	^{137}Cs	Other
ILW-19	June 16-17, 1982	600,000	860,000	156	17,333	354
SI-1	August 10-15, 1982	730,000	1,190,000	28,500	5,500	2,782
SI-2	September 23-24, 1982	440,000	580,000	57,000	4,800	1,473
SI-3	October 26-29, 1982	940,000	1,170,000	61,000	4,100	2,600
SI-4	April 8-10, 1983	30,000	920,000	11,000	450	456
SI-5	May 17-18, 1983	600,000	620,000	7,200	410	301
ILW-20	June 14-15, 1983	420,000	590,000	3,266	7,140	694
SI-6	July 12-14, 1983	770,000	850,000	67,553	2,750	2,230
SI-7	August 9-10, 1983	620,000	720,000	21,613	1,585	464
SI-8	October 25-26, 1983	740,000	916,000	217,400	14,800	4,055
SI-9	December 1-2, 1983	721,000	903,000	125,000	16,200	2,314
SI-10	January 25-27, 1984	700,000	946,000	41,100	5,600	1,898
ILW-21	January 27-28, 1984	462,000	606,000	3,500	2,100	600
	Total	8,475,000	10,874,000	644,505	82,768	22,903

* 1 Ci = 3.7×10^{10} Bq

TABLE II

Comparison of the ORNL Hydrofracture Injection Well with Other Types of Subsurface Injection Wells [adapted from Stow and Haase (6)]

Factor	ORNL	Other
waste form	solid - cement	none - liquid
waste fate	isolated, retarded	diluted, neutralized
host stratum	aquitard	aquifer
porosity	created by fracturing	natural
structure of host	dipping	horizontal
volume of waste	small	large
injection frequency	batch	continuous

Loss and Recovery of the Injection Well

In December 1982, after four injections had been completed at the new facility, it was noted that the injection tubing string was frozen in the injection well (3,8). During normal injection operations at the new facility, the 7.18-cm- (2.825-in-) dia injection tubing string was placed inside the cased injection well such that the bottom of the string was approximately adjacent to where the well casing had been slotted. Corrosion and failure of the injection tubing string during the first four injections lead to the situation illustrated in Fig. 3. The injection tubing had parted and fallen 6 m (20 ft). The upper portion of the injection tubing string was cemented to the injection well casing with radioactive grout, and the bottom portion of the tubing string was both plugged and cemented to the injection well casing (3, 8).

In January 1983 a well recovery operation was begun. The upper portion of the injection tubing string was removed, and an attempt was made to remove the lower portion of the tubing string from the injection well. Two unsuccessful attempts were made to clear the lower section of the injection well. Both recovery attempts ended when the drilling operations to remove the injection tubing string breached the 14-cm- (5.5-in-) dia injection well casing (Fig. 4). After the second breach of the injection well casing, it was decided to redrill the lower portion of the injection well through the uppermost casing breach and to install a new string of 7.18-cm- (2.825-in-) dia injection tubing. This new tubing string was cemented in place and was to serve as both the injection tubing string and as the casing for the lower 350 ft of the recovered injection well. The reconfigured injection well is illustrated in Fig. 4. Altogther, the recovery operation took three months (8).

The loss of the injection well and its subsequent recovery resulted in a well that was significantly different from that originally designed. Most significantly, the double containment feature of the original design was lost for the lower portion of the well. Furthermore, the recovered well lacked an annular space. The ability to monitor pressures in the annular space of an injection well is a key requirement of all injection wells as specified by both federal and state UIC regulations.

