ORNL/M--5307/V2

**Remedial Site Evaluation Report
for the Waste Area Grouping 10 Wells
Associated with the New Hydrofracture Facility
at Oak Ridge National Laboratory,
Oak Ridge, Tennessee**

Volume 2: Field Activities and Well Summaries

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Energy Systems Environmental Restoration Program

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Date Issued—August 1996

Prepared by
Bechtel National, Inc./CH2M Hill/OGDEN/PEER
Oak Ridge, Tennessee
under subcontract 30B-99053C

Prepared for the
U.S. Department of Energy
Office of Environmental Management
under budget and reporting code EW 20

Environmental Management Activities at
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6285
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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PREFACE

This document, *Remedial Site Evaluation Report for the Waste Area Grouping 10 Wells Associated with the New Hydrofracture Facility at Oak Ridge National Laboratory, Oak Ridge, Tennessee, Volume 2: Field Activities and Well Summaries*, DOE/OR/01-1471/V2&D1, was prepared in accordance with requirements under the Comprehensive Environmental Response, Compensation, and Liability Act for reporting the results of a site evaluation for review. This work was performed under Work Breakdown Structure 1.4.12.6.1.10.4 (Activity Data Sheet 3310, WAG 10). Publication of this document meets a Task Work Agreement amended milestone of May 28, 1996. This document provides the Environmental Restoration Program with information about the results of an evaluation of WAG 10 wells associated with the New Hydrofracture Facility at Oak Ridge National Laboratory. Information provided in this document forms the basis for decisions regarding the need for subsequent action at WAG 10.

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ABBREVIATIONS

bgs	below ground surface
cps	counts per second
CSL	Close Support Laboratory
DM	deep monitoring
EDS	energy-dispersive x ray analyzer system
EMI	external mechanical integrity
HF-1	Hydrofracture Experiment Site 1
HF-2	Hydrofracture Experiment Site 2
HF-3	Old Hydrofracture Facility
HF-4	New Hydrofracture Facility
ID	inside diameter
MCL	maximum contaminant level
NHF	New Hydrofracture Facility
OHF	Old Hydrofracture Facility
ORNL	Oak Ridge National Laboratory
P&A	plugging and abandonment
SDWA	Safe Drinking Water Act
SEM	scanning electron microscopy
SP	spontaneous potential
SPR	single-point resistivity
TD	total depth
TDS	total dissolved solids
VDL	variable density log
WAG	waste area grouping

EXECUTIVE SUMMARY

Four hydrofracture sites at the Oak Ridge National Laboratory in Oak Ridge, Tennessee, were used for development, demonstration, and full-scale disposal operations from 1959 to 1984:

- HF-1, Hydrofracture Experiment Site (also known as the 4-acre site), and HF-2, Hydrofracture Experiment Site, demonstrated the hydrofracture concept.
- HF-3, the Old Hydrofracture Facility (OHF) conducted pilot-scale testing followed by operational waste disposal.
- HF-4, the New Hydrofracture Facility (NHF), operated and was designed as a full-scale disposal system for liquid low-level waste and tank sludge.

More than 50,000 yd³ (10.1 million gal) of waste grout mix containing approximately 1.4 million Ci of radioactivity was disposed of via hydrofracture through a series of 43 injections at HF-3 and HF-4. Various types of wells installed to monitor the performance of hydrofracture operations compose Waste Area Grouping (WAG) 10, Wells and Boreholes. Disposal activities were discontinued at NHF in 1984.

The primary goal of this remedial site evaluation was to gain sufficient data about the wells associated with NHF activities to recommend the type and best method of final disposition [plugging and abandonment (P&A)] for the wells. To meet this goal, a full suite of borehole geophysical logs (mechanical, electrical, nuclear, temperature, resistivity, and acoustic) was run in the wells to:

- determine the well casing bond and casing integrity,
- confirm and extract construction details for each well,
- evaluate the extent of contamination sourced from the NHF grout sheets,
- assist in planning for future P&A activities at NHF, and
- determine the suitability of the wells for future temporary site monitoring.

The secondary goals were to determine the stratigraphic position of the rock cover, deep monitoring, and observation wells; the subsurface stratigraphy at NHF; and identify possible artificially induced or natural pathways for the spread of contaminants from hydrofracture activities. Screening-level geochemical characterization of the wellbore water was performed to support the primary and secondary goals and the management of wastes generated during future P&A activities.

This study investigated and evaluated 21 NHF wells. Of those, one well (Well 1970) was not accessible because of small-diameter tubing, but it was evaluated based on a review of historical reports and data. Another well (Well 1972) was sampled but could not be logged because of a bent well riser. Investigation of Injection Well 1968 was not within the scope of this task.

All 21 wells were ranked along with the 25 wells previously studied at OHF to establish a priority for future hydrofracture well P&A activities. All wells were compared with each other but were not evaluated relative to quantitative human health or ecological risk criteria. Six of the NHF wells (2954, 1970, 1972, 1978, 1975, and 2955) received the highest rankings (9) and should be plugged and abandoned as soon as possible.

Five of the NHF wells (1969, 1973, 1974, 2952, and 2375) provide an opportunity for retrofitting and temporary sampling/pressure monitoring at the hydrofracture site; these wells have openhole intervals that cover the Rogersville Shale, Rutledge Limestone, and upper Pumpkin Valley Shale (injection zone).

Geologic cross sections were constructed for the NHF area, using newly acquired geophysical data and historic information, and tied to the OHF site. Interpretations of these and other acquired data reveal that several mechanisms have been active in the spread of radioactive contaminants associated with NHF operations. These are as follows.

- A highly contaminated filtrate plume surrounds the grout sheets within the injection horizon. New gamma ray peaks show evidence that this plume has migrated since the close of operations at NHF. The plume extends < 1000 ft to the north and > 1000 ft to the east and west of the injection well. The extent of contamination to the south, east, and west are unknown. No natural surface expression is known.
- All of the observation wells that penetrate the injection interval were intercepted by grout sheets during NHF operations and are contaminated with grout and/or grout filtrate (aqueous radionuclides). The NHF observation wells provide a potential pathway for migration of contaminants.
- Minor radiological contamination is present in the units that overlie the injection horizon (Rogersville Shale/Rutledge Limestone). Radiological contamination in the rock cover wells is likely due to upward migration from the injection zone and past cross contamination.
- Radiological contamination in the standing water column in deep monitoring wells (2373 and 2374) penetrating into the Rome Formation is "relic" and does not represent downward migration from the grout sheets.
- Most of the wellbores (with the exception of the NHF observation wells) provide a pathway for the upsection migration of high-salinity natural brine.
- Pressurized conditions were encountered in several wells that were intercepted by the grout sheets. The existence of pressure in the injection horizon provides the gradient necessary to create a dynamic groundwater flow system, thereby facilitating migration of contaminants.

The objectives of the P&A options analysis were to select the best method of:

- protecting health, safety, and the environment;
- protecting the shallow freshwater zone (upper Maryville Limestone) and the underlying highly saline zone (Rome Formation);
- isolating the injection horizon (upper Pumpkin Valley Shale); and
- minimizing exposure risks, waste generation, and costs from P&A operations.

These objectives were satisfied by using the same P&A technical approach as used for the study of OHF-associated wells. The approach is summarized below.

For cased wells with external mechanical integrity (EMI) and no evidence of flow behind casing, the preferred P&A approach is to leave the well casing in place and fill the entire well in stages with cement. Hydraulic pressure will be applied as needed to force or "squeeze" the cement slurry into formation voids and around casing shoes. The well casing will be pressure-tested to check casing integrity before this method is used to P&A a well.

For those cased wells that do not have EMI or for which EMI cannot be confirmed, the preferred P&A approach depends primarily on the well casing inside diameter. If the diameter is large enough (> 2.5 in.) to accept standard P&A tools and equipment, the casing and grout sheath will be perforated (by mechanical, explosive, or hydro-jetting) or milled out above the injection zone (if penetrated), at the base of the shallow freshwater zone, and above the formation underlying the injection zone (if penetrated), and cement will be squeezed into the perforations or milled-out window to form isolation plugs. The intervals below, between, and above the isolation plugs will also be filled with cement.

If the casing diameter is too small (< 2.5 in.), the well will be cemented up to the base of the shallow freshwater zone, and then the casing and annular grout seal above the cement plug will be removed using washover or milling techniques. The newly formed openhole interval created by washover or milling will be filled with cement.

This general approach was used to develop more detailed P&A descriptions for the 21 WAG 10 NHF wells according to the unique characteristics of each well. The refined approaches were then used to develop generated waste volume and cost estimates.

1. CHARACTERIZATION ACTIVITIES

1.1 WELL TYPE DESCRIPTIONS

Three types of wells were constructed around the New Hydrofracture Facility (NHF): deep monitoring (DM) wells, observation wells, and rock cover wells. The well locations are shown in Fig. 1.1, and Table 1.1 lists the NHF well types. The following is a description of the well types.

DM Wells. In June 1984, three DM wells (2373, 2374, and 2375) were installed to depths exceeding 1,100 ft. A fourth borehole (2953) was drilled but was abandoned before casing was installed. The wells are approximately 1,000 ft of the NHF injection well (1968). These wells were cased to 550 ft below ground surface (bgs) and were open to total depth (TD) of the well, leaving as many as five different formations in communication.

Initial groundwater sample collection identified radionuclide contamination in Wells 2373 and 2374. In June 1985, an attempt was made to isolate distinct zones (specifically the Pumpkin Valley Shale injection zone) using inflatable packers in Well 2375. The main objective was to obtain additional hydrologic information needed to characterize the hydrology near the hydrofracture facility. The attempted isolation of a specific zone using inflatable packers failed; therefore, the decision was made to drill additional DM wells and recompleting the initial three DM wells and the abandoned borehole. The main objective was to isolate the injection formation and the underlying and overlying formations allowing for radiological and geochemical sampling, and hydraulic testing of each discrete zone. The additional drilling and retrofitting was completed in January 1986.

Observation Wells. Observation wells (1970, 1972, 1977, and 1982) were installed around the NHF in 1973. Observation Wells 1975 and 1978 were installed in 1980. These wells are cased with 2 $\frac{7}{8}$ -in. inside diameter (ID) tubing to TD through the injection horizon (Pumpkin Valley Shale) and some of the wells penetrate into the Rome Formation. Small-diameter (1.25 in. ID) tubing is installed in one of the observation wells (1970). No reports or data was located that would indicate that the water in the observation wells was sampled and analyzed prior to the start of injection operations.

The observation wells were used to establish the approximate vertical and horizontal position of the grout sheets after NHF waste injections. These wells were not designed to be open to the formation water and were used to provide downhole gamma log access to the injection horizon. Typically, borehole bottom depths range from 986 ft to 1,200 ft msl.

Rock Cover Wells. Eight rock cover wells (1969, 1971, 1973, 1974, 1976, 1979, 1980, and 1981) were installed in 1980 and have openhole intervals in the Rogersville Shale and/or Rutledge Limestone above the injection horizon. These wells are constructed with 4-in. ID carbon steel casing cemented to approximately 500 ft. A 3-in. diameter open borehole was then extended approximately 100 ft to a total borehole depth of approximately 600 ft. Actual bottom borehole depths range from 580 ft to 700 ft msl. These wells were designed to monitor pressure and permeability changes in the overlying units during injections at NHF.

No historical records or reports could be located that would indicate that water from these wells was sampled prior to injection operations at NHF.

Fig. 1.1. Aerial view of hydrofracture operations and related wells.

Table 1.1. WAG 10 NHF well construction details

Station	Alias	Northing	Easting	GS Elev. (ft msl)	Riser Casing			Borehole Depth (ft)	Formation at Total Depth	Open Interval	Installation Date
					ID (in.)	Material	Depth (ft)				
Rock Cover Wells											
1969	4E-200RC	28376.61	16487.09	788.59	4	C.Steel	550	650	ert	erg, ert	1980
1971	4N-200RC	28168.74	16716.33	767.99	4	C.Steel	480	580 ^a	ert	erg, ert	1980
1973	4NE-280RC	28434.92	16661.52	764.77	4	C.Steel	480	582	ert	erg, ert	1980
1974	4NW-340RC	27884.13	16695.8	769.33	4	C.Steel	480	580	erg	erg	1980
1976	4S-200RC	28204.99	16305.45	800.51	4	C.Steel	600	700	ert	erg, ert	1980
1979	4SE-280RC	28382.46	16303.52	814.18	4	C.Steel	600	700	ert	erg, ert	1980
1980	4SW-280RC	27922.1	16372.21	785.23	4	C.Steel	600	700	ert	ert	1980
1981	4W-190RC	27984.56	16472.85	783.28	4	C.Steel	550	650 ^b	ert	erg, ert	1980
Observation Wells											
1970 ^c	4E-200W	28374.93	16505.15	787.89	1.25	C.Steel	1135	1135	er	--	1973
1972	4N-200W	28175.75	16705.16	768.17	2.88	C.Steel	1120	1120	er	--	1973
1975	4NW-400W	27909	16703.7	770.34	2.88	C.Steel	986	986	lepv	--	1980
1977	4S-200W	28176.23	16306.72	799.09	2.88	C.Steel	1102	1200	lepv	--	1973
1978	4SE-125W	28304.7	16447.69	786.78	4	C.Steel	1145	1145	er	--	1980
1982	4W-200W	27975.23	16504.8	782.63	2.88	C.Steel	1107	1152	er	--	1973
Deep Monitoring Wells											
2373	DM1-RM	29219.51	16645.54	765.42	4	C.Steel	1092	1149 ^d	er	er	1985
2374	DM2-RM	27075.2	16456.59	757.78	4	C.Steel	1084	1275 ^e	er	lepv,er	1985
2375	DM3A-PV	27311.94	17413.8	768.89	6	C.Steel	550	910 ^f	uepv	ert,uepv	1985
2952	DM1-RT	29238.29	16649.77	765.52	6	C.Steel	615	721	ert	ert	1985
2953	DM3-RT	27214.53	16983.95	753.51	4	C.Steel	552	615	ert	ert	1985
2954 ^g	DM1-PV	29227.37	16664.37	765.45	6	C.Steel	750	1063	lepv	uepv,lepv	1985
2955 ^g	DM2-PV	27091.44	16469.95	758.54	6	C.Steel	750	1063	lepv	uepv,lepv	1985

Note:

- Data gathered from various sources.
- a. Geophones and sand installed up to a depth of 410 ft bgs in well 1971.
- b. Geophones and sand installed up to a depth of 528 ft bgs in well 1981.
- c. Well 1970 is a small diameter well (1.25 ID) and was not geophysically logged or sampled.

- d. DM1-RM was drilled to 1487' and then plugged back to 1149' with grout.
- e. DM2-RM was drilled to 1505' and then plugged back to 1275' with grout.
- f. DM3A-PV was drilled to 1166' and then plugged back to 910' with grout.
- g. Buildings 7802C and 7802D are installed over top of wells 2954 (DM1-PV) and 2955 (DM2-PV), respectively.

1.2 FIELD ACTIVITIES

Within Waste Area Grouping (WAG) 10, 21 wells associated with the NHF operations were selected for investigation, characterization, and evaluation. The field activities performed included tapping potentially pressurized wells, performing sampling and analysis of the water column in each well, collecting water levels, and performing geophysical logging of each well. Modifications were made to each wellhead as part of the field activities.

1.2.1 Well Tapping

Prior to tapping, all wellheads were located and inspected to determine if modifications would be necessary to obtain unimpeded access. A field survey was then performed within the immediate area of each wellhead to identify any radiological, chemical, or work hazards. Once conditions were identified, a survey was performed on all 21 wells associated with the NHF. The scope of the survey included the following activities for each well:

- producing a detailed sketch of existing well conditions (to include pipe dimensions),
- photographing pre-existing wellhead configurations,
- tagging each well with stainless steel ID label, and
- establishing a vertical control point for all reference measurements.

The results of the survey were used to support planned tapping, sampling, and geophysical logging activities.

