HYDROFRACTURE OPERATIONS AT OAK RIDGE NATIONAL LABORATORY*

L. C. Lasher
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37831

ABSTRACT

The hydrofracture process (shale fracture) was developed at ORNL for the purpose of disposing of the liquid low-level radioactive waste (LLW) solutions which are generated by the research and development activities conducted at this facility. The LLW is an alkaline solution (pH≅10) which normally contains from 0.5 to 1.5 Ci of radioactivity per gallon. The major active constituents are ^{60}Co, ^{137}Cs, and ^{90}Sr. A pilot plant constructed in 1964 was used to develop operating techniques and evaluate equipment components. After seven successful experimental injections, this facility was converted into an operating disposal plant and was utilized in this manner from 1966 to 1980 when it was retired from service. Construction of the present disposal plant began in 1979 and was completed in October 1981. Training and shakedown operations were conducted early in 1982, and the first injection at the new site was completed in June of that year. In December 1982, after four injections had been completed, the well was inadvertently cemented in while preparing it for a sand slotting operation. A three-month recovery operation ensued. Operation of the New Hydrofracture Facility (NHF) was resumed in early April 1983, and ten injections consisting of LLW and slurried contaminated sludge have been completed without a major incident.

INTRODUCTION

The hydrofracture process (shale fracturing) was developed at ORNL for the purpose of disposing of the low-level waste (LLW) solutions which are generated at this facility. The LLW is an alkaline solution (pH≅10) which normally contains from 0.5 to 1.5 Ci of radioactivity per gallon (predominatly ^{137}Cs and ^{90}Sr). The process consists of mixing the LLW with a blend of cement, fly ash, and clay additives and pumping the resulting slurry approximately 305 m down a hole into an impermeable red shale formation. The shale fractures horizontally, and as the pumping continues, the grout spreads out into a thin elipsoidial sheet which conforms to the bedding plane, horizontal to the surface. After a few hours, the grout sets and becomes a permanent part of the formation.

The well is prepared for a waste injection by perforating the well casing at the desired injection depth. It is then pressurized with water to generate the initial fracture in the shale. After the initial fracture has been induced, the liquid waste and the blended solids are slurried by a jet mixer and discharged into a surge tank. The mixed waste grout is pumped from the surge tank down a tubing string suspended within the injection well, out through the slot in the well casing, and into the fracture. Figure 1 is a flow diagram of the process.

An indeterminate number of injections can be made through a single slot in the well casing. To date, the maximum number has been ten. Subsequent injections are made by reslotting the casing with explosives or sand erosion depending upon the well configuration. The slots are spaced at 3-m intervals, each slot higher than the preceding one. This procedure results in the formation of a series of thin grout sheets with each sheet parallel to the one below it. Combination of the liquid radioactive waste with additives, which ensure solidification of the mixture within the shale structure, provides assurance that the radioactive constitutents will not migrate into the biosphere at a future date.

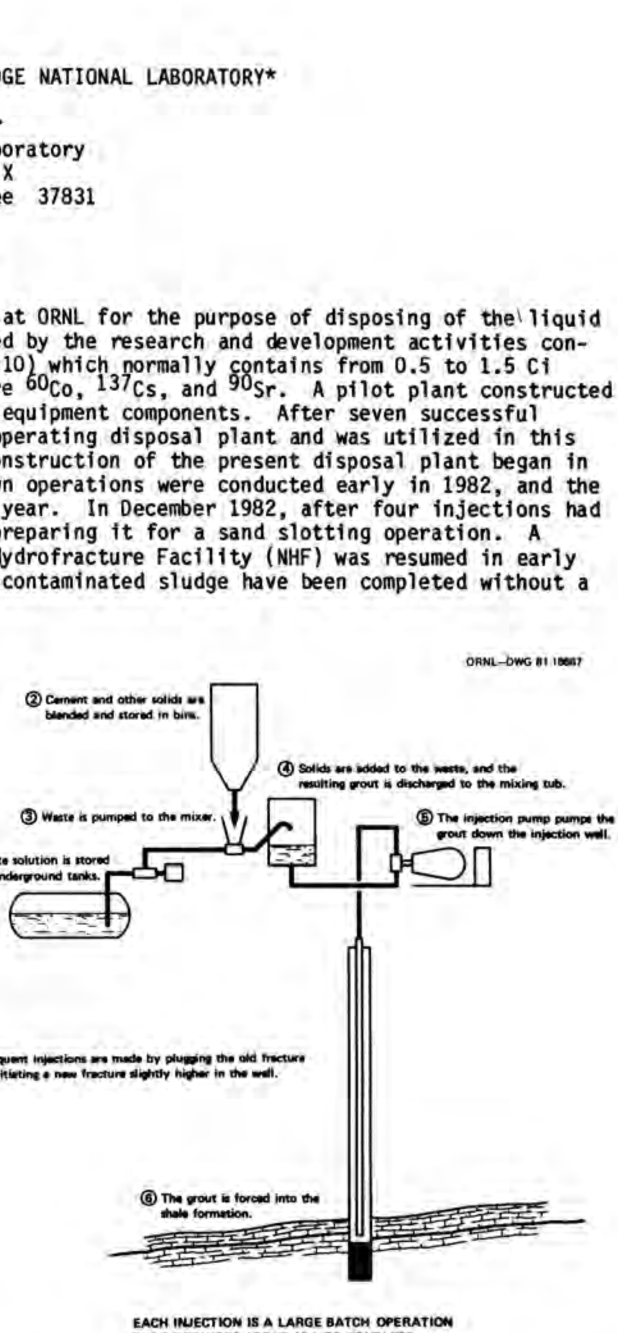

Fig. 1. Flow Diagram of Shale Fracturing Facility.