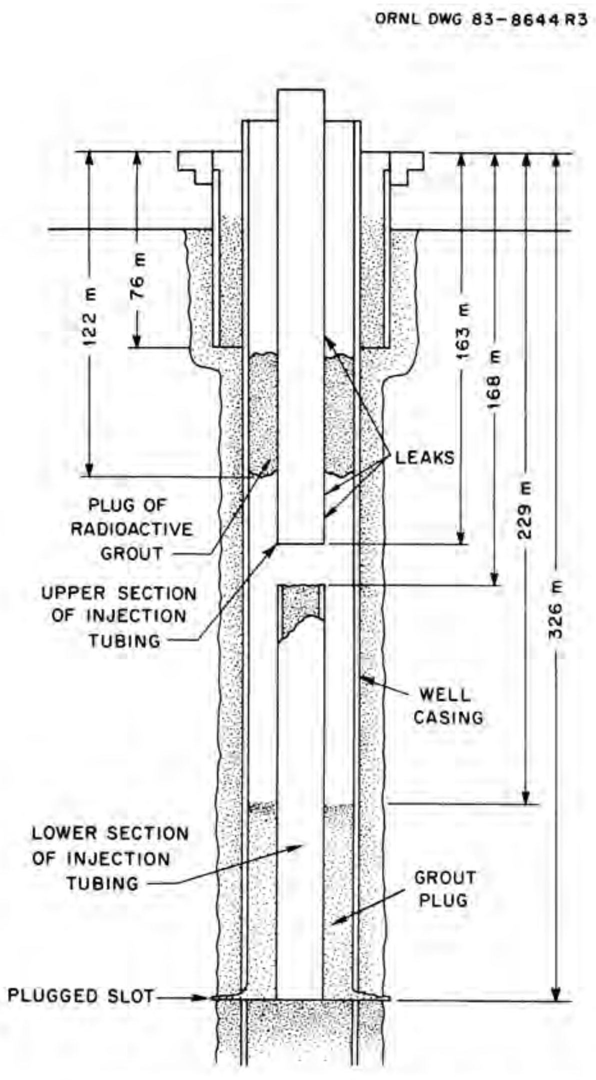


Fig. 3. Configuration of the injection well at the new hydrofracture facility after failure of the injection tubing string [from Weeren et. al. (8)].

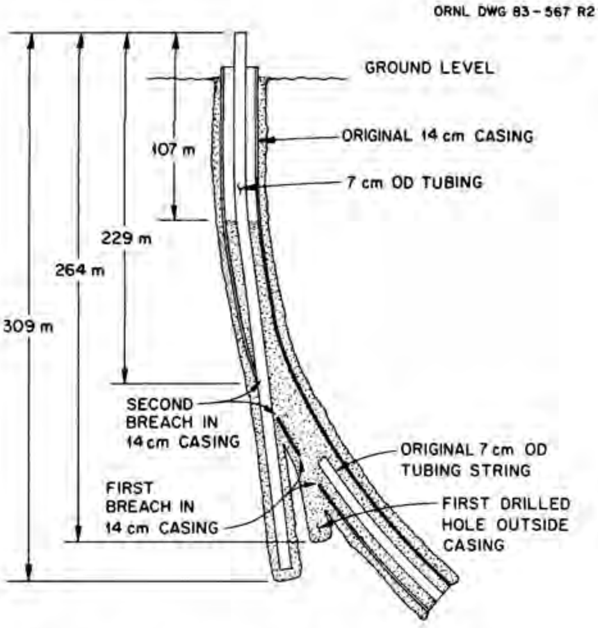


Fig. 4. Final configuration of the recovered injection well at the new hydrofracture facility [from Weeren et al. (8)].

Groundwater Contamination at the New Hydrofracture Site

Contaminated groundwater was discovered in August 1984 in groundwater monitoring wells drilled to investigate hydrological conditions in the host formation (4, 9). Three monitoring wells, DM1, DM2, and DM3a, were drilled at distances of 300 m (1,000 ft) from the injection well. Two of the wells, DM1 and DM2, are along geological strike to the east and to the west, respectively, from the injection well. The third well, DM3a, is updip to the northwest of the hydrofracture facility [from Weeren et. al. (8)]. Contamination was observed in wells DM1 and DM2, while groundwater in well DM3a is uncontaminated. The principal radionuclide contaminant is ^{90}Sr, with concentrations ranging from 70,000 to 150,000 Bq/L (1.89 to 4.05 µCi/L) (9). Only trace amounts of several other radionuclides known to have been disposed of at the new facility (^{3}H, ^{60}Co, and ^{106}Ru) have been noted. Although large quantities of ^{137}Cs were disposed, this radionuclide has not been observed in the contaminated groundwater (9) due to retardation within the grout and apparent sorption on clays of the host stata. The indigenous groundwater of the injection formation is a Na-Ca-Mg-Cl brine with total dissolved solids contents between 150,000 and 250,000 ppm (4, 10).

Subsequent to the discovery of contamination, additional wells have been installed near the new hydrofracture facility, and other wells have been sampled (9, 10, 11). Data obtained from the injection formation approximately 910 m (3,000 ft) along geological strike to the east and 1,200 m (4,000 ft) along strike to the west indicate that injection formation groundwater is not contaminated at those distances. The lack of contaminated water in well DM3a suggests that the contaminated water in the injection formation has not migrated updip to the northwest for distances as great as 300 m (1,000 ft), although additional wells are planned to better define the extent of contamination in the updip directions.