The goal of the tapping procedures was to safely open the closed, potentially pressurized wells so the water column inside the well could be safely sampled and geophysical logging could be performed. A specially designed pressure-rated tapping mechanism was used to bore a small hole in the existing wellhead riser and measure the pressure inside the well. The tapping mechanism was designed to contain pressures up to 125 psig and divert any momentary flow of gases greater than 125 psig through a high-efficiency particulate air, activated charcoal, and desiccant filter system to remove potential airborne radionuclides, including tritium and other gasses.

A pressure-rated saddle was attached to the wellhead, and the tapping apparatus was attached to the saddle. Nitrogen gas was introduced into the system (at 100 psi), and a soap solution was used to check for leaks at joints on the tapping apparatus. After tapping, the tapping mechanism was left on the well to measure the pressure and the lower explosive limit inside the well. If a high lower explosive limit was observed, the headspace gases were displaced with nitrogen gas until the headspace was less than 5 percent of the lower explosive limit. If a positive pressure was detected, the headspace was vented through the filter system. Pressure was monitored in the well for a minimum of 48 hours. If there was no positive pressure after 48 hours, the well was opened.

The pressure and water levels of each well at tapping are listed in Table 1.2. After the wells were tapped, the wellheads were modified as needed to allow for well water sampling, geophysical logging, and for containment of artesian or potentially pressurized systems.

Table 1.2. WAG 10 well tap pressures and water levels

Station	Alias	Date of Tapping	Riser Pressure (psig)	Annulus Pressure (psig)	Water Level Depth ^a (ft bgs ^b)	Comments
Rock Cover Wells						
1969	4E-200RC	6/13/95	0.0	--	70.84	Existing riser was vented. Water level measured on 6/27/95.
1971	4N-200RC	6/12/95	0.0	--	37.50	
1973	4NE-280RC	7/17/95	0.0	--	52.80	
1974	4NW-340RC	--	--	--	20.16	
1976	4S-200RC	6/8/95	0.0	--	80.01	Existing riser was vented. Existing riser was vented.
1979	4SE-280RC	6/14/95	0.0	--	96.91	
1980	4SW-280RC	--	--	--	16.20	
1981	4W-190RC	--	--	--	27.38	
Observation Wells						
1970	4E-200W	6/13/95	7.2	--	+0.66	Water level measured on 7/5/95.
1972	4N-200W	6/13/95	0.0	--	6.49	
1975	4NW-400W	6/27/95	0.0	--	+0.15	
1977	4S-200W	6/12/95	0.0	--	3.50	
1978	4SE-125W	6/14/95	0.0	--	+2.78	
1982	4W-200W	7/24/95	0.0	--	10.61	
Deep Monitoring Wells						
2373	DM1-RM	8/8/95	1.0	0.0	--	Well is artesian.
2374	DM2-RM	7/25/95	0.0	0.0	135.11	
2375	DM3A-PV	8/1/95	--	1.1	--	Existing tubing was vented. Water level measured on 9/6/95.
2952	DM1-RT	8/8/95	0.0	0.0	161.36	
2953	DM3-RT	8/2/95	0.0	0.0	39.90	Water level measured on 9/6/95. Well is artesian.
2954	DM1-PV	8/7/95	26.2	--	--	
2955	DM2-PV	7/25/95	12.2	--	--	

Notes: *a* Column represents the water level measured immediately after tapping. If water level was not measured on the tap date, then the initial water level is given. A "+" indicates water level is above ground surface.

b below ground surface

1.2.2 Well Sampling

The main objective of the well sampling was to collect grab samples of the standing water column at up to three depths within each of the 21 WAG 10 wells associated with the NHF. The resulting analytical data was used to support geophysical logging and to develop and evaluate an appropriate range of waste management options regarding the types and concentrations of chemical and/or radiological components in the well water that must be considered prior to plugging and abandonment (P&A) or reclamation of the wells.

All of the WAG 10 wells associated with the NHF were sampled except for Well1970. Upon tapping of Well1970, 1.25-in. ID tubing was discovered inside the well, which precluded use of the downhole sampling device. Historical records did not indicate that this well was finished with nonstandard small-diameter tubing.

Wellbore water was sampled at a depth of approximately 25 ft from the water surface, in the middle of the water column, and 25 ft above the bottom of the standing water column in each well. Samples were obtained using a Comprobe™ downhole wireline sampling device, which performed well in obtaining grab samples at depth but was not designed to maintain hydrostatic pressure during withdrawal of the sampler or during transfer of samples. A Teflon® hand bailer was used to obtain the top shallow grab samples because significant water pressure is required to fill the wireline sampler within a reasonable time frame. Field parameters were measured for each sample collected (Table 1.3). Quality control samples were collected at a frequency of 1 set (field filling blank, equipment rinsate and duplicate) per 20 regular samples. A quality control trip blank accompanied each sample kit.

Table 1.3. Field measurements and Close Support Laboratory analytes

Field Measurements	CSL Analytes
pH	Gas chromatography (GC) (halogenated and double-bonded volatile organic compounds)
Eh	
Temperature	
Specific Conductance	Anions
Alpha, Beta-gamma screened w/field instruments	Cations
	Gross Alpha
	Gross Beta
	Tritium
	Gamma spectroscopy
	Strontium-90
	Total alkalinity (CaCO ₃)
	Total suspended solids
	Total dissolved solids (TDS)

The sample analyses performed by the Close Support Laboratory (CSL) are listed in Table 1.3. Based on CSL analysis, Wells 2954 and 2955 were identified as "most contaminated" and, therefore, selected for further analysis using Contract Laboratory Programs methods for Target Compound List and Target Analyte List analytes.

Table 1.4 provides a summary of the samples and field parameters collected from the NHF wells. A total of 60 CSL samples (3 samples from 20 wells), 12 quality control samples (4 equipment rinsates, 4 field filling blanks, and 4 duplicates), and 2 offsite laboratory Target Compound List/Target Analyte List environmental samples were collected to support the investigation. One trip blank accompanied each sample.

1.2.3 Well Logging

The Geology, Geophysics, and Geochemistry Group of Lockheed Martin Energy Systems, Inc., Oak Ridge National Laboratory (ORNL) Environmental Sciences Division assisted ORNL Environmental Restoration and the Bechtel National, Inc., team with completing the geophysical logging of wells associated with the NHF.

Nineteen of the 21 wells at NHF were geophysically logged to evaluate well condition and identify well construction detail, contaminated grout sheet intersects, borehole contamination and petrophysical characteristics of the rock units. Well 1972 has a bent section of riser casing just below ground surface, which prevented access of the logging probes. Well 1970 is constructed with 1.25-in. ID tubing, which also would not accommodate logging equipment.

Wells were logged from cleanest to most contaminated based on review of historical data and CSL results from radioactive analyses of borehole water. Two sets of logging equipment were used (one clean and one with fixed contamination). The logging equipment that was fixed with contamination was used if the activity on the tools and/or support cable was less than the activity in the well to be logged based on the groundwater sampling results. Downhole logging probes and cables were wiped down as they were retrieved from each well to minimize the cross contamination of wells. Table 1.5 identifies types of geophysical logs obtained from NHF associated wells.

Table 1.4. NHF well sampling and field parameters summary

Well	Sample	Sample	Sample	Sample	Field Parameters				
					Specific				
Rock Cover Wells									
1969	7/5/95	04958	96	693	20.9	6.00	3	149,400	Teflon® Bailer
(4E-200RC) ¹	7/6/95	04959	339	450	24.2	5.69	108	156,200	2 1/8-in. Comprobe Wireline Sampler
	7/7/95	04960	625	164	18.0	5.12	80	173,000	2 1/8-in. Comprobe Wireline Sampler
1971	6/19/95	04901	62	706	19.9	5.48	-55	168,600	Teflon® Bailer
(4N-200RC)	6/19/95	04902	261	507	18.9	5.70	-25	178,000	2 1/8-in. Comprobe Wireline Sampler
	6/20/95	04903	387	381	18.3	5.58	-6	180,000	2 1/8-in. Comprobe Wireline Sampler
1973	7/17/95	04969	76	689	19.1	6.76	7	101,200	Teflon® Bailer
(4NE-280RC)	7/19/95	04970	317	448	18.2			166,600	2 1/8-in. Comprobe Wireline Sampler
	7/19/95	04973	557	208	20.4			175,000	2 1/8-in. Comprobe Wireline Sampler
1974	7/7/95	04962	45	724	18.2	7.39	-156	152,000	Teflon® Bailer
(4NW-340RC)	7/7/95	04963	300	469	19.8	6.22	10	152,700	2 1/8-in. Comprobe Wireline Sampler
	7/10/95	04961	555	214	21.6	5.04	53	159,200	2 1/8-in. Comprobe Wireline Sampler
1976	6/22/95	04907	105	696	16.7	6.16	-36	56,100	Teflon® Bailer
(4S-200RC)	6/22/95	04908	390	411	29.5	5.37	10	180,000	2 1/8-in. Comprobe Wireline Sampler
	6/27/95	04910	674	127	22.1	5.36	62	183,500	2 1/8-in. Comprobe Wireline Sampler
1979	6/29/95	04915	122	692	19.9	6.52	19	79,500	Teflon® Bailer
(4SE-280RC)	6/29/95	04956	398	416	21.9	5.97	64	163,500	2 1/8-in. Comprobe Wireline Sampler
	7/5/95	04957	675	139	21.4	5.54	111	177,700	2 1/8-in. Comprobe Wireline Sampler
1980	6/28/95	04911	41	744	18.6	6.68	-199	165,900	Teflon® Bailer
(4SW-280RC)	6/28/95	04912	358	427	22.2	5.65	26	186,400	2 1/8-in. Comprobe Wireline Sampler
	6/29/95	04914	675	110	20.6	4.09	91	192,400	2 1/8-in. Comprobe Wireline Sampler
1981	7/26/95	04977	52	731	20.1	7.46	-141	189,700	Teflon® Bailer
(4W-190RC)	7/26/95	04980	339	444	24.3	6.06	58	172,200	2 1/8-in. Comprobe Wireline Sampler
	7/26/95	04981	510	273	18.6	5.94	98	197,900	2 1/8-in. Comprobe Wireline Sampler
Observation Wells									
1972	11/1/95	05020	32	736	16.5	10.50	148	171	Teflon® Bailer
(4N-200W)	11/1/95	05021	563	205	16.5	11.23	66	347	1 1/4-in. Comprobe Wireline Sampler
	11/1/95	05022	1050	-282	16.7	11.58	14	1,420	1 1/4-in. Comprobe Wireline Sampler
1975	7/11/95	04964	25	745	20.4	10.18	105	495	Teflon® Bailer
(4NW-400W)	7/12/95	04965	493	277	23.8	9.73	132	502	2 1/8-in. Comprobe Wireline Sampler
	7/12/95	04966	887	-117	28.1	12.57	-6	115,700	2 1/8-in. Comprobe Wireline Sampler
1977	6/20/95	04904	29	770	20.2	8.69	36	202	Teflon® Bailer
(4S-200W)	6/21/95	04906	256	543	18.4	11.28	49	463	2 1/8-in. Comprobe Wireline Sampler
	6/21/95	04905	483	316	19.4	11.00	68	472	2 1/8-in. Comprobe Wireline Sampler

Table 1.4 (continued)

Well	Sample	Sample	Sample	Sample	Field Parameters					Specific	
1978 (4SE-125W)	7/20/95	04974	22	765	19.6	8.89			140	Teflon® Bailer	
	7/20/95	04975	571	216	25.3	11.44	-12		1,262	2 1/8-in. Comprobe Wireline Sampler	
	7/21/95	04976	1120	-333	24.3	12.29	-44		32,200	2 1/8-in. Comprobe Wireline Sampler	
1982 (4W-200W)	7/27/95	04982	36	747	18.5	11.38	4		760	Teflon® Bailer	
	7/31/95	04983	581	202	19.9	12.11	96		2,330	2 1/8-in. Comprobe Wireline Sampler	
	7/31/95	04984	1094	-311	25.6	11.86	88		2,900	2 1/8-in. Comprobe Wireline Sampler	
Deep Monitoring Wells											
2373 (DM1-RM)	10/23/95	04997	123	642	13.3	8.49	-320		174,300	Teflon® Bailer	
	10/23/95	05008	624	141	18.2	7.82	112		180,900	2 1/8-in. Comprobe Wireline Sampler	
	10/23/95	05009	1124	-359	20.9	11.10	-244		105,800	2 1/8-in. Comprobe Wireline Sampler	
2374 (DM2-RM)	10/26/95	05017	262	496	17.9	7.59	85		121,400	2 1/8-in. Comprobe Wireline Sampler	
	10/26/95	05018	756	2	18.8	6.53	-48		219,000	2 1/8-in. Comprobe Wireline Sampler	
	10/26/95	05019	1245	-487	18.1	6.16	-58		226,000	2 1/8-in. Comprobe Wireline Sampler	
2375 (DM3A-PV)	10/24/95	05010	52	717	15.2	8.45	-87		37,100	Teflon® Bailer	
	10/24/95	05011	469	300	16.2	6.86	-49		35,700	2 1/8-in. Comprobe Wireline Sampler	
	10/24/95	05012	880	-111	16.0	6.51	-58		84,100	2 1/8 in. Comprobe Wireline Sampler	
2952 (DM1-RT)	10/18/95	04994	200	566	17.7	11.26	35		23,800	Teflon® Bailer	
	10/19/95	04995	449	317	14.7	6.06	79		190,500	2 1/8-in. Comprobe Wireline Sampler	
	10/19/95	04996	696	70	20.1	5.55	119		191,500	2 1/8-in. Comprobe Wireline Sampler	
2953 (DM3-RT)	10/25/95	05013	65	689	12.9	7.67	-340		152,500	Teflon® Bailer	
	10/25/95	05014	328	426	13.7	6.35	-11		160,600	2 1/8-in. Comprobe Wireline Sampler	
	10/25/95	05015	580	174	14.9	5.53	22		164,400	2 1/8-in. Comprobe Wireline Sampler	
2954 (DM1-PV)	8/9/95	04989	60	705	19.3	9.26	141		208,000	2 1/8-in. Comprobe Wireline Sampler	
	8/9/95	04993	569	196	23.8	9.05	237		206,000	2 1/8-in. Comprobe Wireline Sampler	
	10/31/95	05027*	1018	-253	17.5	6.12	118		224,000	2 1/8-in. Comprobe Wireline Sampler	
	8/9/95	04992	1038	-273	28.1	8.12	47		200,000	2 1/8-in. Comprobe Wireline Sampler	
2955 (DM2-PV)	8/3/95	04985	32	727	19.1	9.00	-30		224,000	Teflon® Bailer	
	8/3/95	04986	535	224	23.6	7.79	106		222,000	2 1/8-in. Comprobe Wireline Sampler	
	8/3/95	04988	1038	-279	27.2	7.40	110		220,000	2 1/8-in. Comprobe Wireline Sampler	
	10/30/95	05006*	1040	-281	17.8	7.56	108			2 1/8-in. Comprobe Wireline Sampler	

*Samples 05027 and 05006 were selected for offsite laboratory TCL/TAL analysis.

Table 1.5. WAG 10 borehole geophysical logs run for wells associated with the NHF

Sonde	Geophysical Logs Run
Sonde 127 and 131	Fluid temperature log
	Fluid resistivity log
Sonde 125	Natural gamma log
	Caliper log
	Spontaneous potential (SP) log
Sonde 111	Sonic log
	Velocity log
	Variable density log (VDL)
Sonde 101	Neutron log
	Caliper log
Sonde 102	4-Pi density log
	Single-point-resistance (SPR) log
Sonde 129	Dual detector density log
Sonde 123	Borehole deviation log

1.2.4 Packer and Tubing Removal

Five of the seven DM wells [2373 (DM1-RM), 2374 (DM2-RM), 2375 (DM3A-PV), 2953 (DM3-RT), and 2954 (DM1-PV)] required removal of existing tubing, packer retrofits, and pressure monitoring equipment to allow well water sampling and borehole geophysical logging. Equipment removed from each well included 2 $\frac{7}{8}$ -in. ID carbon steel tubing, a J-Type well packer, landing nipple, pressure transducer, and steel transducer cable. The transducer cable was connected to the transducer and ran vertically along the outside of the tubing (attached with tape) up to the ground surface. A general schematic of the transducer/packer assembly is shown in Fig. 1.2.