The thick shale formations underlying a portion of the ORNL Melton Valley site are geologically suited to the disposal of liquid radioactive wastes by the hydrofracture process[1]. The upper portion of this shale formation consists of about 180 to 210 m of a high-integrity, dense gray shale. This is underlain

*Research sponsored by the Office of Defense Waste and Byproducts Management, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

by about 90 m of red shale which is composed of thin, horizontally oriented beds. The red shale fractures easily and preferentially along the bedding planes. Disposal operations are conducted in the red shale formation at depths ranging from 230 to 330 m below the surface. The overlying gray shale formation provides a highly impermeable barrier which prevents the migration of groundwater down to the disposal zone. The essential feature of the system is that the radioactive contamination is contained in the solidified grout and completely isolated from the environment: the water movement in the disposal zone is nil, and even if the system were to be breached in some manner, the leach rate of the grout would be extremely low. In addition, the ion exchange properties of the shale would tend to absorb the radionuclides. Figure 2 is a cutaway drawing which depicts the disposal zone.

HISTORICAL RESUME[1,2]

The technique of hydraulic fracturing as a potential method for the disposal of radioactive liquid waste was first proposed to the AEC (now DOE), in 1958 by officers of the Continental Oil Company. In 1959, an experiment was conducted at ORNL to determine whether grout pumped into shale would fracture the rock horizontally. A slurry, spiked with a radioactive tracer, was pumped via a 90-m cased well into the shale. Subsequent core samples and gamma logging of the core holes revealed that the grout sheet conformed to the horizontal bedding plane. Two additional injections into red shale at depths of 280 and 190 m also resulted in conformable fractures.

Encouraged by the favorable results of these experiments, a full-scale pilot plant was constructed for the purpose of evaluating equipment, developing a waste-cement mix, and defining disposal techniques. The plant utilized mechanical hardware purchased from the petroleum industry. In addition to the injection well, a system of wells and bench marks were provided for the purpose of locating the grout sheets and monitoring the containment provided by the rock cover. The plant was completed early in 1964, and a series of seven successful experimental injections was completed by August 1965. After minor alterations and additions, the pilot plant was converted into an operating facility, and in December 1966, the initial LLW injection was completed. The facility continued to function as a disposal system until 1980 when it was retired from service. During this period, 18 injections amounting to 6,300 m^3 (1,700,000 gal) of slurried waste containing 600,000 Ci of activity were pumped into the disposal zone.

THE ORIGINAL HYDROFRACTURE FACILITY

Description

Subsurface Equipment

Three types of wells are used at the shale fracturing facility: (1) an injection well for the injection of waste grout, (2) observation wells for the determination of the orientation of the grout sheet, and (3) rock-cover monitoring wells for verification of the continued impermeability of the shale above the grout sheets. A sketch of each well type is given in Fig. 3. All waste injections are made through slots cut in the casing and surrounding cement of the injection well. As the grout sheet spreads out from the injection well, it intersects the cemented casing of one or more observation wells. A gamma-sensitive probe in the observation well will then detect the presence of the grout sheet, thereby establishing the depth of the grout sheet at that point. The rock-cover monitoring wells are used to periodically determine the permeability of the shale cover rock at a depth of 180 m (600 ft).

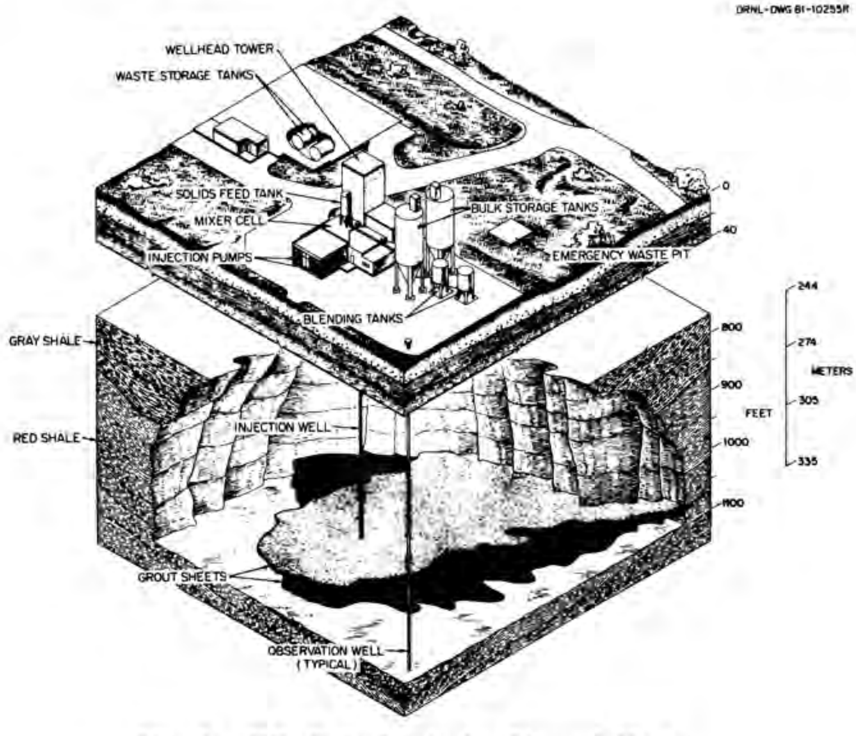

Fig. 2. ORNL Shale Fracturing Disposal Plant.

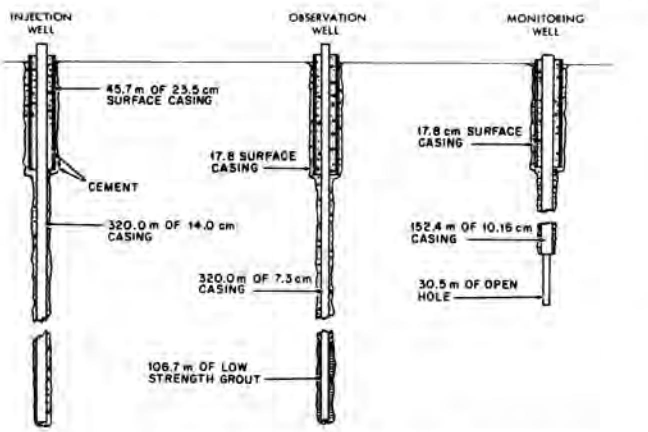

Fig. 3. Sketch of Wells for Shale Fracturing Facility.