Preliminary data indicate that wells finished in strata immediately overlying the injection formation contain only slight amounts of ^{90}Sr [50 to 200 Bq/L (1.35 to 5.4 nCi/L)] suggesting that minor upward movement of contaminated groundwater may have occurred.

The discovery of significantly-contaminated groundwater in the injection formation was not anticipated (1, 2, 12). Although the concentration of ^{90}Sr observed in the contaminated groundwaters is approximately 1.0×10^{-4} times the concentration of this radionuclide in the slurries originally injected (average ^{90}Sr concentrations in the injected slurries were approximately 2.0×10^{9} Bq/L (54 mCi/L)], the levels are high enough for concern. The reason(s) for the occurrence of significant ^{90}Sr concentrations in groundwater within the injection formation surrounding the facility are currently being investigated, and a comprehensive study of groundwater in the vicinity of the facility has been initiated.

RECENT REGULATORY DEVELOPMENTS

For many decades, the experimental and operational injections at ORNL's hydrofracture injection sites were conducted, as were other disposal operational at federal facilities, autonomously with respect to regulatory control. As part of the increased adherence to regulatory oversight, in response to the Presidential order of 1978 applying to all federal facilities, the hydrofracture operations came under the UIC provisions of the Safe Drinking Water Act (SDWA) in the early 1980s.

At that time, the State of Tennessee was preparing UIC regulations for subsurface injection wells, and considerable interaction occurred between the U. S. Department of Energy (DOE) and the state in anticipation of issuance of its UIC regulations and eventual granting of primacy. The state UIC regulations were issued in June 1985, and they called for filing of permits for all injection wells in the state by March 1986.

In early 1986, DOE decided not to file for an injection permit for the new hydrofracture facility. This decision was reached because it was evident that there were significant issues that would need to be resolved before a permit could be granted. These issues included the construction history of the injection well, the problems associated with the loss and recovery of the injection well, and an insufficient data base for hydrological characterization of the site. Guidance from the federal and state regulators was received indicating that a site closure plan should be prepared if a permit for the injection well was not to be requested. This closure document, called a Remedial Action Plan (RAP), was issued in January 1987 (13); the scope of this document, which covers not only the new facility, but also the three previous hydrofracture sites and all associated surface facilities, and includes detailed site characterization activities, will be discussed later.

In the spring of 1986, when plans were being made to close the new facility and other previous injection wells under the UIC provisions of the SDWA, the U. S. Environmental Protection Agency (EPA) issued guidance that all waste disposal sites at ORNL - including the injection wells - were to be closed under the 3004(u) section of the Resource Conservation and Recovery Act (RCRA). The surface facilities at the new injection facility were to be closed as permitted RCRA units.

Accordingly, the RAP that was being prepared, was designed to be in accord with RCRA provisions, including a remedial investigation, with a resulting alternatives assessment and feasibility study.

At the present time, all hydrofracture sites are being closed under both the UIC regulations and RCRA. Although the state does not have primacy for either UIC or RCRA 3004(u), there is close regulatory coordination with both the state and the EPA. It is uncertain when the state will seek primacy.

There is at least one major issue that is yet to be resolved regarding closure of the new site: the classification of the injection well. Both federal and state UIC regulations define five classes of injection wells that cover the most frequently used underground injection waste disposal processes. Because of its unique design and application to radioactive waste disposal, the ORNL hydrofracture facility does not fall unambiguously into any one of the five UIC well classes. The state has tentatively agreed to assign the injection well at the new facility a Class V status; Class V is a "catch-all" category for, among other things, injection wells that employ new and innovative technologies. The EPA has not yet established a position on well classification and has raised the question of the possible existence of an underground source of drinking water (USDW) below the injection zone. If an USDW exists under the site, then the injection well is automatically placed into Class IV; Class IV wells require immediate shut down - a moot point for the ORNL site because the facility is being closed anyway. There has been discussion of the need for construction of a 1,500-m-(5000-ft-) deep exploratory well through strata deep underneath the the ORNL site to determine if an USDW exists so that the injection wells can be classified as IV or V. A Class I (for hazardous wastes) status cannot be assigned because the injection pressures were, of course, great enough to cause fracturing of the host injection strata.

CLOSURE ACTIVITIES

As indicated earlier, a Remedial Action Plan (RAP) has been prepared to cover the general approach toward site characterization and site closure (13). This plan encompasses all four hydrofracture sites, including the surface facilities and the underground grout sheets and associated contaminant-bearing groundwater, as well as all wells within a one-mile area of review that are either associated with the injection operations or that penetrate the injection zone. The greatest emphasis is placed on the two injection sites where large amounts of radionuclides were disposed (the old and new facilities). Of greatest interest for this present paper are the activities associated with site characterization and plugging and abandonment (P&A) of selected wells.