A mobile drill rig was used to unseat the packer and lift the tubing assembly from the borehole. None of the landing nipples were plugged, so the water contained in the tubing was not brought to the surface. Tubing identified as contaminated using field monitoring instrumentation was sleeved in plastic for health and safety control during processing activities. After removal from the well, the tubing was cut in small sections (< 6 ft lengths) and stored in B-25 boxes before final disposition by ORNL. The transducer cable was coiled into a 55-gal drum as temporary storage.

1.2.5 Wellhead Modifications and Completion Activities

During the investigative activities (tapping, sampling, and logging), each wellhead was modified to increase accessibility. Wells that had the potential for becoming pressurized were fitted with wellhead configurations that could be controlled and monitored through gate and ball valves. Wells not under pressure and exhibiting static water levels consistently greater than 10 ft below ground surface were left open (vented) with locking aluminum caps. Figure 1.3 is a typical schematic of both types of wellhead configurations.

At the conclusion of intrusive activities, a detailed as-built sketch was drawn for each wellhead modification. Each well was also surveyed for vertical and horizontal controls (Table 1.6), photographed with scale, and primed and painted yellow to maintain casing integrity prior to future implementation of P&A activities. If P&A activities are delayed, the wells should be placed on a routine maintenance schedule.

Fig. 1.2. Deep monitoring well transducer and packer assembly.

WAG 10 NHF as-built wellhead

A. Vented Aluminum Cap Type

B. Shut-In Type

C. Tree (Shut-In) Type

Fig. 1.3. Wellhead configurations installed at NHF wells.

Table 1.6. NHF well civil survey

Station	Alias	Northing	Easting	GS Elev. (ft msl)	TOC Elev. (ft msl)	GS Reference Description	TOC Reference Description
Injection Well							
1968	4-Inject	16502	28178	784.00			
Rock Cover Wells							
1969	4E-200RC	16487.09	28376.61	788.59	791.44	Iron pin	Top of casing
1971	4N-200RC	16716.33	28168.74	767.99	769.57	Paint mark on pad	Top of casing
1973	4NE-280RC	16661.52	28434.92	764.77	766.49	Iron pin	Top of casing
1974	4NW-340RC	16695.80	27884.13	769.33	770.58	Paint mark on pad	Top of casing
1976	4S-200RC	16305.45	28204.99	800.51	802.08	Top of casing at ground	Top of casing
1979	4SE-280RC	16303.52	28382.46	814.18	816.09	Iron pin	Top of casing
1980	4SW-280RC	16372.21	27922.10	785.23	787.11	Iron pin	Top of casing
1981	4W-190RC	16472.85	27984.56	783.28	783.92	Iron pin	Top of casing
Observation Wells							
1970	4E-200W	16505.15	28374.93	787.89	789.49	Paint mark on pad	Top of casing at top of bull plug
1972	4N-200W	16705.16	28175.75	768.17	770.29	Top of 6" surface casing @ GS	Top of casing
1975	4NW-400W	16703.70	27909.00	770.34	773.01	Iron pin	
1977	4S-200W	16306.72	28176.23	799.09	801.13	Paint mark on pad	
1978	4SE-125W	16447.69	28304.70	786.78	789.02	Northeast casing bolt = 787.89	
1982	4W-200W	16504.80	27975.23	782.63	784.45	Iron pin	
Deep Monitoring Wells							
2373	DM1-RM	16645.54	29219.51	765.42	768.98	Iron pin	Top of casing at highest point of plug
2374	DM2-RM	16456.59	27075.20	757.78	760.70	Iron pin	Top of casing
2375	DM3A-PV	17413.80	27311.94	768.89	770.16	Iron pin	Top of casing
2952	DM1-RT	16649.77	29238.29	765.52	767.34	Iron pin	Top of casing
2953	DM3-RT	16983.95	27214.53	753.51	755.21	Iron pin	Top of casing
2954	DM1-PV	16664.37	29227.37	765.45	767.36	Paint mark on pad	Top of casing during sampling with ball valve off
2955	DM2-PV	16469.95	27091.44	758.54	760.77	Paint mark on pad	Top of casing during sampling with ball valve off

Note: GS - ground surface
TOC - top of casing

1.3 SAMPLE ANALYSIS

Samples were collected from the standing water column in 20 NHF-related wells to provide data that would assist in developing and evaluating an appropriate range of waste management options regarding the types and concentrations of chemical and/or radiological components in the well water that must be considered during P&A or temporary reclamation of the wells. Samples were collected from the top of the water column (about 25 ft below the top of the column), one from the center of the column, and one from the bottom of the column (about 25 ft from the bottom of the well). The samples were collected using a wire-line sampler. The sampler was lowered to the desired depth with the port closed, and a signal was sent to open the port. The sampler was allowed to fill for about 10 minutes to allow the sampler temperature to adjust to the temperature of the standing water column. The sampler port was then closed, and the sampler was returned to the surface. The pH, temperature, specific conductivity, and Eh were immediately measured in the field, and the sample containers were filled.

Each sample was analyzed at the CSL for the major cations and anions, radionuclides, and organics. The results of the samples analyzed at the CSL are provided in Tables 1.7–1.10.

In addition to the samples collected for CSL analysis, samples were collected from Wells 2954 and 2955 to send for offsite analysis. One sample was collected from each well at approximately the same depth as the lower samples that were analyzed at the CSL. The main purpose in collecting the samples was to allow for an extensive analysis of metals. The two wells were selected for metals analysis because they had the highest levels of radioactivity compared to all the other NHF-related wells. Both wells are DM wells that are open in the Pumpkin Valley Shale. It is assumed Wells 2954 and 2955 are representative of the worst case of metals contamination. The results of the analysis by the offsite laboratory are provided in Table 1.11.

1.4 BOREHOLE LOG CHARACTERISTICS AND CAPABILITIES

The discussion and interpretation of the geophysical logs run at WAG 10 are based on the experience of the log interpreter, comparison with other logs, and reference documents (Hilchie 1982; Keys 1989; Nielson and Aller 1984; Thornhill and Benefield 1990).

1.4.1 Mechanical

A three-arm summation caliper tool was used to produce the caliper log run in all NHF wells logged. The caliper log provides a continuous record of borehole diameter (shape). The tool can be run in any borehole condition (open or cased hole). In open holes, the caliper provides useful information on lithology, fractures, vugs, solution cavities, obstructions, and washouts. The caliper is also used to correct other logs before interpretation to compensate for borehole conditions.

The caliper log is a valuable tool for evaluating the integrity and construction details of cased holes. Casing collars in wells can usually be located with this tool. Other casing conditions, such as excessive corrosion, pitting, casing openings, and scaling, may also be indicated by the caliper response.

Table 1.7. Close Support Laboratory analytical data summary for pH, alkalinity, total dissolved solids, and total suspended solid

Station	Sample		pH		Alkalinity (mg CaCO ₃ /L)	TDS (mg/L)	TSS (mg/L)
	Depth, ft	Elev., ft	field	laboratory			
Rock Cover Wells							
1969 (4E-200RC)	96	693	6.00	4.44	—	147,355	200
	339	450	5.69	4.62	—	167,258	70
	625	164	5.12	4.45	—	180,688	210
1971 (4N-200RC)	62	706	5.48	4.67	—	144,940	122
	261	507	5.70	4.77	—	160,794	95
	387	381	5.58	4.24	—	162,616	140
1973 4NE-280RC	76	689	6.76	4.36	—	73,436	46
	317	448		4.08	—	140,146	84
	557	208		4.32	—	155,621	110
1974 NW-340R	45	724	7.39	4.92	—	152,848	107
	300	469	6.22	4.51	—	149,714	146
	555	214	5.04	4.10	—	162,658	150
1976 (4S-200RC)	105	696	6.16	4.58	—	45,092	79
	390	411	5.37	3.61	—	207,380	139
	674	127	5.36	3.79	—	221,949	252
1979 4SE-280RC	122	692	6.52	5.41	—	54,838	52
	398	416	5.97	4.36	—	141,989	60
	675	139	5.54	6.10	21	200,919	223
1980 4SW-280R	41	744	6.68	8.18	144	159,623	810
	358	427	5.65	4.83	10	237,858	192
	675	110	4.09	4.18	—	246,504	135
1981 4W-190RC	52	731	7.46	4.85	—	185,726	192
	339	444	6.06	3.98	—	189,219	168
	510	273	5.94	4.33	—	193,268	105
Observation Wells							
1972 (4N-200W)	32	736	10.50	7.67	35	133	29
	563	205	11.23	10.71	131	318	—
	1050	-282	11.58	11.23	955	1,742	35
1975 4NW-400W	25	745	10.18	9.84	192	492	32
	493	277	9.73	9.82	189	457	20
	887	-117	12.57	12.33	9,031	89,927	924
1977 (4S-200W)	29	770	8.69	8.45	12	212	23
	256	543	11.28	11.06	98	333	12
	483	316	11.00	11.15	112	1,382	—
1978 (4SE-125W)	22	765	8.89	7.57	24	258	14
	571	216	11.44	11.48	199	709	10
	1120	-333	12.29	12.06	1,422	20,139	7
1982 (4W-200W)	36	747	11.38	11.65	192	432	7
	581	202	12.11	11.90	571	1,262	25
	1094	-311	11.86	11.78	915	1,646	153

Table 1.7 (continued)

Station	Sample		pH	Alkalinity (mg CaCO ₃ /L)	TDS (mg/L)	TSS (mg/L)
	Depth, ft	Elev, ft				
Deep Monitoring Wells						
(DM1-RM)	2373	123	642	8.49	7.34	24
	624	141	7.82	6.35	38	156,099
	1124	-359	11.10	8.41	31,378	146,150
(DM2-RM)	2374	262	496	7.59	7.60	65
	756	2	6.53	5.28	28	266,015
	1245	-487	6.16	5.19	21	277,376
(DM3A-PV)	2375	52	717	8.45	6.24	14
	469	300	6.86	5.94	21	24,132
	880	-111	6.51	5.60	21	59,120
(DM1-RT)	2952	200	566	11.26	10.74	121
	449	317	6.06	5.07	15	221,933
	696	70	5.55	4.20	-	237,648
(DM3-RT)	2953	65	689	7.67	6.64	31
	328	426	6.35	6.05	30	153,229
	580	174	5.53	5.22	16	156,265
2954	60	705	9.26	8.90	612	211,321
	569	196	9.05	9.03	461	217,745
	1038	-273	8.12	8.19	4,959	200,500
2955	32	727	9.00	8.59	332	254,516
(DM2-PV)	535	224	7.79	4.55	-	270,250
	1038	-279	7.40	5.13	14	268,125
	179					

Note: "-" indicates the analyte was not detected.

Table 1.8. Close Support Laboratory analytical data summary for cations and anions
in NHF wells

Station	Sample		Cations (mg/L)						Anions (mg/L)							
	Depth, ft	Elev., ft	Ammonium	Calcium	Lithium	Magnesium	Potassium	Sodium	Chloride	Sulfate	HCO ₃	CO ₃	Bromide	Fluoride	Nitrate	Phosphate
Rock Cover Wells																
1969 (4E-200RC)	96	693	--	14000	--	2170	164	43000	91000	--	--	--	722	--	--	--
	339	450	--	15200	--	3480	131	46700	102000	--	--	--	866	--	--	--
	625	164	--	18700	--	3910	126	48800	114000	--	--	--	959	--	--	--
1971 (4N-200RC)	62	706	--	13500	--	2570	90	36500	91400	--	--	--	714	--	--	--
	261	507	--	15000	--	3100	96	40600	99600	--	--	--	776	--	--	--
	387	381	--	15000	--	3080	93	41300	99600	--	--	--	782	--	--	--
1973 (4NE-280RC)	76	689	--	5280	--	1410	56	21700	48000	--	--	--	134	--	--	--
	317	448	--	12400	--	2930	207	38600	85800	--	--	--	680	--	--	--
	557	208	--	14300	--	3300	96	42100	94900	--	--	--	2170	--	--	--
1974 (4NW-340RC)	45	724	--	13200	--	3080	102	43000	92300	--	--	--	697	--	--	--
	300	469	--	13200	--	3130	98	42800	89800	--	--	--	696	--	--	--
	555	214	--	14900	--	3450	99	45200	99400	--	--	--	791	--	--	--
1976 (4S-200RC)	105	696	--	4110	--	827	36	11100	27100	--	--	--	208	--	--	--
	390	411	--	23300	--	4430	134	49800	134000	--	--	--	1230	--	--	--
	674	127	--	25200	--	4710	119	53500	138000	--	--	--	1260	--	--	--
1979 (4SE-280RC)	122	692	--	4670	--	78	89	16700	34000	--	--	--	230	--	--	--
	398	416	--	13400	--	2190	144	39000	87800	--	--	--	668	--	--	--
	675	139	--	21800	--	4320	138	51100	125000	--	26	0	1060	--	--	--
1980 (4SW-280RC)	41	744	--	19500	--	1520	123	41200	101000	--	176	0	901	--	--	--
	358	427	--	28500	--	5580	140	57800	155000	--	12	0	1390	--	--	--
	675	110	--	28700	--	5840	137	56300	151000	--	--	--	1450	--	--	--
1981 (4W-190RC)	52	731	--	20300	20	3820	145	48100	117000	--	--	--	939	--	--	--
	339	444	--	21200	20	4190	136	49300	116000	--	--	--	996	--	--	--
	510	273	--	21400	20	4220	130	49200	122000	--	--	--	983	--	--	--
Observation Wells																
1972 (4N-200W)	32	736	4.76	15.5	--	1.62	2.68	10.9	6.33	33.8	10	11	--	1.86	--	--
	563	205	19.4	53.5	--	--	3.46	12	8.96	51.3	8	48	--	0.62	--	--
	1050	-282	199	369	--	0.21	20.5	17.3	5.95	155	34	496	--	3.04	--	--
1975 (4NW-400W)	25	745	4.7	2.4	0.2	0.3	6.5	93.3	15.4	--	100	63	--	0.5	--	--
	493	277	4.6	2.5	0.2	0.7	6.5	95.8	24.9	0.6	153	37	--	0.5	--	--
	887	-117	54	--	--	--	854	37000	35100	811	22	3966	119	--	12600	203
1977 (4S-200W)	29	770	1.7	11.8	--	0.6	3.3	10.3	6.6	29.5	14	0	--	0.9	--	--
	256	543	2.7	51	--	--	3.4	11.1	15.1	45.1	3	23	--	1.9	--	--
	483	316	3.5	50.3	--	--	3.6	10.6	6.6	46.3	11	42	--	2	--	--

Table 1.8 (continued)