Surface Plant

The Original Hydrofracture Facility (OHF) surface plant consisted of five component systems: (1) a bulk solids handling system with mixing, storage, and metering capabilities; (2) a waste storage system with similar capabilities; (3) a slurry system consisting of a continuous mixer and a surge tank; (4) a high-pressure system comprised of a pump, circulation pipe, and wellhead all rated at 70 MPa working pressure; and (5) an internal waste-collection system designed to recycle waste fluids that are generated internally. Hot-cell enclosures provided containment for the fluid handling systems.

The original plant was a conglomerate of purchased and used surplused equipment. Solids handling, mixing, and high-pressure equipment items, together with techniques, were purchased from the petroleum industry. The waste-handling systems, however, consisted primarily of serviceable used tankage, pumps, and accessory items. Originally intended as a nonrad pilot demonstration, the facility was designed accordingly. Functioning later as a radwaste disposal plant, it proved to have a number of operating deficiencies that had to be surmounted during each ensuing disposal job. The OHF layout is shown in Fig. 4.

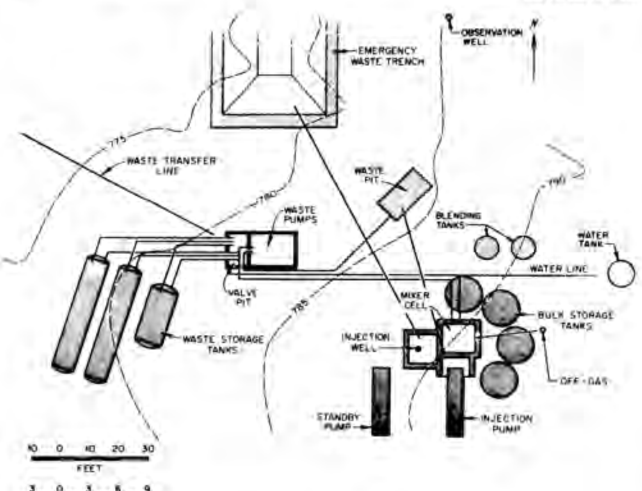

Fig. 4. Layout of Original Hydrofracture Facility.

The Disposal Operation

Preparation

LLW generation rates have varied over the years in the range of 22.7 to 45.4 m^3 per month requiring a disposal rate of one job per 12 to 18 months. Each job date was scheduled about 3 months in advance. This early schedule provided ample time to procure chemicals and to reactivate the plant, a checklist process which required cleaning and reassembling of components parts, recalibrating instruments, and testing the component systems. The chemical blending operation required about 5 d and was normally scheduled 2 weeks prior to the scheduled injection date. An additional 2 to 3 d of preparatory work of a specialized nature was required by the contracted personnel after their arrival on site.

Procedures

Cutting a New Slot. Operating procedures governing the OHF limited the number of injections to four per slot. This was a deliberately conservative and arbitrarily selected limitation — a practical limit would be the operating pressures encountered down hole. It was a two-step process: (1) the existing slot was plugged by pumping a cement mix into the hole and displacing (flushing) the well clear of cement; and (2) re-rigging the wellhead with a hydraulically operated, rotating (360°) slick joint which is an equipment item designed for sand slurry circulation. The casing is severed 10 ft above the existing slot by circulating slurried sand through a hydrojet tool attached to the bottom of the tubing string[3]. The overall operation required a minimum of 2 d; a 24-h setting time was required for the plug and an additional day to rig the wellhead. The bulky equipment items required the use of a 33-metric-ton mobile crane, and the working personnel were governed by contamination zone restrictions.

Waste Injection. The disposal operation proceeded in the following manner. A waste water flow was established and the pumping systems were pressure tested. The safety systems were calibrated and tested. Simultaneous to these operations, the solid storage bins were aerated, fluidizing the solids. The fracture was initiated with water pressure, and when the formation was taking water at an operating rate, the solids flow was started and adjusted to an operating level. As soon as steady-state flows were achieved, the LLW flow was substituted for water.

Operating Problems

The hybrid plant functioned but not without problems. The influence of the petroleum industry prevailed during design, and the surface plant equipment, which was designed for oil-field mobility and specific for cement handling, required a great deal of "hands on" attention which was inhibited by the containment and remote operations characteristic of a rad handling system. Nevertheless, the operation was conducted safely and with quality as attested by 14 years of successful performance.

The bulk-solids handling system, aerated by nonconditioned compressed air and metered by a manually operated butterfly valve, proved to be a constant source of process interruption. Solids bridged the bin discharge and frequently would not flow or would flow intermittently. The solids mixer hopper flooded when the injection pump lost prime and rapidly plugged with solids when operations were resumed. The sensitivity of the density and mass flow indicators degraded as the job progressed due to material accumulating on the contact components. A sketch of the mixing components is shown in Fig. 5. Seals and valve seats were eroded by the abrasive slurry flowing under elevated pressure. Pipe nipples plugged with cement. Finally the HT-400 diesel engine threw a rod, thereby terminating a job at midpoint.

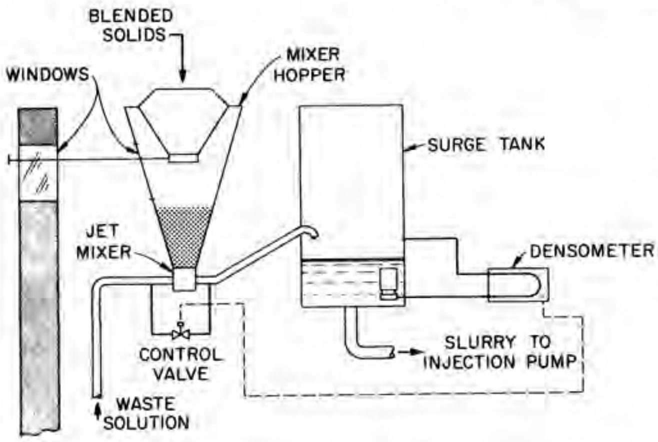

Fig. 5. Equipment for Proportioning and Mixing Preblended Dry Solids and Liquid Waste.