The site characterization activities are described in detail in the Remedial Investigation (RI) plan, which was issued in draft form to the federal and state regulatory agencies in February 1987. This plan is directed toward acquisition of sufficient technical data so that an alternative assessment leading toward site closure can be undertaken. This remedial investigation phase, which is currently scheduled as a three-year activity, is heavily directed toward technical studies that address the nature and stability of the waste source (grouts) in contact with the highly saline groundwaters of the injection formation; determination of the extent of contaminated groundwaters surrounding the facilities; the mechanisms and rates characteristic of contaminated groundwater movement; possible interactions between groundwater at the sites and regional flow patterns; and an assessment of transport scenarios to the accessible environment. Because of the natural hydrogeological and structural *complexity* of the ORNL area, and the effect that the injections may have had on groundwater flow paths, considerable emphasis is being placed on structural analysis of joint, fault, and other fracture systems and their relationship to local and regional groundwater flow. A related major issue to be resolved is how hydrologically isolated is the injection zone with respect to the overlying and underlying confining strata and to possible USDWs. Geochemical studies are planned to determine the effect of highly saline waters on contaminant transport. In addition to the technical studies, the RI Plan includes full consideration of quality assurance, health and safety, waste management, and data management.

In addition to the site characterization covered by the RI Plan, plans are being made to initiate some remedial actions at this time in the form of plugging selected wells near the old and new hydrofracture facilities. Initial P&A plans for over 150 wells within the area of review have been prepared (14), and detailed plans for selected, high-priority wells in the immediate vicinity of the facilities are being prepared. These wells are generally cased observation wells that contain a standing column of contaminated water, and could represent a pathway for rapid migration of radionuclides to the accessible environment.

IMPLICATIONS FOR THE FUTURE DISPOSAL OF RADIOACTIVE WASTES

Application of the hydrofracturing technology for the disposal of liquid, radioactive wastes has been abandoned at ORNL. The new facility will not be operated again. Volume reduction methods have greatly reduced the amount of liquid wastes generated, and solidification technologies are being implemented to solidify and dispose of those liquid wastes that were formerly disposed of by hydrofracture. The closure activities will provide much valuable information about the geological and hydrological ramifications of the technology. Hopefully, the geohydrological research activities associated with closure will provide a solid technical data base to not only evaluate the environmental status of the ORNL facility, but to guide further research and development, and perhaps implementation, of the technology at other sites.

Nationally, there is an uncertain outlook for the disposal of wastes using underground injection. Currently, the EPA is reviewing all wells used for the injection of hazardous wastes (Class I wells). A possible outcome of that review is that Class I wells would be banned or severely restricted in operation in the late 1980s. Such a position would also have major implications for the injection of radioactive wastes, even though such wastes may not be classified as hazardous. Therefore, application of the hydrofracture technology to other sites is uncertain, in large part because of regulatory ambiguities surrounding the technology. For the merits of the application of the hydrofracture technique to the disposal of liquid radioactive wastes to be fully evaluated elsewhere, some regulatory reconsideration must be granted. Successful resolution of the review of Class I wells mandated in the the RCRA regulations will permit progress toward resolution of questions concerning permitting of the hydrofracturing subsurface disposal technology. Such action would be helped by expansion and/or modification of existing underground injection regulations. It would be desirable to develop regulations that specifically address this method of waste disposal, so that the technology is not lost if the more common methods of subsurface injection cannot be continued.

SUMMARY

The hydrofracture technology at ORNL was used for over 20 years to dispose of liquid radioactive wastes. The technology is an unique variation of widely-applied subsurface injection methodologies combined with hydraulic fracturing technology from the petroleum industry. It provided a cost efficient method to dispose of over 5.2×10^{16} Bq (1.4×10^{6} Ci) of radionuclides.

Recent operational events at the new hydrofracture facility and changes in the regulatory atmosphere surrounding DOE facilities and the underground injection of wastes in general, have resulted in the halting of all hydrofracture injections at ORNL. A decision has been made to not seek to permit the facility but to close it under the provisions of RCRA and federal and state UIC regulations. Closure activities will address not only the new hydrofracture facility, but also three previous sites used for research and development activities and for routine waste disposal injections prior to 1982.

The future application of subsurface injection for waste disposal of hazardous materials is uncertain pending a thorough review of the practice by regulatory agencies. This uncertainty, combined with the ambiguities of the existing regulations regarding the hydrofracture process, make the status and future application of the technology uncertain.

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