Station	Sample		Cations (mg/L)						Anions (mg/L)							
	Depth, ft	Elev., ft	Ammonium	Calcium	Lithium	Magnesium	Potassium	Sodium	Chloride	Sulfate	HCO ₃	CO ₃	Bromide	Fluoride	Nitrate	Phosphate
Observation Wells (cont.)																
1978 (4SE-125W)	22	765	0.5	12.3	--	0.8	6.4	5.9	6.2	24.3	27	1	--	1	--	--
	571	216	1.3	100	--	--	7.4	87.1	105	46	3	33	0.8	1	14	--
	1120	-333	--	2080	3	--	88.3	6650	7570	141	3	289	65	--	3950	--
1982 (4W-200W)	36	747	3.4	88.6	--	--	4.2	11.7	6.8	49.2	7	68	--	2	--	--
	581	202	12	233	--	--	6.8	14.1	20.9	15.4	2	80	--	5.6	--	--
	1094	-311	106	378	--	--	25.9	75.6	131	96.7	9	313	--	23.8	18.7	--
Deep Monitoring Wells																
2373 (DM1-RM)	123	642	--	14300	--	743	263	42300	85400	336	29	0	672	--	--	--
	624	141	--	14600	--	2160	274	46100	94700	338	46	0	742	--	--	--
	1124	-359	--	26200	--	3710	231	55000	131000	--	3263	17194	1110	--	--	--
2374 (DM2-RM)	262	496	--	11100	--	732	210	28300	61700	--	79	0	530	--	--	--
	756	2	--	27200	--	3870	360	65100	153000	--	34	0	1410	--	--	--
	1245	-487	--	28300	--	3510	341	71300	163000	--	26	0	1510	--	--	--
2375 (DM3A-PV)	52	717	--	896	--	186	21.8	7820	13100	1070	17	0	71.7	--	--	--
	469	300	--	676	--	143	17.7	6220	10100	827	26	0	59.8	--	--	--
	880	-111	--	3930	--	822	49	18000	33700	602	26	0	221	--	--	--
2952 (DM1-RT)	200	566	--	866	--	--	741	4620	8190	117	5	39	52.5	--	--	--
	449	317	--	25000	--	5390	316	53800	136000	--	18	0	1220	--	--	--
	696	70	--	27300	--	5870	171	55800	134000	--	--	--	1320	--	--	--
2953 (DM3-RT)	65	689	--	14100	--	3060	100	39800	91000	--	38	0	694	--	--	--
	328	426	--	14900	--	3290	94.1	41200	94700	--	37	0	738	--	--	--
	580	174	--	15800	--	3820	97.4	42600	99600	--	20	0	773	--	--	--
2954 (DM1-PV)	60	705	191	24000	--	2500	124	57000	124000	--	649	48	1150	--	2230	--
	569	196	138	23500	--	2710	32	57600	124000	--	510	26	1160	--	3750	--
	1038	-273	--	27200	--	5180	123	67000	149000	--	5972	38	1370	--	258	--
2955 (DM2-PV)	32	727	112	32800	--	4790	267	63100	152000	--	374	15	1530	--	231	--
	535	224	--	33400	--	5310	92	68200	162000	--	--	--	1620	--	1920	--
	1038	-279	--	34000	--	5440	185	68800	163000	--	17	0	1660	--	2040	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 1.9. Close Support Laboratory analytical data summary for radionuclides in NHF wells

Station	Sample		Gross α (pCi/L)	Gross β (pCi/L)	C-14 (pCi/L)	Cs-137 (pCi/L)	Co-60 (pCi/L)	Total γ (pCi/L)	Sr-90 (pCi/L)	H-3 (pCi/L)
	Depth, ft	Elev., ft								
Rock Cover Wells										
1969 (4E-200RC)	96	693	--	--	--			--		--
	339	450	--	--	--	293		293		--
	625	164	--	--	--	29.3		29.3		--
1971 (4N-200RC)	62	706	--	--	--			--		200.9
	261	507	--	--	--			--		4561.3
	387	381	--	--	--			--		1156.8
1973 (4NE-280RC)	76	689	--	--	--			--		--
	317	448	--	--	--	107		107		--
	557	208	--	--	--	234		234		--
1974 (4NW-340RC)	45	724	--	--	--			--		--
	300	469	--	--	--			--		--
	555	214	--	--	--			--		--
1976 (4S-200RC)	105	696	--	--	--	32.4		32.4		--
	390	411	--	--	--	36.9		36.9		--
	674	127	--	--	--	37.1		37.1		--
1979 (4SE-280RC)	122	692	--	1589.2	--			--		161.3
	398	416	--	--	--			--		--
	675	139	--	--	--			--		--
1980 (4SW-280RC)	41	744	--	--	--			--		211.7
	358	427	--	--	--			--		535.1
	675	110	--	--	--			--		153.2
1981 (4W-190RC)	52	731	--	1837.3	227			--		--
	339	444	--	4484.5	--	48.8		48.8		--
	510	273	--	1819.9	--	45.9		45.9		--
Observation Wells										
1972 (4N-200W)	32	736	--	9954.9	5109	483		483	5808.6	--
	563	205	--	3489.1	1945	403		403		--
	1050	-282	--	997.1	1116.2	841		841		--
1975 (4NW-400W)	25	745	6.2	458.5	--	212		212		--
	493	277	--	743.1	--	216		216		--
	887	-117	--	11744757.5	4546.8	14100000	219000	14300000	35059.6	1662216.2

Table 1.9 (continued)

Station	Sample		Gross α (pCi/L)	Gross β (pCi/L)	C-14 (pCi/L)	Cs-137 (pCi/L)	Co-60 (pCi/L)	Total γ (pCi/L)	Sr-90 (pCi/L)	H-3 (pCi/L)
	Depth, ft	Elev., ft								
Observation Wells (cont.)										
1977 (4S-200W)	29	770	--	4766.1	--	220		220		538.7
	256	543	--	1062.5	--	143		143		--
	483	316	--	1222.7	--	472		472		426.1
1978 (4SE-125W)	22	765	--	2028.9	--	28.4		28.4		--
	571	216	--	107554.8	--	2110		2110	77723.4	1500
	1120	-333	--	32189878.8	--	309000	32600	341000	20399490.1	235719.8
1982 (4W-200W)	36	747	--	2303.8	--	252		252		--
	581	202	--	1210.6	--	257		257		201.8
	1094	-311	--	141411.5	--	17500		17500	283564.8	3213.5
Deep Monitoring Wells										
2373 (DM1-RM)	123	642	--	272943.5	144666.7			--	61752.4	--
	624	141	--	64254.3	35193.7	31.6		615	14995.2	--
	1124	-359	22874.4	53262.2	17540.5			67.9		--
2374 (DM2-RM)	262	496	--	150077.6	--	35.5		35.5	91510.9	2827
	756	2	--	122064.8	79175.7	37.7		2060	15329.6	--
	1245	-487	--	54388.4	33153.2	45		--	4472.1	--
2375 (DM3A-PV)	52	717	--	--	--	45.2		45.2		--
	469	300	--	--	--	28.8		28.8		--
	880	-111	--	--	--	34.6		34.6		--
2952 (DM1-RT)	200	566	--	522	--			--		1693.7
	449	317	--	--	--	53.4		53.4		--
	696	70	--	--	--			--		--
2953 (DM3-RT)	65	689	--	--	--	37.8		37.8		--
	328	426	--	--	--	45.2		45.2		--
	580	174	--	--	--	28.8	111	560		--
2954 (DM1-PV)	60	705	--	59934300.7	--			--		255036.9
	569	196	--	82426724	1718		549	549		291591
	1018	-253	--	5231303.2			820	7070		
	1038	-273	4241.4	97839602.3	--		1880	1880		9103.6
2955 (DM2-PV)	32	727	--	2594735.7	--		1360	1360	2108270.5	35789.2
	535	224	--	4679242.4	1020.7		2480	2480	4418410.7	69421.6
	1038	-279	--	4039660.2	220.7		2450	2450	4470921.1	71678.4
	1040	-281	4551.1	9214946.6			5110	52500		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

α - alpha, β - beta, and γ - gamma

Table 1.10. CSL analytical data summary of detected organics in NHF wells

Station	Sample		1,1,1-Trichloroethane (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Chloro- benzene (µg/L)	Dichloro- methane (µg/L)	Ethyl- benzene (µg/L)	Naphthalene (µg/L)	Tetrachloro- ethene (µg/L)	Toluene (µg/L)	Trichloro- ethene (µg/L)	Total Xylenes (µg/L)
	Depth, ft	Elev., ft											
Rock Cover Wells													
1969 (4E-200RC)	96	693	--	148	2	--	269	64	--	--	4	--	256
	339	450	--	11	--	--	--	--	--	--	--	--	--
	625	164	--	15	--	--	8	2	--	--	--	--	8
1971 (4N-200RC)	62	706	--	129	--	--	--	--	--	--	--	--	--
	261	507	--	16	--	--	--	--	--	--	--	--	--
	387	381	--	10	--	--	--	--	--	--	--	--	--
1973 (4NE-280RC)	76	689	--	60	--	--	10	2	2	--	--	--	8
	317	448	--	--	--	--	--	--	--	--	--	--	5
	557	208	--	--	--	--	--	--	--	--	--	--	2
1974 (4NW-340RC)	45	724	--	424	3	--	--	--	3	--	--	--	--
	300	469	--	27	--	--	--	--	--	--	--	--	--
	555	214	--	45	--	--	--	--	--	--	--	--	--
1976 (4S-200RC)	105	696	--	262	2	--	6	--	4	--	--	--	--
	390	411	--	14	--	--	--	--	--	--	--	--	--
	674	127	131	--	--	--	--	--	--	--	--	--	--
1979 (4SE-280RC)	122	692	--	113	7	--	530	309	3	--	63	--	1294
	398	416	--	15	--	--	--	3	--	--	--	--	7
	675	139	--	--	--	--	--	2	--	--	--	--	8
1980 (4SW-280RC)	41	744	--	298	3	--	7	2	--	--	4	--	12
	358	427	--	11	--	--	--	--	--	--	--	--	--
	675	110	--	--	--	--	--	--	--	--	--	--	--
1981 (4W-190RC)	52	731	--	16	--	--	--	--	--	--	--	--	--
	339	444	--	13	--	--	--	--	--	--	--	--	--
	510	273	--	7	--	--	--	--	--	--	--	--	--
Observation Wells													
1972 (4N-200W)	32	736	--	--	--	--	10	--	--	--	--	--	3
	563	205	--	12	--	--	11	3	--	--	3	--	9
	1050	-282	--	383	--	--	4	5	--	--	2	--	15
1975 (4NW-400W)	887	-117	--	103	4	--	--	--	--	3	--	4	
1977 (4S-200W)	29	770	--	27	2	--	9	--	--	--	3	--	4
	256	543	--	13	3	--	16	3	3	--	5	--	9
	483	316	--	13	3	--	17	3	3	--	6	--	11
1978 (4SE-125W)	22	765	--	--	--	--	4	--	--	--	--	--	--
	571	216	--	15	--	--	2	--	--	--	--	--	--
	1120	-333	--	114	3	--	--	--	--	--	--	--	--

Table 1.10 (continued)

Station	Sample		1,1,1-Trichloroethane (µg/L)	Acetone (µg/L)	Benzene (µg/L)	Chloro- benzene (µg/L)	Dichloro- methane (µg/L)	Ethyl- benzene (µg/L)	Naphthalene (µg/L)	Tetrachloro- ethene (µg/L)	Toluene (µg/L)	Trichloro- ethene (µg/L)	Total Xylenes (µg/L)
	Depth, ft	Elev., ft											
Observation Wells (cont.)													
1982 (4W-200W)	36	747	--	17	--	--	10	--	--	--	--	--	--
	581	202	--	11	--	--	5	--	--	--	--	--	6
	1094	-311	--	--	--	--	--	--	--	--	--	--	8
Deep Monitoring Wells													
2373 (DM1-RM)	123	642	--	594	4	2	--	--	3	--	61	--	8
	624	141	--	527	5	4	--	--	2	--	244	--	8
	1124	-359	--	24	4	5	--	5	18	4	239	--	24
2374 (DM2-RM)	262	496	--	385	2	4	--	--	--	--	2	--	3
	756	2	--	620	--	--	--	--	--	--	--	--	--
	1245	-487	--	383	--	--	--	--	--	--	--	--	--
2375 (DM3A-PV)	52	717	--	23	--	--	--	--	3	--	27	--	7
	469	300	--	24	--	--	--	--	--	--	19	--	6
	880	-111	--	23	4	--	--	--	--	5	5	2	--
2952 (DM1-RT)	200	566	--	123	3	--	--	2	--	--	--	--	9
	449	317	--	16	--	--	--	--	--	--	--	--	9
	696	70	--	11	--	--	--	--	--	--	--	--	2
2953 (DM3-RT)	65	689	--	132	3	3	--	3	3	--	3	--	8
	328	426	--	6	--	--	--	--	--	--	3	--	7
	580	174	--	--	--	--	--	--	--	--	--	--	--
2954 (DM1-PV)	60	705	--	257	2	3	--	--	--	--	--	2	8
	569	196	--	85	--	5	--	--	--	--	--	--	9
	1038	-273	--	46	--	--	--	--	--	--	--	--	--
2955 (DM2-PV)	32	727	--	165	2	6	--	--	5	--	--	3	9
	535	224	--	50	--	3	--	--	--	--	--	--	--
	1038	-279	--	40	--	3	--	--	--	--	--	--	--

Note: "--" indicates the analyte was not detected.

Table 1.11 Offset laboratory analytical results for Wells 2954
(DM1-PV) and 2955 (DM2-PV)

	Well 2954	Well 2955
Metals, mg/L		
Aluminum	2.23	12.3
Antimony	2.76	2.76
Arsenic	--	--
Barium	709	643
Cadmium	0.23	0.273
Calcium	23300	27200
Chromium	0.37	0.434
Cobalt	0.946	0.501
Copper	1.39	1.34
Iron	39.6	9370
Lead	0.08	0.08
Magnesium	4430	7290
Manganese	91.8	352
Mercury	0.00019	0.0001
Nickel	1.13	1.13
Potassium	--	--
Selenium	--	--
Silver	0.6	0.6
Sodium	36800	41600
Thallium	0.41	0.41
Vanadium	1.83	1.15
Zinc	3.43	328
Detected organics, µg/L		
Acetone	39	52
Detected pesticides/PCB, µg/L		
none		
Sulfide, µg/L		
Sulfide	--	--
Detected BNAE, µg/L		
Bis(2-ethylhexyl)phthalate	--	3
Di-N-butyl phthalate	--	4
Diethyl phthalate	5	--
Cyanide, µg/L		
Cyanide	1.4	1.4

1.4.2 Electrical

Spontaneous potential (SP) and single-point resistivity (SPR) logs were run in NHF wells. The SP log provides a record with depth of the direct current potential of a moving electrode within an open borehole and a reference surface electrode. Differences in spontaneous (current) potential are caused by the borehole fluid, in situ formation fluid, type and amount of clay and/or shale present, porosity/permeability, and lithology.

The SP log is used to estimate "shaliness," locate contacts between permeable and less-permeable beds, correlate beds from well to well, identify permeable beds, and determine formation water resistivity. According to literature, the SP log is useful only in open boreholes containing conductive fluid.

SPR logging is based on Ohm's Law:

$$E = Ir$$

E = voltage (in volts)

I = current (in amperes)

r = resistance (in ohms)

SPR measures the resistance ($r = E/I$) of the rock unit(s), formation fluid(s), and borehole fluid. The principle of SPR logging is straightforward. The current (I) is held constant while the voltage (E) is measured between the movable lead electrode and a surface electrode. Voltage is then converted to resistance and plotted. SPR logs are valuable for obtaining information on lithology, unit contacts, porosity/permeability, fractures, and solution cavities. The logs are run in open boreholes containing conductive fluid.

The SP and SPR logs were run in the cased intervals of the NHF wells. The resulting logs provided useful information to aid in interpretation of well integrity. In many cases, the responses of these logs confirmed an interpretation of low casing integrity. The response observed consisted of a blocky pattern, with the top and bottom of the block correlating to casing joints.

1.4.3 Nuclear

Natural gamma, 4-Pi density, and neutron nuclear logs were run in WAG 10 wells.

The natural gamma log (also referred to as a gamma log or gamma ray log), in borehole environments that have not been affected by man, measures total (passive) gamma radiation within a selected energy range in the borehole. The most significant naturally occurring radionuclides that account for gamma response are ^{40}K and the daughter products of the ^{238}U and ^{232}Th decay series.

Where manmade radionuclides may be encountered in the groundwater, formation, or well annulus and/or adsorbed on shale intervals, they contribute cumulatively to the total gamma response (i.e., they are additive). The specific radionuclides, however, cannot be identified on the routine gamma log unless spectral-logging equipment is used. Some of the possible contributors to the total gamma ray response could include illite, smectites, potassium feldspar, glauconite, mica, muscovite, organic material, organic colloids, uranyl ion precipitates, aqueous radionuclides, contaminated grout, and contaminated grout filtrate.

Gamma ray logs, which can be run in open or cased boreholes, are commonly used to estimate clay and/or shale content. The same application can be made in aquifers if suitable laboratory data are available to support a relationship. Gamma logs are also used for lithologic determination, correlation, and estimation of effective porosity/permeability.

In a cased borehole, the gamma ray formation signature is suppressed by any hole conditions that modify the travel path of the photons. Casing, multiple casing, cement, and large-diameter boreholes will, in general, reduce the gamma response. Care should be taken when interpreting a gamma log run in a cased well if construction details are unknown.