Virtually all of the maintenance was hands on and not conducive to modification for remote maintenance. Controlling radiation exposure was a significant problem. Figure 6 illustrates the background readings encountered in the mixing cell.

Summary Of Operations

The pilot injections demonstrated beyond doubt that hydraulic fracturing was a viable method for the disposal of the radioactive wastes generated at ORNL and that the existing plant with minimal additions could function as a disposal facility. The transition became a reality in December 1966 when the first injection of radioactive waste was successfully completed. The addition of waste storage tanks and a weigh tank to facilitate solids blending rendered the facility fully operational, and injections were

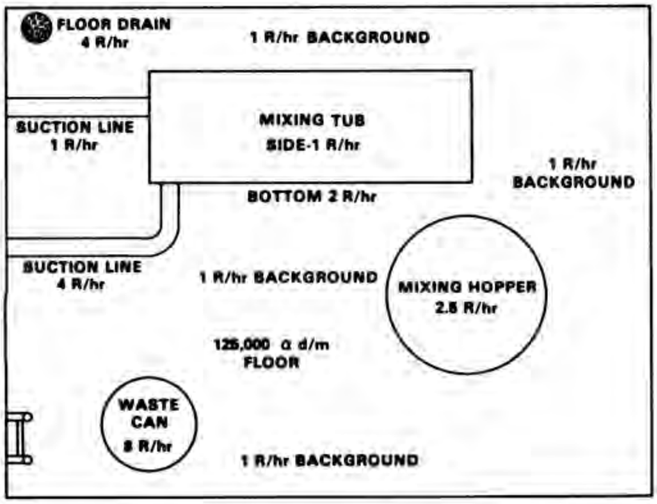

Fig. 6. Mixing Cell Background Radiation Readings.

routinely completed through 1970 at the rate of about one annually.

The hydrofracture disposal operations were suspended in late 1970 by AEC directive, pending the completion of a safety analysis of the facility. Operations were resumed in the final quarter of 1972, and four injections were completed at the rate of one per month. This cleared the tankage for another long-term outage. The plant received a much needed refitting throughout 1973 and 1974.

Operations resumed in January 1975, and the plant continued to routinely dispose of ORNL LLW until June 1979 when it was phased out of service and the operation was relocated to the New Hydrofracture Facility.

Table I summarizes the work that was completed at the OHF site.

THE NEW HYDROFRACTURE COMPLEX[4]

Description

The components of the New Hydrofracture Facility (NHF) are housed in a building which contains an injection well cell, mixing cell, and pump cell together with other related service areas. A high bay area located above the injection well provides a contained area for well maintenance. Biological shielding is provided by 0.8-m-thick reinforced concrete cell walls. The well cell contains the wellhead, circulation manifold, and high-pressure piping; slurry equipment consisting of the solids hopper-jet mixer assembly and the slurry tub are contained within the mixing cell; and a HT-400 high-pressure triplex pump is located within the pump cell. The cells are maintained at a negative pressure by two exhaust systems. One system maintains an airflow from the well and pump cells; the second maintains a flow from the mixing cell and the mixing tub. Each air stream is filtered by a roughing and high-efficiency (HEPA) filtering system and is discharged to the atmosphere via a 5-m-high stack. Adjacent to the cells is a control room in which instrumentation readouts and electrical controls are located. Viewing windows are provided into the injection pump cell, mixing cell, and injection well cell to permit observations of the in-cell operations. A compressor room houses air compressors and dryers. A floor plan of the building is shown in Fig. 7.

In addition to the injection well which provides a conduit into the disposal zone, the NHF utilizes an array of observation and rock-cover wells designed to monitor both the grout sheets (gamma logging) and the integrity of the rock seal. These components were developed and proven at the OHF site.

The bulk-solids storage and transfer system is a turnkey package purchased from the Fluid Transport Division of Ducon Company, Inc. It is a fully instrumented system with remote operation capability, and it provides real-time mass flow data. The system consists of storage tanks, an interconnecting network of piping, a metered delivery system, and dust-handling equipment.

The waste feed (solution or sludge) is stored on site in the LLW storage tank facility. This is an eight-tank system (1500 m^3) which is contained within shielded vaults and is located west of the disposal facility. Two waste-transfer pumps are installed in pits adjacent to the storage tanks, and the waste is transferred via a doubly contained interconnecting pipeline.