The 4-Pi density log (also referred to as a gamma-gamma log) uses an activated source (^{137}Cs) and measures the effect of induced radiation and its degradation. The log, if borehole compensated, can be used to determine bulk density. In lithologies where both the matrix and fluid densities are known, total porosity can be determined by using the compensated bulk density. The ORNL 4-Pi density tool is a single detector tool, not a dual detector or compensated tool; dual detectors allow for borehole rugosity compensation. The ORNL 4-Pi density tool is calibrated and produces an apparent density log, but not a compensated bulk density log. An apparent density log cannot be used to determine porosity other than in a relative sense. The 4-Pi density tool can be run in open and cased boreholes.

The 4-Pi density log is affected by borehole conditions, casing, cement, and gravel pack. Quantitative log interpretation of formation characteristics would be suspect unless well construction details and conventional core are available for calibration. This tool, however, can provide some information on well construction details. Top(s) of cemented zones, gravel packs, and bottom(s) of multiple casing string can, in some cases, be recognized based on 4-Pi density response.

The neutron log response reflects the hydrogen content within the borehole environment and the formation. A detector on the tool measures attenuation by hydrogen of neutrons emitted from an americium and beryllium (Am/Be) source within the tool. Neutrons have no electrical charge and have approximately the same mass as a hydrogen atom. Therefore, hydrogen is responsible for most of the energy loss. Neutron logs can be run in open or cased boreholes.

The neutron log response can be used to determine total porosity (below water table), moisture content (above water table), specific yield of unconfined aquifers, perched water, and lithology. Log response can also be used for well-to-well correlation. Well casing will not cause a major effect on the neutron log response. Changes in thickness and/or the lack of fill in the annular space will affect the neutron response because of water filling the voids.

1.4.4 Borehole Fluid

The ORNL fluid temperature tool recorded both fluid temperature (degree Fahrenheit) and fluid resistivity (ohm-m). This tool was the first run in each well logged (it was not run in Wells 1973 and 1974). The fluid temperature and fluid resistivity logs were recorded going down the borehole at 6 ft/min to measure undisturbed borehole fluid. The fluid temperature tool is the only tool run in the NHF wells capable of detecting fluid flow.

Fluid temperature logs in open boreholes are used to indicate which fractures are hydraulically active. The fluid resistivity log provides information on borehole fluid quality.

Fluid temperature and fluid resistivity logs are very useful in evaluating casing integrity. Fluid temperature anomalies in cased boreholes with corresponding fluid resistivity anomalies indicate flow through the casing wall or coupling leakage. If there is no fluid resistivity anomaly with a fluid temperature anomaly, this could indicate flow behind the casing.

1.4.5 Acoustic

Full-waveform acoustic logs were run in all NHF wells logged.

Processing of the full-waveform acoustic log generates four types of geophysical logs; the acoustic amplitude log, the transit-time or delta-t log, acoustic velocity, and VDL (variable-density log).

The ORNL acoustic tools used in the NHF wells are digital, multiple-receiver tools. The tool transmits an acoustic signal (28 kHz) and records the returning waveforms at two receivers spaced 1 ft apart.

The acoustic amplitude log is a log of the amplitude of the first compressional (P) wave arrival from the far, or second receiver. The amplitude log is often referred to as a cement-bond log.

The acoustic transit-time, or delta-t, log records the shortest time (interval transit time) required for a compressional (P) wave to travel vertically through a known distance of formation next to the wellbore. This log is the difference in travel time at the two receivers. A velocity log is computed by using the reciprocal of interval transit time.

The velocity log, in an open fluid-filled borehole that is in good condition, is directly related to degree of rock consolidation, lithology, porosity, rock elasticity, and strength. In common applications, it is used primarily to determine lithology and porosity. The velocity log response is also useful for well-to-well correlation.

The VDL is a display of the acoustic waveform in which the display density, or color, is proportional to the acoustic amplitude of the full waveform.

Interpretation of the VDL (open borehole) can provide information on lithology, fracturing, and structure. A digital VDL, as run by the ORNL Geology, Geophysics, and Geochemistry Group, can be most useful because the data can be quantitatively analyzed to obtain elastic rock properties (e.g., bulk modulus, shear modulus, Poisson's ratio, and Young's modulus).

Run in a cased borehole, the VDL provides valuable information that can be used to evaluate well integrity, casing bond quality. In the case of good casing/cement/formation bond quality the compressional (P) wave arrival will be from the formation; this will be reflected in the VDL as formation response, as from an uncased borehole. Examples of good casing/cement/formation bond can be seen in Parts (A) and (B) of Fig. 1.4. In the case of bad or nonexistent casing/cement/formation bond, the compressional (P) wave arrival will be from the steel casing; this will be reflected in the VDL as parallel bands representative of the ringing steel. An example of bad casing/cement/formation bond can be seen in Part (C) of Fig. 1.4.

Fig. 1.4. Variable density logs for Wells 1979, 2954, and 1975 showing interpreted cement bonding.

Well integrity designations (below) from the standpoint of casing/cement and cement/formation bonding can be evaluated by interpretation of the amplitude and velocity logs, in combination with the VDL. The most common log responses are outlined below.

- Good casing/cement and cement/formation bond
  - weak or nonexistent casing arrivals on the VDL
  - strong formation arrivals on the VDL
  - the amplitude log will be low, reflecting formation response
  - velocity log reflects formation response
- Good casing bond but poor formation bond
  - subdued casing arrivals on the VDL
  - weak or nonexistent formation arrivals on the VDL
  - amplitudes higher and flatter than formation response
  - consistent velocity on the velocity log
- Poor casing/cement bond
  - strong casing (casing ringing) arrivals on the VDL
  - very weak or nonexistent formation arrivals on the VDL
  - clear chevron ("W") patterns at casing collars on the VDL
  - the amplitude log will be high and flat from the ringing steel casing
  - the velocity log reflects the velocity of the steel casing (approximately 17,500 ft/sec)
  - slight decrease in velocity at collars on the velocity log

2. WELL SUMMARY AND PLUGGING AND ABANDONMENT RECOMMENDATIONS

This section of the report is designed to provide summaries for all 21 wells studied at NHF. The intent is to provide a "well packet" that contains all relevant data, a concise interpretation, present well conditions, the well ranking, and the recommended P&A approach for each well. The wells are ordered for highest to lowest ranking. The appropriate tables and figures are also included for each well. The well summaries contain the following:

- well history,
- construction details,
- recent field activities,
- analytical results (historical and recent),
- geophysical log interpretation,
- well ranking, and
- general P&A plan.

The well packets can be removed/copied from the document and be used for field guides, bid packages, hazardous work permits, radiation work permits, and excavation and penetration permits. This format was chosen to assist in preparation and planning of future P&A, temporary monitoring, or other well related activities at NHF. The wells are discussed in the following order:

<u>ORNL Well ID No.</u>	<u>Well Alias</u>	<u>Well Ranking Total</u>
2954	DM1-PV	9
1970	4E-200W	9
1972	4N-200W	9
1978	4SE-125W	9
1975	4NW-400	9
2955	DM2-PV	9
1982	4W-200W	8
1977	4S-200W	8
2373	DM1-RM	6
2374	DM2-RM	6
1981	4W-190RC	5
1979	4SE-280R	5
2952	DM1-RT	4
1969	4E-200RC	4
1971	4N-200RC	4
1973	4NE-280R	4
1974	4NW-340R	4
1976	4S-200RC	4
1980	4SW-280R	4
2953	DM3-RT	4
2375	DM3A-PC	4

2.1 SUMMARY OF WELL 2954 (DM1-PV)—RANKED 9

Well History. Well 2954 (DM1-PV), one of seven deep-monitoring wells, was installed (January 1986) in the vicinity of the NHF. The well, located 1,060 ft east of the injection well (Well 1968), has an openhole interval in the upper and lower Pumpkin Valley Shale (injection horizon).

Two past incidents occurred at Well 2954 (DM1-PV). In the summer of 1985, a Tennessee Valley Authority geophysical logging crew and their equipment were contaminated at this well. Radiological contamination was not suspected or expected by the geophysical logging crew because the well was uncapped and flowing artesian. After this incident, the well was capped. In January 1986, a second incident occurred when an ORNL sampling team was splattered with radionuclide-contaminated liquids that spewed out of the well after it was opened (uncapped). The sampling team did not expect the well to be pressurized when the attempt to sample was made at this location. After these incidents, the well was shut-in until well tapping, sampling, and borehole logging in August 1995.

Construction Details. A 10 $\frac{3}{4}$ -in. surface casing was installed in the top 50 ft of Well 2954. The surface casing was grouted in place in a nominal 15-in. diameter borehole. A nominal 10-in. hole was drilled from 50 to 750 ft in depth, and 6-in. ID black steel casing was grouted in place. A nominal 6-in. diameter openhole interval was then drilled from 750 to 1,063 ft bgs. The borehole logging and sampling teams both measured the TD of the well to be 1,062 ft bgs.

A bermed concrete pad was poured around the wellhead, and a metal building (7802C) was installed on the pad over the top of the wellhead. Figures 2.1–2.4 show the current well configuration and the proposed P&A.

Field Activities. Well 2954 was tapped on August 9, 1995. The annulus between the 6-in. well casing and the 2 $\frac{3}{8}$ -in. steel tubing was not under pressure; however, the tubing had a pressure of 26.2 psig. The water level immediately after tapping was 34.59 ft bgs. A series of pressure and water level measurements were made through November 1995. One other water level measurement was made in October 1995, and the water level was above the ground surface (flowing artesian). The tapping information and water level data are provided in Table 2.1.

The water column in Well 2954 was sampled at three depths (60, 569, and 1038 ft bgs) in August 1995 as part of the WAG 10 field investigation. Well 2954 was sampled again in October 1995 at a depth of 1,018 ft bgs for offsite laboratory analysis.

Analytical Results. Table 2.1 provides the results of the CSL sample analysis for Well 2954. The water sampled from this well is basic (pH between 8.12 and 9.26). All three samples are highly saline brine (TDS > 200,500 mg/L), composed predominantly of sodium with lesser amounts of calcium, and the major anion is chloride (Fig. 2.5). Nitrate was detected in the 1995 round of sampling at a concentration that ranged from 258 to 3,750 mg/L. The highest concentration was measured in the middle sample (569 ft). These nitrate results compare with those from the historical sampling of the well (442 mg/L, nitrate). No organics were detected at significant levels.

Very high gross beta (59.9 to 97.8 μ Ci/L) and moderate ^{60}Co (549 to 1,880 pCi/L) activities were detected in Well 2954. Very high beta (7.3 μ Ci/L) and ^{90}Sr (0.9 μ Ci/L) were also detected by ORNL in the 1986 sampling. The radionuclides detected in the water sampled from this well

were sourced from the waste grout sheets emplaced in the Pumpkin Valley Shale. Induced or natural fractures containing water contaminated with aqueous radionuclides were intercepted by this well.

The analytical results for historical samples collected and the results of the offsite laboratory analysis for Well 2954 are presented in Table 2.1. This particular sample contained fairly high solids. That factor is reflected in the offsite results. Besides the major common metals, the sample contains relatively high barium (709 mg/L) and slightly elevated iron (39.6 mg/L) and zinc (3.43 mg/L). The high barium reflects the highly saline water or drill fluid. These results are not representative of the water sampled and analyzed from Well 2954.

The bottom water sample collected from Well 2954 contained high solids. A sample of the solid material was mounted on filter paper, glued to a scanning electron microscopy (SEM) sample stub, coated with gold (Au) to provide a conductive layer, and examined in an ISI SEM equipped with an energy-dispersive x ray analyzer system (EDS). The service was provided as a courtesy of Dr. S. Y. Lee and Dr. M. Elless of ORNL.

The SEM photomicrograph and EDS spectrum for the material collected from Well 2954 is shown on Fig. 2.6. The fibrous material seen in the photomicrograph is filter paper. The solids display no crystal form or recognizable shape (such as fly ash). The amorphous nature and elements detected would indicate that the solids are comprised primarily of metal casing and drilling pieces. No indication of solid waste grout was found.

Geophysical Log Interpretation. The neutron log response is useful for porosity, lithology, and picking formation tops. The caliper log shows 20-ft casing strings. The caliper also indicates hydraulic fractures within the openhole interval. The apparent density shows joints in the cased section and a fracture in the openhole. The temperature log exhibits four anomalies: between 615 ft and 630 ft possible upward flow, 880 ft inflow, 948 ft fracture with inflow, and below 985 ft zone of constant temperature. The anomaly at 948 ft correlates with a gamma spike, rugose caliper response, and an apparent density low indicative of an active hydraulic fracture.

The VDL indicates very good bonding from 0 to 554 ft and good bonding from 554 ft to bottom of casing. The fracture is marked on the sonic and amplitude logs.

The gamma log response is anomalous through the entire well. Gamma counts increase from 750 counts per second (cps) near the top of the well to 1,200 cps near the bottom of casing. The gamma counts then increase to 1,900 cps between 750 to 950 ft, which is not characteristic of the area. The "old" openhole gamma log run in nearby Well 2373 was evaluated to determine if the broad gamma ray peak was present in the Pumpkin Valley Shale in 1984. No indication of the gamma peak is observed. This observation implies that filtrate sourced from the waste grout sheets has intercepted Well 2954 since the first logs were collected in the area in 1984. The broad gamma peak, therefore, may represent the "leading edge" of a filtrate plume. This would imply that waste filtrate from past injections was migrating, along fractures (between 1984 and 1995).

Several other gamma ray spikes are of interest. They are:

- 924 ft correlates with caliper, VDL, and low velocity
- 949 ft correlates with caliper, temperature, and a decrease in apparent density

- 1,010 ft to 1,040 ft correlates with a slight enlargement of the borehole, temperature break, neutron low, and marked decrease in apparent density

These log anomalies confirm the presence of active hydraulic fractures within the injection horizon. These fractures could be hydrofracture operation induced or have been planes of weakness that were already present in the section.

Well Ranking. Well 2954 is a DM well. There is evidence of casing leakage on the temperature log. Therefore, this well does not have external mechanical integrity (EMI). The water in this well is highly contaminated (gross beta 97.8 $\mu\text{Ci/L}$) with radionuclides that mimic and are sourced from the grout sheets. The well is artesian and presents a threat for the spread of radiological contamination uphole through the wellbore and/or annulus. The wellhead is presently shut-in and will require continual maintenance. The well should be P&A as soon as possible. Well 2954 is ranked very high (9) for P&A.

General P&A Plan. Figures 2.1–2.4 show the surface and wellhead configuration, well details, and proposed P&A for Well 2954. The well construction is based on good historical records of this well.

Well 2954 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (730 to 1,063 ft) before pressure testing casing to approximately 100 psi (surface gauge pressure) for 1 hour by either shutting in the well or placing a packer.

Two plugs are expected to be placed in this well (below the upper Maryville Limestone, freshwater zone and near the base of the Rutledge Limestone, overlying the injection horizon). The first 30-ft (approximately 700 to 730 ft) interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out near the base of the Rutledge Limestone. The perforated/milled window interval will be squeezed (approximately 670 to 730 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged. The next cement stage will be placed from 275 to 670 ft below the upper Maryville Limestone contact.

The second 30-ft (245 to 275 ft) interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 245 ft). Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 215 to 275 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 215 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

Fig. 2.1. Wellhead construction details.

Fig. 2.2. Well 2954 (DMI-PV) acoustic variable density log.

B = Gross Beta

Fig. 2.3. Characteristic log responses, observations, and summary chemical data for Well 2954 (DM1-PV)

Fig. 2.4. Existing well construction and proposal P&A for Well 2954 (DMI-PV).

Table 2.1. Well water measurements Well 2954 (DM1--PV)

Well Construction		
Original Date Well Completed	1985	ORNL Grid Coordinates Northing = 16664.37 Easting = 29227.37
Well Type	Deep Monitoring	
Formation Penetration	Pumpkin Valley Shale	
Ground Surface Elev (ft)	765.45	
Bottom Riser Casing Depth (ft bgs)	750	Historical Notes:
Bottom Riser Casing Elev (ft)	15.45	
Total Depth (ft bgs)	1063	
Total Depth Elev (ft)	-297.55	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	8/7/95	26.2	20.4	3	280	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
8/9/95	60	705	211,321
8/9/95	569	196	217,745
8/9/95	1038	-273	200,500

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Pressure	8/8/95		GS	2	6.41	771.86
Water Level	8/9/95	34.59	GS			730.86
Pressure	8/9/95		GS	1	4.11	769.56
Pressure	9/6/95		GS	2.2	6.87	772.32
Water Level	10/16/95	1.30	+ GS			766.75
Pressure	10/31/95		GS	3	8.72	774.17
Pressure	11/13/95		GS	4.2	12.49	777.94
Average						766.21
Minimum						730.86
Maximum						777.94

+ GS = Above Ground Surface
GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.1 (continued). Well water sample analysis for Well 2954 (DM1-PV)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	9.26	9.05	8.12
Lab pH	8.9	9.03	8.19
Temperature (C)	19.3	23.8	28.1
Specific Conductivity ($\mu\text{S} / \text{cm}$)	208000	206000	224000
Eh (mV)	140.6	237.3	47
Alkalinity (mg CaCO_3 / L)	612	461	4959
Total Dissolved Solids (mg / L)	211321	217745	200500
Total Suspended Solids (mg / L)	79	136	82360
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	24000	23500	27200
Sodium	57000	57600	67000
Magnesium	2500	2710	5180
Potassium	124	32	123
Ammonium	191	138	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	124000	124000	149000
Sulfate	--	--	--
HCO_3	649	510	5972
CO_3	48	26	38
Bromide	1150	1160	1370
Phosphate	--	--	--
Nitrate - Nitrogen	2230	3750	258
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	4241.4
Gross Beta	59934300.7	82426724	97839602.3
Gamma Activity	--	549	7070
Sr - 90			
Co - 60		549	820
H - 3	255036.9	291591	9103.6
C - 14	--	1718	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	257	85	46
Benzene	2	--	--
Chlorobenzene	3	5	--
Trichloroethene	2	--	--
Xylenes (total)	8	9	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.1 (continued). Historical sample analysis for Well 2954 (DM1-PV)

pH, Alkalinity, and TDS

Analyte	January 1986
	unfiltered
pH	4.4
Alkalinity (mg HCO ₃ /L)	--
Total Dissolved Solids (mg/L)	237640

Cations, mg/L

Analyte	January 1986
	unfiltered
Calcium	22000
Sodium	59000
Magnesium	4100
Potassium	240
Manganese	140
Iron	170
Lithium	55
Barium	680
Strontium	2300
Phosphorus	18

Anions, mg/L

Analyte	January 1986
	unfiltered
Chloride	150000
Sulfate	--
Bromide	1400
Phosphate	17
Nitrate	442
Fluoride	.46
Iodide	19

Radionuclides, pCi/L

Analyte	January 1986
	unfiltered
Gross Beta	7297290
Sr-90	945945
Cs-137	--
Co-60	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.
The January 1986 sample was collected at a depth of 1050 ft bgs.

Table 2.1 (continued). Offsite laboratory analysis for Well 2954 (DM1-PV)

Metals, mg/L	
Aluminum	2.23
Antimony	2.76
Arsenic	--
Barium	709
Cadmium	0.23
Calcium	23300
Chromium	0.37
Cobalt	0.946
Copper	1.39
Iron	39.6
Lead	0.08
Magnesium	4430
Manganese	91.8
Mercury	0.00019
Nickel	1.13
Potassium	--
Selenium	--
Silver	0.6
Sodium	36800
Thallium	0.41
Vanadium	1.83
Zinc	3.43
Detected organics, µg/L	
Acetone	39
Detected pesticides/PCB, µg/L	
none	
Sulfide, µg/L	
Sulfide	--
Detected BNAE, µg/L	
Diethyl phthalate	5
Cyanide, µg/L	
Cyanide	1.4

Note: Sample collected from a depth of 1018 ft bgs.

Fig. 2.5. Chemistry of standing water column in NHF deep monitoring Well 2954.

A.

2-14

B.

Courtesy of Dr. S. Y. Lee and Dr. M. Elless of ORNL

Fig. 2.6. Scanning electron microscopy and energy-dispersive x ray analyzer system images of solids from Well 2954.

2.2 SUMMARY OF WELL 1970 (4E-200W)—RANKED 9

Well history. Well 1970 (4E-200W) is one of six observation wells surrounding the NHF. Well 1970 was installed in 1973 and is located 200 ft east of the NHF injection well (ORNL Well 1968). The well is cased throughout its length.

The observation wells were drilled through the injection zone (Pumpkin Valley Shale) to the top of the Rome Sandstone. The observation wells were constructed to enable determination of grout sheet orientation. A gamma sensitive probe was lowered down the wells to detect the position and presence of grout sheets at depth. Numerous grout sheets were reported to have intercepted the Well 1970 borehole.

Construction details. The TD of Well 1970 is reported to be 1,135 ft. The well is cased (1,086 ft) and grouted throughout its length. Well 1970 is unique from the other observation wells in that it contains 2 $\frac{7}{8}$ -in. ID black-carbon steel well casing enclosing nonstandard 1.25-in. ID steel tubing. The annulus at the surface between the tubing appears to be grouted. It can be assumed that the grout in the annulus does not extend to TD.

The observation wells at NHF were designed with 2 $\frac{7}{8}$ -in. ID casing (Weeren 1974). Why the small diameter tubing was installed in this well is unknown. Several observation wells at the Old Hydrofracture Facility (OHF), however, also have small diameter tubing. This "change" in well construction design could cause problems during P&A operations because normal-sized tools will not fit in the small diameter tubing. Similar problems were encountered during the NHF injection well recovery operation (Weeren 1984). Figures 2.7–2.8 show the current configuration of the wellhead, well details, and proposed P&A. The gamma log shown on Fig. 2.8 was recorded in 1975 after the site proof test but before NHF batch operations.

Field Activities. Well 1970 was tapped on June 13, 1995. The well had a pressure of 7.2 psig at tapping, and the water level was above the ground surface (flowing artesian). A series of water level measurements were made through November 1995, and in each measurement, the water level was above the ground surface. A list of the tapping information and water level data is provided in Table 2.2.

The water column in Well 1970 was not sampled or logged because of the nonstandard, small diameter, 1.25-in. steel tubing inside the well casing. It is assumed, however, that the casing is breached and contamination in the standing water column of this well will be similar to that found in the other four observation wells (high gross beta, ^{137}Cs , ^{90}Sr , ^{60}Co , and ^3H). Formation tops are estimated from a report completed by Weeren, et al. 1974.

Well Ranking. Well 1970 is a small-diameter (1.25 ID tubing) observation well. Historical records indicate that the well is cased to TD. This well could not be sampled or logged because of the nonstandard tubing used to finish the well. Because the well was intercepted by NHF grout sheets it is expected that the water would be highly contaminated with radionuclides: high gross beta, ^{90}Sr , ^{137}Cs , ^3H , etc. The well is artesian and does present the potential for uphole migration of contaminants through the wellbore and/or annulus to the overlying fresh water zone or to the surface. The well should be P&A as soon as possible. Well 1970 is ranked very high (9) for P&A.

General P&A Plan. Figures 2.7 and 2.8 show the surface and wellhead configuration for small-diameter observation Well 1970, qualitative well details, and a sketch of the proposed P&A

well. The well details should be considered as best estimates based on historical records because of the lack of available engineering drawings.

Well 1970 is assumed to be cased (1.25-in. ID) to TD, with casing keyed into the very top of the Rome Formation. The following are the proposed general steps for P&A of this well.

The well will be brought to static equilibrium before P&A activities begin. Coiled tubing will be used to feed evacuation fluids into the well. Entering the 1.25-in. ID casing with coiled tubing for establishing equilibrium and placing cement will be difficult, if not impossible. Purging and evacuation fluids will be diverted and contained for treatment. Cement will be placed in stages through coiled tubing to 30 ft below the contact of the upper Maryville Limestone (shallow freshwater zone, 250 ft). Cement will be placed in stages, squeezed by shutting in the well, allowed to cure, and tagged.

The casing and grout will be washed over, and the casing will be cut and removed from the wells to the top of the last staged cement plug (250 ft). The casing diameter and length to be washed over will be specified before P&A operations begin. As an option, the casing and grout could be milled out rather than washed over.

After removal or milling out of the casing, the borehole will be plugged from 5 ft bgs to 30 ft below the upper Maryville Limestone contact at a depth of 250 ft. The plug will be tagged and the well will be closed using the established procedure for finishing the well from ground surface to 5 ft bgs.

OBSERVATION WELL 1970 (4E-200W)

Fig. 2.7. Wellhead construction details.

WELL 1970 (4E-200W)
PROPOSED PLUGGING AND ABANDONMENT

WELL 1970 (4E-200W)
EXISTING WELL CONDITION

Fig. 2.8. Existing well construction and proposed P&A for Well 1970 (4E-200W).

Table 2.2. Well water measurements Well 1970 (4E-200W)

Well Construction						
Original Date Well Completed = 1973				ORNL Grid Coordinates		
Well Type = Observation				Northing = 16505.15		
Formation Penetration = Rome Formation				Easting = 28374.93		
Ground Surface Elev (ft) = 787.89				Historical Notes: .125-in. ID tubing is grouted inside the 2-7/8-in. casing.		
Bottom Riser Casing Depth (ft bgs) = 1135						
Bottom Riser Casing Elev (ft) = -347.11						
Total Depth (ft bgs) = 1135						
Total Depth Elev (ft) = -347.11						
Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	6/13/95	7.2	20.9	0	100	--
Casing Annulus	--	--	--	--	--	--
Sample Details						
	Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)		

Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Pressure	6/14/95		GS	5	13.33	801.22	
Pressure	6/26/95		GS	2	6.41	794.30	
Pressure	7/5/95		GS	2.4	7.34	795.23	
Water Level	7/5/95	0.66	+ GS			788.55	Well left vented
Water Level	7/6/95	0.66	+ GS			788.55	Well left vented
Water Level	7/7/95	0.66	+ GS			788.55	
Water Level	7/13/95	0.67	+ GS			788.56	Well closed
Pressure	7/18/95		GS	0	0		
Water Level	9/6/95	0.68	+ GS			788.57	
Pressure	9/6/95		GS	0.3	2.49	790.38	
Water Level	10/16/95	0.70	+ GS			788.59	
Water Level	11/13/95	0.73	+ GS			788.62	
Average						791.01	+ GS= Above Ground Surface
Minimum						788.55	GS= Ground Surface
Maximum						801.22	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

2.3 SUMMARY OF WELL 1972 (4N-200W)—RANKED 9

Well History. Well 1972 (4N-200W) is one of six observation wells surrounding the NHF. Well 1972 was installed in 1973 and is located 200 ft north of the NHF injection well (ORNL Well 1968). This particular well penetrated OHF grout sheets. The well is cased throughout its length.

The observation wells were drilled through the injection zone (Pumpkin Valley Shale) to the top of the Rome Sandstone. The observation wells were constructed and cased to TD to determine the position and orientation of the grout sheet. A gamma sensitive probe was lowered down the observation wells to detect the presence of grout sheets at depth. Numerous NHF grout sheets intercepted the Well 1972 borehole.

Construction Details. The total reported depth of Well 1972 is 1,120 ft. The riser is bent and damaged below ground surface. It appears that the riser was struck by a vehicle prior to placement of guard posts. The sampling team was able to bypass the bend in the riser and sample the well. The depth was measured to be 1,082 ft bgs in November 1995. This well was not geophysically logged. The logging sondes, because of length, could not bypass the bend in the riser. The well is cased with 2 $\frac{7}{8}$ -in carbon steel and grouted throughout its length. Figures 2.9 and 2.10 show the current configuration of the wellhead, well construction details, and the proposed P&A. The gamma log shown on Fig. 2.10 was recorded in 1975 after the site proof test but before NHF batch operations.

Field Activities. Well 1972 at the time of tapping (June 13, 1995) was not under pressure. The water level immediately after tapping was 6.49 ft bgs. A series of water level measurements were made through November 1995. A list of the tapping information and water level data is provided in Table 2.3.

The standing water column in Well 1972 was sampled at three depths (32, 563, and 1,050 ft bgs) in November 1995 as part of the field investigation.

Analytical Results. Table 2.3 provides the results of the sample analysis for Well 1972. The pHs measured indicate basic water (> 10.50 to 11.58) of fresh water (TDS < 1,800 mg/L) salinity. The top sample is predominantly calcium with lesser amounts of sodium, and the major anions were bicarbonate and sulfate. The bottom sample is calcium bicarbonate. Nitrate was not detected in the water samples analyzed for Well 1972. Dichloromethane was the only organic compound detected at levels above the Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs).

Strontium-90 (5808.6 pCi/L) was detected in the top sample. Strontium-90 was not reported in the lower two samples. Gross beta activity decreases with depth in the standing water column (9,954.9 to 997.1 pCi/L). Cesium-137 (< 841 pCi/L) was detected in all three samples. The ¹³⁷Cs displays a very minor increase in activity with depth.

Well Ranking. Well 1972 is an observation well and is cased to TD. The well was reported to have penetrated OHF grout sheets during drilling. The riser on this well is bent and in poor condition. Geophysical logs could not be run because of the damaged riser. Water samples, however, were collected and analyzed. Results indicate moderate levels of radiological contamination. The contamination in this well is not indicative of cross contamination during monitoring of NHF operations. The contamination is sourced from the grout sheets. This well

presents a threat for the spread of radiological uphole through the wellbore and/or annulus. The well should be P&A as soon as possible. Well 1972 is ranked very high (9) for P&A.

General P&A Plan. Figure 2.9 shows the surface and wellhead configuration, and Fig. 2.10 shows the interpreted well detail and a sketch of the proposed P&A well. The formation contacts were extracted from the cross sections constructed for the area.

The riser on Well 1972 will need to be straightened prior to starting P&A operations. The well will be brought into static equilibrium before P&A begin. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option is presented below.

The casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. The lower 35 ft of casing will be cemented prior to pressure testing (1,047 to 1,082 ft). Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well. Three 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out one below the upper Maryville Limestone (shallow freshwater zone, estimated contact at 310 ft), another near the base of the Rutledge Limestone (estimated contact at 740 ft), and a third near the top of the Rome Formation.

After placement of the 35-ft initial cement plug (top at 1,047 ft), a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the lower Pumpkin Valley Shale, the unit that overlies the Rome Formation, to maximize hydraulic separation. It is expected that the next cement stage will be set from approximately 714 to 987 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone (684 to 714 ft), the unit that overlies the upper Pumpkin Valley Shale (injection horizon). The perforated/milled window interval will be squeezed using matrix-penetrating cement. After curing, the plug will be tagged.

The next cement stage will be placed from 280 to 654 ft. After placement of this plug, a 30-ft casing interval will be perforated or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (220 to 280 ft). Ultrafine-grain, matrix-penetrating cement, and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged, and a final cement stage will be placed from 5 to 220 ft.

OBSERVATION WELL 1972 (4N-200W)

Fig. 2.9. Wellhead construction details.

Fig. 2.10. Existing well construction and proposed P&A for Well 1972 (4N-200W).