TABLE I

Summary of Injections Made at Original Hydrofracture Facility

Injection[a]	Date	Depth (m)	Volume (m^3)			Activity (Ci)			
			Waste	Waste Plus Water	Grout	^{90}Sr	^{137}Cs	^{244}Cm	^{239}Pu
				Experimental Injections					
1-7	2/64-8/65	288-266		1,731.0	2,566.0	1,436	5,237		
				Operational Injections					
ILW-1A	12/12/66	266	136.3	264.7	360.3				
ILW-1B	12/13/66	266	94.4			3	19,950	NA	NA
ILW-2A	4/20/67	263	325.5	623.8	872.1				
ILW-2B	4/24/67	263	234.7			1,050		NA	NA
ILW-3A	11/28/67	263	117.3	374.9	555.5				
ILW-3B	11/29/67	263				9,000	17,000	NA	NA
Water Test	12/13/67	260	169.2						
ILW-4A	4/3/68	260	90.9						
ILW-4B	4/4/68	260	235.4	367.5	494.6	4,300	51,900	NA	1.10
ILW-5	10/30/68	257	309.6	329.7	435.9	500	69,400	NA	1.15
ILW-6	6/11/69	257	300.3	347.3	478.2	8,900	89,000	NA	0.24
ILW-7	9/23/70	257	314.2	407.5	551.4	2,747	44,833	19.20	1.77
ILW-8	9/29/72	254	275.2	309.1	411.1	45	28,000	0.20	0.13
ILW-9	10/17/72	254	258.5	286.1	431.5	231	23,400	6.51	None
ILW-10	11/8/72	254	320.8	354.2	503.3	1,330	18,800	26.67	0.37
ILW-11	12/5/72	254	286.8	310.8	475.0	1,100	23,500	155.74	None
ILW-12	1/24/75	251	97.3	113.0	159.3	1,324	12,752	1.02	None
ILW-13	4/29/75	251	306.6	325.1	477.3	3,368	35,750	17.84	0.03
ILW-14	6/20/77	251	314.0	350.0	525.0	2,874	30,592	3.58	None
ILW-15	6/30/77	251	344.4	393.6	549.0	138	26,390	None	0.66
ILW-16	11/17/77	248	208.9	224.1	300.9	1,618	14,964	None	None
ILW-17	9/1/78	244	311.5	338.8	520.4	90	22,270	2.27	0.07
ILW-18	5/18/79	241	314.2	368.8	526.1	28	16,880	0.19	0.29
TOTALS			5,196.8	6,258.2	8,626.9	38,646	545,381		

[a]The liquid waste stream disposed at the Hydrofracture Facility was called intermediate level waste or ILW until 1984, when the terminology was changed to low-level waste or LLW to be consistent with the definitions in 10 CFR 61. The injection designations (ILW-1A, ILW-1B, etc.) have not been changed to reflect this terminology change).

Preoperational Testing

About three months were devoted to pressure testing, calibrating, and load testing the new system. Initially all of the instrument and control systems were tested. The procedure consisted of pressure testing airlines and sensors, continuity checks, transmitter calibration, adjusting set points, and testing safety interlocks. The work was completed systematically, using written procedures and checklists which were signed off when complete. It also provided on-the-job training for the technicians who would maintain the system in the future.

A preoperational test procedure was written to provide a guide for making a complete systematic test of the new facility. The tests were completed before the introduction of radioactive material into the system and utilized process water as the test medium for all systems. Abnormal conditions or problems encountered during the tests were corrected and documented. This information, along with the requested data, documented the proper operation of the system. The completed records were filed to serve as a comparison standard for evaluating the future performance of the facility.

Training

Following the precedent established by the OHF, the operating plan for the NHF was to employ a petroleum industry field service group to operate the disposal plant with support and guidance from ORNL whose personnel would be responsible for the operation. This plan had economic and practical merit because of the annual operating frequency and the fact that the purchase included a wealth of petroleum engineering experience which was considered necessary. The contract was awarded to Halliburton Services, Inc., whose oil field personnel had been invaluable during the development and operation of the OHF.

Although the flow sheet was basically a copy of the prototype OHF, the components were more sophisticated and, except for the high-pressure hardware, were unfamiliar items to both ORNL and the contractor. On this basis, a training program was evolved which is outlined in Table II. The program consisted of

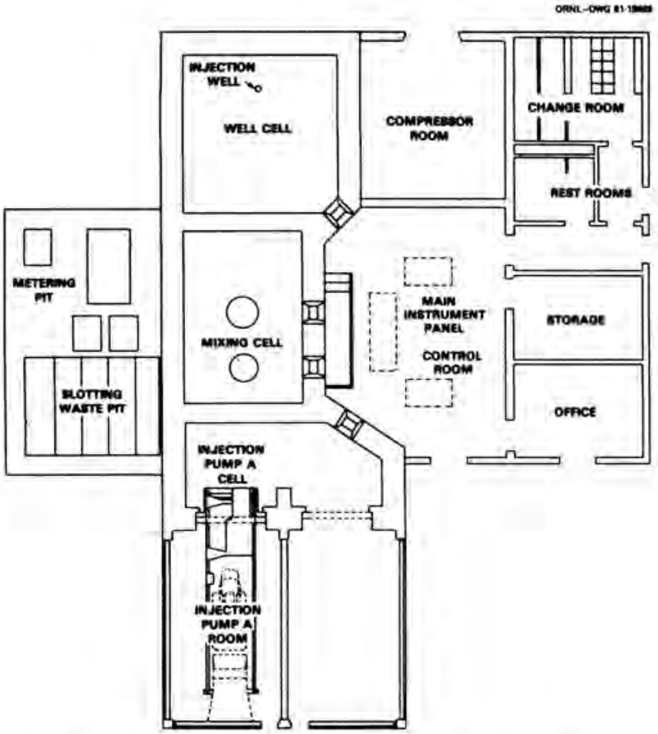

Fig. 7. New Hydrofracture Facility Floor Plan.

classroom work, lectures, audio-visual aids, and finally, a shake-down operation employing every facet of the system. The program entailed 14 d of on-site work terminating with a "cold" injection of 151.5 m^3 of fresh-water-slurried blended solids. During the "shakedown," a number of minor equipment failures occurred and were corrected as encountered. These upsets had been anticipated and were a part of the reasons for the exercise. However, a major incident which was not anticipated occurred during the sand slotting operation: approximately 10 m of tubing were ejected from the well when the return line plugged with sand as the hydrojet tool was being reversed from the bottom of the hole. The subsequent equipment damage was minor.

1982 Disposal Operations

Low-Level Waste Injection

The plant went into operation in June 1982 when 605.6 m^3 of LLW were disposed of via the new well. During the interim, the problems which had surfaced during the training job were addressed, and some of the systems were modified as follows:

1. the HT-400 pump was repacked with a new style of packing which was designed for 50 h of maintenance-free service,
2. a pneumatically operated throttle was installed on the HT-400 diesel engine,
3. the high-pressure cut-off system (HT-400) was upgraded,
4. a wash system was added to the mixing tub viewing window, and
5. the rotary feed valves for (bulk solids) were overhauled.

TABLE II

NHF Training Outline for Halliburton Service Personnel

1. Plant Safety
   - a. Radiation Safety and Control
   - b. Industrial Safety
   - c. Industrial Hygiene
   - d. Understand/Accept Final Safety Analysis Report
   - e. Understand/Accept Operating Safety Requirements
2. High-Pressure Systems
   - a. HT-400 Maintenance
   - b. HT-400 Operation
   - c. Wellhead Maintenance
   - d. Panel Board Orientation
   - e. Panel Board Component Operation
   - f. Slurry System Operation
3. Ducon Bulk Handling System
   - a. Panel Board Orientation
   - b. Panel Board Component Operation
   - c. Solids Feed System Operation

The job was a success in the sense that the disposal objective was satisfied. However, there were periods of aberrant operation which were indicative of nagging design problems. Also the plant was still new to the operators; hence, techniques had not fully matured. The most significant of the problems are described in the following list.

1. The HT-400 pump cavitated quite frequently due to air entrainment — this not only upset the process flows, but the resulting hammer also vibrated both the circulating pipe and the wellhead significantly.
2. The suction legs of the HT-400 pump tended to plug, causing excessive in-cell maintenance and process interruptions.
3. The bulk-solids delivery system, in particular the mixing hopper, plugged too often.
4. Vision into both the slurry tub and the mixing hopper was inadequate.
5. There was excessive dusting in the mixing cell as a result of ineffective operation of the exhaust system.
6. The slurry tub agitator was undersized.
7. The turbine-actuated flowmeters jammed with sand granules as soon as flows were established. A redundant system employing electromagnetic measuring elements was activated and performed satisfactorily.

The GTSR Sludge Injection Program

An ambitious program was then scheduled for the NHF. The work involved the disposal of a bentonite slurry of resuspended radioactive sludge which had accumulated in six 568-m^3 capacity gunite tanks over a period of 30 years of LLW generating operations.[6] The gunite tank sludge removal (GTSR) project job plan projected a slurry generation rate of about 600 m^3 per month with subsequent hydraulic injections of the slurry at that rate.

The first of the GTSR series was completed in August 1982. The average pumping rate was low. This was caused by the inconsistency of the solids delivery system which resulted from intermittent plugging of the solids hopper at the mixing jet. An embarassing and frustrating event took place when the fuel delivery system malfunctioned and the HT-400 diesel engine ran out of fuel. However, 890 m^3 of contaminated waste were pumped into the disposal formation.

A 44-item punch list was completed prior to the second sludge injection (most noteworthy were alterations to the mixing system — solids hopper and tub), and the operators were gaining experience. Consequently, Injections 2 and 3 were methodical and efficient, and design flow rates (0.8 m^3 per min) were achieved. One significant event entirely overlooked at the time was the 55-MPa breakdown pressure which initiated Sludge Injection 2 — the tubing may have parted during Injection 1, and the well was not flushed out completely during cleanup operations. An annoying problem common to both jobs was the generation of small solids nodules which accumulated in the injection pump causing mis-seating of the valves and subsequent cavitation.

In December 1982, after four jobs had been completed, the well was inadvertently cemented in while preparing the system for a sand slotting operation. A three-month well recovery operation[7] ensued, and as a result of the recovery operation, the well configuration was changed significantly.

The Well Recovery Operation

The trouble began December 6, 1982, when a cement plug was pumped downhole and the piping was flushed to a depth of 325 m to plug the slot at that location. This was standard operating practice and in accordance with the operating limit of four injections per slot. The following day, the plug was pressure tested at 35 MPa, and the wellhead was dismantled in preparation for the slotting operation. The tubing string was discovered to be "cemented in" when it could not be lifted out of the hole to attach the "slick joint," a hydraulically operated tubing swivel. There followed cycles of wellhead reassembly, flushing the well, and pulling on the tubing string, but to no avail. The next day, a gamma log of the well was run, and the instrument lead-wire line bottomed at 168 m. The remainder of the week was devoted to alternate cycles of acid circulation followed by stressing the tube string with hydraulic jacks. The tubing stretched 11.4 cm (measured) when subjected to a load equivalent to 41,400 kg. These data indicated that only 61 m of the tubing string were clear of the cement. On December 13, 1982, a measured volume of dye pumped into the well short circuited at 76 m, indicating a hole in the string at that depth. This was confirmed by pressurizing the well with nitrogen on the following day. The job was terminated, pending a plan to recover the well.

The problem was attacked from two directions: an engineering study and estimate to drill a new well within, or adjacent to, the well cell was initiated and the petroleum industry was consulted and requested to recommend a method for recovering the well. Preliminary estimates voided further consideration of a new well in terms of both time and money. The industry proposed and supported well recovery utilizing a drilling technique common to oil fields. The latter course was chosen because both the estimated cost and forecast elapsed time were compatible with ORNL project commitments. Consequently, contractural arrangements were completed with Tri-State Oil Tool Industries, Laurel, Mississippi, to provide field supervision and the equipment to rebore the well; Halliburton and ORNL forces did the work. ORNL was responsible for the overall operation.

The approach adopted for recovering the well included two phases. Phase 1 consisted of mechanically drilling the cement from the bore of the 7.3-cm-diam tubing string by using a rotary cement drill. This operation is termed "washout." Phase 2 consisted of mechanically drilling out the cement in the annulus between the 7.3-cm-diam tubing and the 14-cm-diam well casing by using a rotary "washover" shoe; this operation is termed "washover." The two-phase approach was adopted because initially there was an option, depending upon the condition of the well after Phase 1, that could be exercised to restore the well to service without proceeding to the second phase. This option would have consisted of explosively slotting the casing and, if necessary, the 7.3-cm-diam tubing after drilling it out. However, the condition of the 7.3-cm-diam tubing string (particularly after a 5.8-m separation was verified during washout of the tubing string) coupled with the highly questionable integrity at other elevations that was verified from TV viewing and dye-return tests essentially mandated proceeding to the washover second phase.

Tri-State and Halliburton arrived on site January 10, 1983. The NHF was rapidly converted into a drilling facility (Fig. 8 is a diagram of the process), and the washout or drilling of the 7.3-cm-diam tubing string began the same day. The work progressed satisfactorily, and on January 13, the

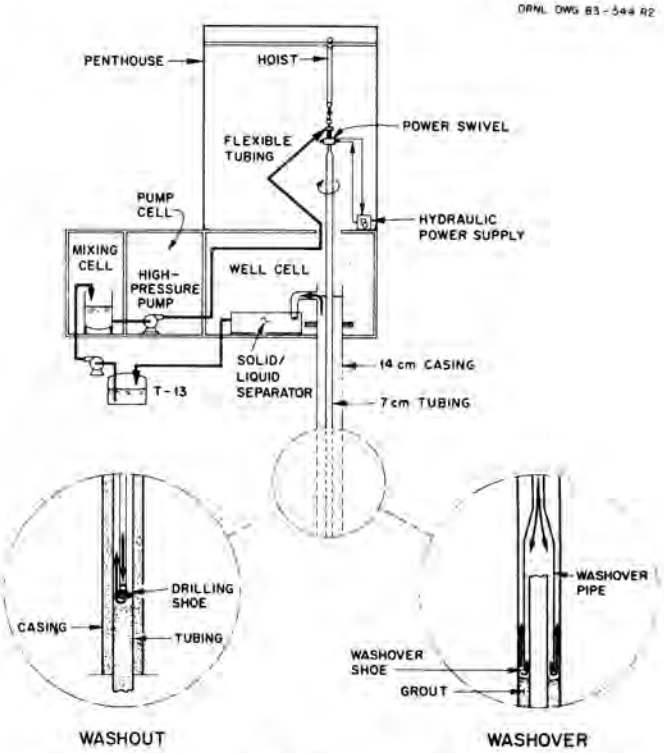

Fig. 8. Diagram of Washout and Washover Operation.

seating nipple at the bottom of the string was tagged at 329 m — 5.8 m lower than the length of the string; about 120 m of the tubing string had uncoupled at 153-m depth and fallen to the bottom of the hole. A gamma log of the well was run, and the washover phase of recovery was initiated.

The washover operations were characterized by hard work, frustration, and disappointment. The procedure involved freeing the tubing from the casing by milling the cement bond with a type of drill bit called a "washover shoe," severing the freed section with explosives and extracting it with a grapple tool. The NHF was not a straight borehole but deviated grossly from the center, as indicated in Table III. This hampered the operation because almost immediately the shoe was milling both casing and tubing as well as cement. The shoe's milling metal wore quickly, and trips into and out of the well multiplied as the well penetration increased. By the end of January, the washover operations had extracted only 45 m of tubing from the well, predominately in slivers and short sections 2.5 to 3.0 m in length.

TABLE III[5]

Summary of Injection Well Measurements

Hole Length (m)	Vertical Deviation[a]	Horizontal Distance Increment (m)
30.5	1° 45 min	0.93
61.0	4°	4.26
91.5	8°	12.73
122.0	9° 12 min	19.51
152.5	12°	31.71
183.0	9° 48 min	31.15
213.5	10° 36 min	38.91
244.0	21° 30 min	89.43
274.0	16°	75.53
305.0	16° 36 min	87.14
343.5	17° 18 min	102.15

Total Vertical Distance: 335.8 m

[a]Vertical deviation is the angle the well makes with the vertical at the bottom of the hole length.

The shoe finally breached the casing completely and drilled into the formation at 240-m depth. The job scope changed at this point — a 11.4-cm rotary rock drill was attached to the string, and it became a drilling operation. A new borehole was drilled to 264-m deep where the wall apparently collapsed, a coupling sheared, and 12 m of drilling tools were lost in the hole. Attempts to retrieve the tools proved fruitless; in fact, the string could not get past the 230-m level. Now the washover operation was resumed, the casing was again breached, and a hole was drilled into the formation to a depth of 238 m. At this point, the drilling operation was resumed, and a well was bored to 314-m depth. The job was completed March 6, 1983. Table IV is a summary of the washover operation.

The partially new, straight well was refitted with 7.3-cm Armco N-80 tubing, and an attempt was made to seal the annulus to the formation with cement by pumping a slurry down the hole and back up the annulus to the surface, but circulation was lost when the

TABLE IV

Washover Operation - Summary of Significant Events

Date	Well Depth (m)	Well Trip	Event
1/20/84	66	2	Start washover.
2/3/84	141	32	Remove six joints of tubing.
2/15/84	237	53	Section of tubing and casing removed.
2/17/84	241	57	Section of tubing and rock core removed.
2/18/84	252	60	Drilling new hole with rotary bit.
2/23/84	260	62	Drill string broke.
2/25/84	229	66	Segment of casing and shale recovered.
3/1/84	234	68	Drilling second hole.
3/6/84	310	69	Completed drilling.

annulus became plugged with drilling debris at approximately 107-m depth. A cementing shoe (check valve) installed at the bottom of the tubing prevented reverse circulation, and the tubing could not be flushed with water. The tubing was cemented in, top to bottom, and 107 m of clear annular space remained at the top of the well. The system was again rigged up for the washout operation, and the tubing was drilled free of cement and slotted with explosive charges. Normal operations were resumed in April 1983. Figure 9 is a drawing of the existing well.

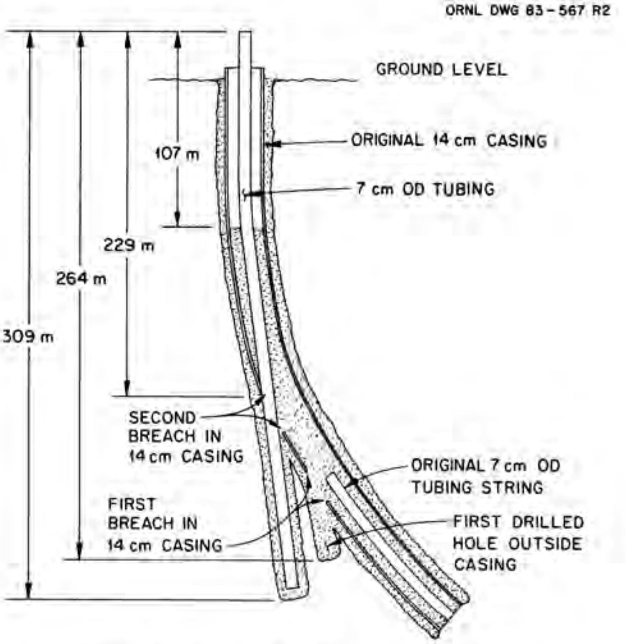

Fig. 9. Final Configuration of Well.

Disposal Operations Through January 1984

With the well operational, the NHF was now prepared for disposal work. Equipment items abused during the recovery (namely, the HT-400 transmission, the slotting circulation pump, and the 6800-kg hoist) were replaced. Electromagnetic flowmeters were installed in lieu of the maintenance-prone turbine devices; a larger, variable-speed agitator was installed in the mixing tub. The short annular section of the well was equipped with a pressure monitor, and it was isolated from the circulation manifold.

A bond log of the well was run - this assured the integrity of the cement seal. The well was slotted with explosives purchased from the Jet Research Center, Inc., and detonated by the Dia-Log Company who provided the wire-line vehicle and also ran the bond log. Three assemblies were fired before a fracture was finally achieved. The third shot employed a string of 14 perforating charges and a jet cutter which is a shaped charge designed to sever the tubing circumferentially. A combination of collar and jet cutters had been fired on the previous shots. The formation finally yielded at 49.6 MPa.

The injection (SI-4) was viewed with some concern because both the solids and slurry had been in storage for more than three months. But it proved to be an ordinary operation with relatively low flow rates and some delays caused by a sometimes recalcitrant solids delivery system.

A monthly regime was then established. The work became methodical and repetitive, the outcome predictable. The operating upsets were minimal — confined to the solids delivery system and the fluid viscosity, they were handled proficiently as encountered. A problem developed with the HT-400 pump transmission late in the year, and a spare rebuilt unit was installed. This was a matter of concern because this unit had been replaced in April. The work continued through the end of the year without incident.

The final injection of the series was completed on January 27, 1984. It was a two-phase operation which disposed of the "tails" of GTSR and the LLW concentrate which this system had accumulated during the year. Two types of blended solids were required. This was handled by scheduling. A routine disposal operation ensued which was terminated by plugging the slot with cement, rendering the plant into a standby condition.

Table V is a summary of the disposal work that was completed at the New Hydrofracture Facility.

REFERENCES

1. W. DeLaguna et al., Engineering Development Hydraulic Fracturing as a Method of Permanent Disposal of Radioactive Wastes, ORNL-4259 (August 1968).

2. W. DeLaguna, Radioactive Waste Disposal by Hydraulic Fracturing, ORNL/CF-70-3-17 (March 1970).

3. R. E. Lampton et al., Conceptual Design Report, New Hydrofracture Facility, ORNL/TM-4826 (July 1985).

4. Title 1 Report, New Hydrofracture Facility, Contract No. EW-78-C-05-5677, Project No. 78-18-d, (May 1978).

5. H. O. Weeren et al., Hydrofracture Proof Study at Oak Ridge National Laboratory, ORNL/TM-4713 (November 1974).

6. H. O. Weeren, Sluicing Operations at Gunite Waste Storage Tanks, ORNL/NFW-84/42 (September 1984).

7. H. O. Weeren et al., Recovery of the Injection Well at the New Hydrofracture Facility ORNL/TM-8823 (April 1984).

TABLE V

Summary of Injections Made at the New Hydrofracture Facility

Injection[a]	Date	Waste Volume (m^3)	Grout Volume (m^3)	Activity Injected (Ci)				
				TRU	^{244}Cm	^{90}Sr	^{137}Cs	Other Emitters
ILW-19	6/16-17/82	605.6	863.0	2	5	156	17,330	347
SI-1	8/10-15/82	726.7	1,192.0	72	710	28,500	5,500	2,000
SI-2	9/23-24/82	439.1	582.9	73		57,200	4,800	1,400
SI-3	10/26-29/82	938.7	1,169.0	290	510	61,000	4,100	1,800
SI-4	4/8-10/83	734.3	923.5	130	96	11,000	450	230
SI-5	5/17-18/83	598.0	620.7	65	76	7,200	410	160
ILW-20	6/14-15/83	420.1	586.7	14	53	3,266	7,140	627
SI-6	7/12-14/83	772.1	947.8	240	1,060	67,553	2,750	930
SI-7	8/9-10/83	616.6	718.4	84	220	21,630	2,585	160
SI-8	10/25-26/83	741.9	916.0	357	2,980	217,400	14,800	3,400
SI-9	12/1-2/83	721.4	903.1	404	920	125,000	16,200	990
SI-10	1/25-27/84	700.2	946.3	375	763	41,100	5,600	760
ILW-21	1/27-28/84	461.8	605.6	19	71	3,500	2,100	510
TOTALS		8,476.5	10,875.9	2,125	7,464	644,505	83,765	13,314

[a]The liquid waste stream disposed at the Hydrofracture Facility was called intermediate level waste or ILW until 1984, when the terminology was changed to low-level waste or LLW to be consistent with the definitions in 10 CFR 61. The injection designations ILW-19, ILW-20, and ILW-21 have not been changed to reflect this terminology change.