Table 2.3. Well water measurements for Well 1972 (4N-200W)

Well Construction	
Original Date Well Completed = 1973	ORNL Grid Coordinates
Well Type = Observation	Northing = 16705.16
Formation Penetration = Rome Formation	Easting = 28175.75
Ground Surface Elev (ft) = 768.17	
Bottom Riser Casing Depth (ft bgs) = 1120	Historical Notes:
Bottom Riser Casing Elev (ft) = -351.83	
Total Depth (ft bgs) = 1120	
Total Depth Elev (ft) = -351.83	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	6/13/95	0	20.9	4	0	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
11/1/95	32	736	133
11/1/95	563	205	318
11/1/95	1050	-282	1,742

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Water Level	6/13/95	6.49	GS			761.68
Water Level	6/14/95	6.50	GS			761.67
Water Level	7/13/95	6.50	GS			761.67
Water Level	9/6/95	6.67	GS			761.50
Water Level	10/16/95	6.68	GS			761.49
Water Level	11/1/95	6.72	GS			761.45
Water Level	11/13/95	10.12	GS			758.05
Average						761.07
Minimum						758.05
Maximum						761.68

+ GS = Above Ground Surface
GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.3 (continued). Well water sample analysis for Well 1972 (4N-200W)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	10.5	11.23	11.58
Lab pH	7.67	10.71	11.23
Temperature (C)	16.5	16.5	16.7
Specific Conductivity ($\mu\text{S} / \text{cm}$)	171	347	1420
Eh (mV)	148	66.2	13.8
Alkalinity ($\text{mg CaCO}_3 / \text{L}$)	35	131	955
Total Dissolved Solids (mg / L)	133	318	1742
Total Suspended Solids (mg / L)	29	--	35
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	15.5	53.5	369
Sodium	10.9	12	17.3
Magnesium	1.62	--	.21
Potassium	2.68	3.46	20.5
Ammonium	4.76	19.4	199
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	6.33	8.96	5.95
Sulfate	33.8	51.3	155
HCO_3	10		34
CO_3	11		496
Bromide	--	--	--
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	1.86	.62	3.04
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	9954.9	3489.1	997.1
Gamma Activity	483	403	841
Sr-90	5808.6		
Cs-137	483	403	841
H-3	--	--	--
C-14	5109	1945	1116.2
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	--	12	383
Dichloromethane	10	11	4
Ethylbenzene	--	3	5
Toluene	--	3	2
Xylenes (total)	3	9	15

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

2.4 SUMMARY OF WELL 1978 (4SE-125W)—RANKED 9

Well History. Well 1978 (4SE-125W) is one of six cased observation wells surrounding the NHF. The well was installed in 1980 and is located 140 ft southeast of the NHF injection well (ORNL Well No. 1968).

The observation wells were designed to be drilled through the injection zone (Pumpkin Valley Shale) to the top of the Rome Formation. This particular well does reach the top of the Rome Formation. These wells were constructed to enable determination of grout sheet position and orientation. A passive gamma probe was lowered down the observation wells to detect and log the presence of grout sheets at depth. Numerous grout sheets intercepted Well 1978.

Construction Details. The reported TD of Well 1978 is 1,145 ft. The borehole logging and sample teams each measured the TD of the well to be 1,127 ft bgs. The well is cased with 2 $\frac{7}{8}$ -in. ID carbon steel and grouted throughout its length. Figures 2.11–2.14 show the current configuration of the wellhead, the well construction details, and the proposed P&A.

Field Activities. Well 1978 was tapped on June 14, 1995. The well was not under pressure, and the water level immediately after tapping was 2.78 ft above the ground surface (flowing artesian). A series of water level measurements were made through November 1995. The water level gradually dropped to 4.46 ft bgs in November 1995. The tapping information and water level data are provided in Table 2.4.

The water column in Well 1978 was sampled at three depths (22, 571, and 1,120 ft bgs) in July 1995 as part of the field investigation.

Sample Analysis. Table 2.4 provides the results of the sample analysis for Well 1978. The water sampled is basic with a pH ranging from 8.89 to 12.29. The most basic pH was measured for the bottom sample. The high pHs would be indicative of reaction with grout. The water sampled in the cased well is fresh (258 to 709 mg/L, upper two samples) to slightly saline (20,139 mg/L, bottom sample). The waters sampled are not representative of the formation(s). The two top samples contain nearly equivalent concentrations of calcium and sodium, and bicarbonate is the major anion. The bottom sample is predominantly a sodium-chloride type. A minor amount of nitrate was detected in the middle sample (14 mg/L). The bottom sample, however, contains a significant concentration of nitrate (3,950 mg/L). No organics were detected at significant levels.

Gross beta activity is extremely high in the bottom sample collected from this well (32.2 $\mu\text{Ci/L}$). Cesium-137 and ^{90}Sr display a steady and marked increase in activity with depth. Very high activities of ^{137}Cs (0.3 $\mu\text{Ci/L}$), ^{60}Co (0.03 $\mu\text{Ci/L}$), ^{90}Sr (20 $\mu\text{Ci/L}$), and ^3H (0.24 $\mu\text{Ci/L}$) were detected in the deepest water sample collected from this well. The bottom sample had the highest activity of ^{90}Sr of all samples collected from any of the NHF wells. The contamination is sourced from the grout sheets.

Geophysical Log Interpretation. The neutron log response appears normal for the area and is usable for picking formation tops over the whole drilled section. Interpretation of the log indicates that the well bottoms in the Rome Formation. The gamma ray log response is characteristic for the general area down to approximately 300 ft. The gamma counts, below this depth, display a general increase to 935 ft (top of grout). There may be a breach in casing at 238 ft (indicated by log response and radiological data). The top of grout is marked by an increase

in temperature. Maximum counts on the gamma log, through the grout sheets are slightly < 15,000 cps.

The caliper log measures a reduction in casing diameter from 4 to 3.4 in. from 960 to the bottom of the logged interval. The reduction in diameter may be due to breached casing and grout in the casing. The caliper, apparent density, and SPR indicate joints at 30 ft.

The VDL indicates some intervals of good bonding from 0 to TD. The borehole may be double cased from 0 to 120 ft. The records that are available, however, do not confirm this interpretation.

The temperature and resistivity logs display a break at 536 ft. This feature is interpreted to indicate flow within casing. Numerous breaks in temperature occur between 850 and 992 ft. These temperature breaks do not correlate with resistivity shifts and are interpreted to indicate flow behind casing. The temperature log also displays a very interesting feature between 992 ft and TD; the temperature remains constant. Constant resistivity is also measured over the zone. This temperature anomaly is similar to that noted at the bottom of Well 1977. The interval probably indicates a zone of relatively major flow and mixing of waters.

Well Ranking. Well 1978 is an observation well and is cased to TD. There is evidence of casing leakage. Therefore, this well does not have EMI. The water in this well is highly contaminated (gross beta 32.2 $\mu\text{Ci/L}$) with radionuclides that mimic and were sourced from the grout sheets. The well is artesian and presents a threat for the spread of radiological contamination uphole through the wellbore and/or annulus. The wellhead of this well will require continual maintenance. The well should be P&A as soon as possible. Well 1978 is ranked very high (9) for P&A.

General P&A Plan. Figures 2.11–2.14 show the surface and wellhead configuration, interpreted well detail, and a sketch of the proposed P&A well. The well details should be considered as best estimates based on poor historical records and evaluation and interpretation of the geophysical borehole logs.

Well 1978 will be brought to static equilibrium before P&A begins. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option for Well 1978 is presented below.

The casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. The lower 35 ft of casing will be cemented prior to pressure testing. Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well. Three 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out one below the upper Maryville Limestone (shallow freshwater zone, contact at 290 ft), another near the base of the Rutledge Limestone (contact at 790 ft), and a third near the top of the Rome Formation (contact at 1,120 ft, top of first plug at 1,085 ft).

After placement of the 35 ft initial cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the lower Pumpkin Valley Shale, the unit that overlies the Rome Formation, to maximize hydraulic separation. It is expected that the next cement stage will be set from approximately 795 to 1,025 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will

be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval (765 to 795 ft) will be perforated or a window will be milled out to establish contact with the Rutledge Limestone, the unit that overlies the upper Pumpkin Valley Shale (injection horizon). The perforated/milled window interval will be squeezed using matrix-penetrating cement. After curing, the plug will be tagged.

The next cement stage will be placed from 320 to 725 ft. After placement of this plug, a 30-ft casing interval will be perforated, or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (290 to 320 ft). Ultrafine-grain, matrix-penetrating cement, and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged, and a final cement stage will be placed from 5 to 260 ft.

C.

OBSERVATION WELL 1978 (4SE-125W)

Fig. 2.11. Wellhead construction details.

Fig. 2.12. Well 1978 (4SE-125W) acoustic variable density log.

Fig. 2.13. Characteristic log responses, observations, and summary chemical data for Well 1978 (4SE-125W).

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Table 2.4. Well water measurements for Well 1978 (4SE-125W)

Well Construction

Original Date Well Completed = 1980

Well Type = Observation

Formation Penetration = Rome Formation

Ground Surface Elev (ft) = 786.78

Bottom Riser Casing Depth (ft bgs) = 1145

Bottom Riser Casing Elev (ft) = -351

Total Depth (ft bgs) = 1145

Total Depth Elev (ft) = -351

ORNL Grid Coordinates

Northing = 16447.69

Easting = 28304.7

Historical Notes:

Original ground surface (el. 794 ft) was regraded to current elevation (el. 786.8 ft) msl - Casing and total depth elevations are based on the original elevation.

Tapping Details

	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	6/14/95	0	20.9	0	0	--
Casing Annulus	--	--	--	--	--	--

Sample Details

Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
7/20/95	22	765	258
7/20/95	571	216	709
7/21/95	1120	-333	20,139

Water Level Measurements

Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/14/95	2.78	+ GS			789.56	
Water Level	7/18/95	2.71	+ GS			789.49	
Water Level	7/20/95	2.64	+ GS			789.42	
Water Level	9/6/95	0.16	GS			786.62	
Water Level	10/16/95	4.53	GS			782.25	
Water Level	11/13/95	4.46	GS			782.32	
Average						786.61	+ GS = Above Ground Surface
Minimum						782.25	GS = Ground Surface
Maximum						789.56	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.4 (continued). Well water sample analysis for Well 1978 (4SE-125W)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	8.89	11.44	12.29
Lab pH	7.57	11.48	12.06
Temperature (C)	19.6	25.3	24.3
Specific Conductivity ($\mu\text{S} / \text{cm}$)	140.4	1262	32200
Eh (mV)		-11.9	-44.2
Alkalinity ($\text{mg CaCO}_3 / \text{L}$)	24	199	1422
Total Dissolved Solids (mg / L)	258	709	20139
Total Suspended Solids (mg / L)	14	10	7
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	12.3	100	2080
Sodium	5.9	87.1	6650
Magnesium	.8	--	--
Potassium	6.4	7.4	88.3
Ammonium	.5	1.3	--
Lithium	--	--	3
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	6.2	105	7570
Sulfate	24.3	46	141
HCO_3	27	3	3
CO_3	1	33	289
Bromide	--	.8	65
Phosphate	--	--	--
Nitrate - Nitrogen	--	14	3950
Fluoride	1	1	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	2028.9	107554.8	32189878.8
Gamma Activity	28.4	2110	341000
Sr - 90		77723.4	20399490.1
Cs - 137	28.4	2110	309000
Co - 60			32600
H - 3	--	1500	235719.8
C - 14	--	--	--
Detected Organics, $\mu\text{g} / \text{L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	--	15	114
Benzene	--	--	3
Dichloromethane	4	2	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

2.5 SUMMARY OF WELL 1975 (4NW-400W)—RANKED 9

Well History. Well 1975 (4NW-400W) is one of six observation wells surrounding the NHF. Well 1975 was installed in 1980 and is 340 ft northwest of the NHF injection well (ORNL Well 1968). The well is cased throughout its length.

The observation wells were drilled through the injection zone (Pumpkin Valley Shale) to the top of the Rome Formation. This particular well does not extend into the Rome Formation. The wells were constructed to enable determination of grout sheet position and orientation. A gamma-sensitive probe was lowered down the observation well to detect the presence of grout sheets at depth. Several grout sheets were reported to have intercepted Well 1975.

Prior to initiation of batch injections at NHF, Well 1975 was found to be plugged at about 700 ft bgs. In October 1982 (before injection SI-3), the well was drilled out and recompleted. A rubber plug was hit at 500 ft bgs and some cement at 700 ft bgs. Steel was hit at 910 ft bgs. It is believed the casing was offset at that depth (Weeren 1984).

Construction Details. The total reported depth of Well 1975 is 986 ft bgs. The borehole logging probes stopped at a depth of 914 ft bgs, and the wireline sampler used by the WAG 10 sample team in July 1995 stopped at 917 ft bgs. The well is cased with 2 $\frac{7}{8}$ -in. ID carbon steel and was supposedly grouted throughout its length. All of the NHF observation wells were to be grouted in the lower 350 ft with low strength grout. It is unclear if this procedure was used on Well 1975. Figures 2.15–2.18 show the current wellhead configuration, well details, and proposed P&A.

Field Activities. Well 1975 was tapped on June 27, 1995. The well was not under pressure, and the water level immediately after tapping was 0.15 ft above the ground surface (artesian). A series of water level measurements were made through November 1995. The water level gradually dropped down to 11.60 ft bgs in November 1995. A list of the tapping information and water level data is provided in Table 2.5.

The water column in Well 1975 was sampled at three depths (25, 493, and 887 ft bgs) in July 1995 as part of the field investigation.

Analytical Results. Table 2.5 provides the results of the sample analysis for Well 1975. The well has relatively low levels of TDS compared to the rock cover and DM wells, which are open to a formation. The resistivity log run in the well also confirms this finding.

The pHs measured indicate basic (9.73 to 12.57) water and probable reaction with construction grout. The bottom sample from Well 1975 had the highest TDS of all the samples collected from the observation wells (89,927 mg/L). The TDS would indicate very high saline water. This water is not considered representative of formation water. The top two water samples are of sodium bicarbonate; the bottom sample is sodium chloride. No significant levels of organics were detected in Well 1975.

The bottom sample in Well 1975 contains high levels of nitrate (12,600 mg/L). Nitrate is below detection in the other two samples. Gross beta activity is extremely high (11.7 $\mu\text{Ci/L}$) in the deepest sample collected from this well. The bottom sample also contains very high activities of ^{60}Co (0.02 $\mu\text{Ci/L}$), ^{137}Cs (14 $\mu\text{Ci/L}$), ^{90}Sr (0.04 $\mu\text{Ci/L}$), and ^3H (1.7 $\mu\text{Ci/L}$). The source of the contamination is the NHF grout sheets.

Geophysical Log Interpretation. The neutron log is usable for picking formation tops over the whole drilled section. The gamma ray log responses are characteristic for the area down to approximately 550 ft. Below this depth, the gamma counts begin to increase due to influence of the waste grout sheets. The top of the first detected grout sheet is at approximately 730 ft. The top of grout is marked by an increase in temperature. Counts within the grout sheets are > 15,000 cps.

The caliper log indicates joints at 30-ft intervals and casing of three slightly different IDs was used for construction of the well. The slight decrease in casing ID from approximately 650 ft to logged depth may indicate solidified grout on the casing wall. The apparent density confirms the location of joints. There is no openhole. There is evidence on the temperature log of flow behind the casing over the grout-impacted interval.

The VDL indicates poor casing bond from ground surface to TD. The casing is "hanging in the hole," as evidenced by the ringing signature and poor rock signature.

The construction details for Well 1975 are very unclear because no detailed records for recompletion of this well were located. It appears that the well was originally installed with 4-in. ID casing grouted in place to TD in 1980. It is unknown whether the lower 350 ft was low-strength grout.

In 1983, prior to grout injection operations at NHF, the well was found to be obstructed at 700 ft. It was believed that the casing was offset at that depth (Weeren 1984). The cause for the casing offset was not given. Before emplacement of grout sheets during SI-3, the well was drilled out and recompleted to 986 ft (bgs). It appears that 2.78-in. ID casing was grouted within the existing 4-in. ID casing.

It should be expected that Well 1975 has multiple casing strings to total cased depth. This factor must be considered in the selection of the shaped charges to be used to reestablish contact with the formation.

Well Ranking. Well 1975 is an observation well and is cased to TD. Results indicate a high level of radiological contamination (gross beta 11.7 $\mu\text{Ci/L}$). The contamination in this well is indicative of radiological contamination sourced from the grout sheets. The well is artesian and presents a threat for the spread of radiological contamination uphole through the wellbore and/or annulus. If left inactive, the wellhead will require continual maintenance. The well should be P&A as soon as practically possible. Well 1975 is ranked very high (9) for P&A.

General P&A Plan. Figures 2.15–2.18 show the surface and wellhead configuration, interpreted well detail, and a sketch of the proposed plugged and abandoned well. The well details should be considered as best estimates based on poor historical records and evaluation and interpretation of the geophysical borehole logs. This well was recompleted and multiple casing strings are expected.

Well 1975 will be brought to static equilibrium before P&A begins. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option for Well 1975 is presented below.

The casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. The lower 35 ft of casing will be cemented

before pressure testing. If pressure is maintained, subsequent plugs will be placed, squeezed using the bradenhead method, and tagged. Two 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out one below the upper Maryville Limestone (shallow freshwater zone) contact (240 to 270 ft) and another near the base of the Rutledge Limestone (688 to 718 ft). The well appears to be doubly cased over the intervals.

It is expected that the second cement stage will be set from approximately 718 to 875 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone, the unit that overlies the upper Pumpkin Valley Shale (injection horizon), and maximize hydraulic separation. The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug will be tagged.

The next cement stage will be placed from 270 to 658 ft (may be placed in two stages). After placement of this plug, a 30-ft casing interval will be perforated or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (210 to 270 ft). Ultrafine-grain, matrix-penetrating cement and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged and a final cement stage will be placed from 5 to 210 ft.

OBSERVATION WELL 1975 (4NW-400W)

Fig. 2.15. Wellhead construction details.

Fig. 2.16. Well 1975 (4NW-400W) acoustic variable density log.

Fig. 2.17. Characteristic log responses, observations, and summary chemical data for Well 1975 (4NW-400W).

Fig. 2.18. Existing well construction and proposed P&A for Well 1975 (4NW-400W):

Table 2.5. Well water measurements for Well 1975 (4NW-400W)

Well Construction							
Original Date Well Completed = 1980				ORNL Grid Coordinates			
Well Type = Observation				Northing = 16703.7			
Formation Penetration = Rome Formation				Easting = 27909			
Ground Surface Elev (ft) = 770.34							
Bottom Riser Casing Depth (ft bgs) = 986				Historical Notes: 			
Bottom Riser Casing Elev (ft) = -215.66							
Total Depth (ft bgs) = 986							
Total Depth Elev (ft) = -215.66							
Tapping Details							
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments	
Riser Casing	6/27/95	0	20.5	5.5	0.1	--	
Casing Annulus	--	--	--	--	--	--	
Sample Details							
	Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)			
	7/11/95	25	745	492			
	7/12/95	493	277	457			
	7/12/95	887	-117	89,927			
Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/27/95	0.15	+ GS			770.49	
Water Level	7/11/95	0.14	+ GS			770.48	
Water Level	7/13/95	0.14	+ GS			770.48	
Water Level	9/6/95	10.18	GS			760.16	
Water Level	10/16/95	11.63	GS			758.71	
Water Level	11/13/95	11.60	GS			758.74	
Average					764.84	+ GS= Above Ground Surface	
Minimum					758.71	GS= Ground Surface	
Maximum					770.49		

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.5 (continued). Well water sample analysis for Well 1975 (4NW-400W)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	10.18	9.73	12.57
Lab pH	9.84	9.82	12.33
Temperature (C)	20.4	23.8	28.1
Specific Conductivity ($\mu\text{S} / \text{cm}$)	495	502	115700
Eh (mV)	105.3	132.2	-6.4
Alkalinity (mg CaCO_3 / L)	192	189	9031
Total Dissolved Solids (mg / L)	492	457	89927
Total Suspended Solids (mg / L)	32	20	924
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	2.4	2.5	--
Sodium	93.3	95.8	37000
Magnesium	.3	.7	--
Potassium	6.5	6.5	854
Ammonium	4.7	4.6	54
Lithium	.2	.2	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	15.4	24.9	35100
Sulfate	--	.6	811
HCO_3	100	153	22
CO_3	63	37	3966
Bromide	--	--	119
Phosphate	--	--	203
Nitrate - Nitrogen	--	--	12600
Fluoride	.5	.5	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	6.2	--	--
Gross Beta	458.5	743.1	11744757.5
Gamma Activity	212	216	14300000
Sr-90			35059.6
Cs-137	212	216	14100000
Co-60			219000
H-3	--	--	1662216.2
C-14	--	--	4546.8
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	--	--	103
Benzene	--	--	4
Toluene	--	--	3
Xylenes (total)	--	--	4

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

2.6 SUMMARY OF WELL 2955 (DM2-PV)—RANKED 9

Well History. Well 2955 (DM2-PV), one of seven deep-monitoring wells installed in the vicinity of the NHF, is located 1,090 ft west of the injection well (Well 1968). The well has an open interval in the upper and lower Pumpkin Valley Shale. The well was completed to a depth of 1,063 ft bgs in January 1986.

Well 2955 was sampled by ORNL in January 1986. The well was shut-in after the 1986 sampling as a safety measure in response to the ORNL sampling team being spattered with contaminated groundwater from DM Well 2954. The well remained shut-in until tapping by the WAG 10 team in July 1995.

Construction Details. A 10¾-in. surface casing is installed in the top 50 ft of Well 2955. The surface casing was grouted in place in a nominal 15-in. diameter borehole. A nominal 10-in. diameter hole was drilled from 50 to 750 ft and 6-in. ID black steel casing was grouted in place. A nominal 6-in. diameter openhole was then drilled from 750 to 1,063 ft bgs. The borehole logging team measured the TD of the well to be 1,064 ft bgs.

A bermed concrete pad was poured around the wellhead, and a metal building (7802D) was installed on the pad over the top of the well. Figures 2.19–2.22 show the current wellhead configuration, well details, and proposed P&A.

Field Activities. Well 2955 was tapped on July 25, 1995. The annulus between the 6-in. wellhead casing and the 2¾-in. steel tubing was not under pressure; however, the tubing had a pressure of 12.2 psig. The water level immediately after tapping was 6.89 ft bgs. A series of pressure and water level measurements were made through November 1995 that indicate flowing artesian conditions. The tapping information and water level data are provided in Table 2.6.

The water column in Well 2955 was sampled at three depths (32, 535, and 1,038 ft bgs) in August 1995 as part of the WAG 10 field investigation. Well 2955 was sampled again in October 1995 at a depth of 1,040 ft bgs for offsite laboratory analysis.

Analytical Results. Table 2.6 provides the results of the CSL sample analysis for Well 2955. The water sampled from this well is basic (pH between 7.4 and 9.0). All three samples are high saline brine (TDS > 254,516 mg/L). The water is composed predominantly of sodium with lesser amounts of calcium, and the major anion is chloride (Fig. 2.23). Nitrate was detected in the 1995 round of sampling at a concentration that ranged from 231 to 2,040 mg/L. The highest concentration was measured in the bottom sample. These nitrate results compare with those from the historical sampling of the well (1991 mg/L, nitrate). No organics were detected at significant levels.

Very high gross beta activity (2.6 to 9.2 µCi/L), very high ⁹⁰Sr (2.0 to 4.5 µCi/L), and moderate ⁶⁰Co (1,360 to 5,110 pCi/L) activities were detected in Well 2955. Very high beta (10.8 µCi/L) and ⁹⁰Sr (2.5 µCi/L) were also detected by ORNL in the 1986 sampling. The radionuclides detected in this well were sourced from the waste grout sheets emplaced in the Pumpkin Valley Shale. Induced or natural fractures containing water contaminated with radionuclides were intercepted by this well.

The analytical results for historical samples and the results of the offsite laboratory analysis for Well 2955 are presented in Table 2.6. This particular sample contained high solids. That factor

is reflected in the offsite results. Besides the major common metals, the sample contains relatively high iron (9,370 mg/L), barium (643 mg/L), and zinc (328 mg/L). The high barium may be from the highly saline water or drill fluid. These results are representative of the solid drilling debris and not the water sampled and analyzed from Well 2955.

The bottom water sample collected from Well 2955 contained high solids. A sample of the solid material was mounted on filter paper, glued to an SEM sample stub, coated with gold (Au) to provide a conductive layer, and examined in an ISI SEM equipped with an EDS system. The service was provided as a courtesy of Dr. S. Y. Lee and Dr. M. Elless of ORNL.

The SEM photomicrograph and EDS spectrum for the material collected from Well 2955 is shown on Fig. 2.24. The fibrous material seen in the photomicrograph is filter paper. The solids are amorphous and display no crystal form or recognizable shape (such as fly ash). The lack of crystal form and elements detected would indicate that the solids are comprised of drilling debris (clay, drill cuttings, and casing and drilling component metal pieces). No indication of solid waste grout was found.

Geophysical Log Interpretation. The neutron log response is useful for lithology and picking formation tops. The caliper log shows 20 ft casing strings. The caliper also indicates an anomalous narrowing of casing from 621 to 638 ft. The apparent density displays an unusual response throughout the well. The response is rather consistent from 0 to 280 ft, shows a general decrease from 280 ft to bottom of casing, and then is consistent in the openhole. The SPR log is shorted out and would confirm laboratory results indicative of high saline brine. Several breaks in temperature (282, 448, and 545 ft) are noted on the log.

The VDL indicates good bonding to bottom of casing. No fractures are apparent, just bedding features.

The gamma log response is not characteristic of the area. The log measures a continually increasing count rate from the top to the bottom of the well. Filtrate sourced from the waste grout sheets is contributing gamma to the logging tool. A sharp gamma peak is logged at 1,040 ft bgs. This peak correlates with temperature and caliper anomalies, which would imply a hydraulically active fracture. The log was then compared to the "old" openhole gamma log run in nearby Well 2374 to confirm the gamma peak. The gamma peak does not appear on the old log. This would imply that waste filtrate from past injections was still migrating along fractures (from 1984 to 1995).

Well Ranking. Well 2955 is a DM well. There is evidence of casing leakage. Therefore, this well does not have EMI. The water in this well is highly contaminated (gross beta 97.8 $\mu\text{Ci/L}$) with radionuclides that mimic and are sourced from the grout sheets. The well is artesian and presents a threat for the spread of radiological contamination uphole through the wellbore and/or annulus. The wellhead is presently shut-in and will require continual maintenance. The well should be P&A as soon as possible. Well 2955 is ranked very high (9) for P&A.

General P&A Plan. Figures 2.19–2.22 show the surface and wellhead configuration, well details, and proposed P&A for Well 2955. The well construction is based on good historical records of this well.

Well 2955 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be

placed (730 to 1,064 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h above the casing shoe by either shutting in the well or placing a packer.

Two plugs are expected to be placed in this well (below the upper Maryville Limestone freshwater zone and near the base of the Rutledge Limestone, overlying the injection horizon). The first 30-ft (approximately 700 to 730 ft) interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out near the base of the Rutledge Limestone. The perforated/milled window interval will be squeezed (approximately 670 to 730 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged. The next cement stage will be placed from 276 to 670 ft below the upper Maryville Limestone contact.

The second 30-ft (246 to 276 ft) interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 246 ft). Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 216 to 276 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 216 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

DEEP MONITORING WELL 2955 (DM2-PV)

Fig. 2.19. Wellhead construction details.

Fig. 2.20. Well 2955 (DM2-PV) acoustic variable density log.

Fig. 2.21. Characteristic log responses, observations, and summary chemical data for Well 2955 (DM2-PV).

2-50

Table 2.6. Well water measurements for Well 2955 (DM2-PV)

Well Construction	
Original Date Well Completed = 1985	ORNL Grid Coordinates
Well Type = Deep Monitoring	Northing = 16469.95
Formation Penetration = Pumpkin Valley Shale	Easting = 27091.44
Ground Surface Elev (ft) = 758.54	
Bottom Riser Casing Depth (ft bgs) = 750	Historical Notes:
Bottom Riser Casing Elev (ft) = 8.54	
Total Depth (ft bgs) = 1063	
Total Depth Elev (ft) = -304.46	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	7/25/95	12.2	7.9	7	350	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
8/3/95	32	727	254,516
8/3/95	535	224	270,250
8/3/95	1038	-279	268,125

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Pressure	7/27/95		GS	1	4.36	762.90
Water Level	8/2/95	6.89	GS			751.65
Water Level	8/3/95	6.89	GS			751.65
Pressure	9/6/95		GS	4.7	12.89	771.43
Pressure	10/16/95		GS	5.4	14.51	773.05
Water Level	10/30/95	1.63	GS			756.91
Pressure	10/30/95		GS	5.9	15.66	774.20
Pressure	11/13/95		GS	5.3	15.27	773.81
Average						764.45
Minimum						751.65
Maximum						774.20

+ GS = Above Ground Surface
GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.6 (continued). Well water sample analysis for Well 2955 (DM2-PV)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	9	7.79	7.56
Lab pH	8.59	4.55	5.13
Temperature (C)	19.1	23.6	27.2
Specific Conductivity ($\mu\text{S} / \text{cm}$)	224000	222000	220000
Eh (mV)	-30	106.3	110
Alkalinity ($\text{mg CaCO}_3 / \text{L}$)	332	--	14
Total Dissolved Solids (mg / L)	254516	270250	268125
Total Suspended Solids (mg / L)	172	379	179

Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	32800	33400	34000
Sodium	63100	68200	68800
Magnesium	4790	5310	5440
Potassium	267	92	185
Ammonium	112	--	--
Lithium	--	--	--

Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	152000	162000	163000
Sulfate	--	--	--
HCO_3	374	--	17
CO_3	15	--	0
Bromide	1530	1620	1660
Phosphate	--	--	--
Nitrate - Nitrogen	231	1920	2040
Fluoride	--	--	--

Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	4551.1
Gross Beta	2594735.7	4679242.4	9214946.6
Gamma Activity	1360	2480	52500
Sr - 90	2108270.5	4418410.7	4470921.1
Co - 60	1360	2480	5110
H - 3	35789.2	69421.6	71678.4
C - 14	--	1020.7	220.7

Detected Organics, $\mu\text{g} / \text{L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	165	50	40
Benzene	2	--	--
Chlorobenzene	6	3	3
Naphthalene	5	--	--
Trichloroethene	3	--	--
Xylenes (total)	9	--	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.6 (continued). Historical sample analysis for Well 2955 (DM2-PV)

pH, Alkalinity, and TDS

Analyte	January 1986
	unfiltered
pH	4.3
Alkalinity (mg HCO ₃ /L)	--
Total Dissolved Solids (mg/L)	240230

Cations, mg/L

Analyte	January 1986
	unfiltered
Calcium	26000
Sodium	57000
Magnesium	4400
Potassium	230
Manganese	100
Iron	130
Lithium	51
Barium	610
Strontium	2600
Phosphorus	20

Anions, mg/L

Analyte	January 1986
	unfiltered
Chloride	150000
Sulfate	--
Bromide	2100
Phosphate	17
Nitrate	1991
Fluoride	.28
Iodide	18

Radionuclides, pCi/L

Analyte	January 1986
	unfiltered
Gross Beta	10810800
Sr-90	2540538
Cs-137	--
Co-60	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.
The January 1986 sample was collected at a depth of 1050 ft bgs.

Table 2.6 (continued). Offsite laboratory analysis for Well 2955 (DM2-PV)

Metals, mg/L	
Aluminum	12.3
Antimony	2.76
Arsenic	--
Barium	643
Cadmium	0.273
Calcium	27200
Chromium	0.434
Cobalt	0.501
Copper	1.34
Iron	9370
Lead	0.08
Magnesium	7290
Manganese	352
Mercury	0.0001
Nickel	1.13
Potassium	--
Selenium	--
Silver	0.6
Sodium	41600
Thallium	0.41
Vanadium	1.15
Zinc	328
Detected organics, µg/L	
Acetone	52
Detected pesticides/PCB, µg/L	
none	
Sulfide, µg/L	
Sulfide	--
Detected BNAE, µg/L	
Bis(2-ethylhexyl)phthalate	3
Di-N-butyl phthalate	4
Cyanide, µg/L	
Cyanide	1.4

Note: Sample collected from a depth of 1040 ft bgs.

Fig. 2.23. Chemistry of standing water column in NHF deep monitoring Well 2955.

A.

B.

Courtesy of Dr. S. Y. Lee and Dr. M. Elless of ORNL

Fig. 2.24. Scanning electron microscopy and energy-dispersive x ray analyzer system images of solids from Well 2955.

2.7 SUMMARY OF WELL 1982 (4W-200W)—RANKED 8

Well History. Well 1982 (4W-200W) is one of six observation wells surrounding the NHF. Well 1982 was installed in 1973 and is 200 ft west of the NHF injection well (Well 1968). The well is cased throughout its length.

The observation wells were designed to be drilled through the injection zone (Pumpkin Valley Shale) to the top of the Rome Sandstone. Well 1982 does penetrate into the Rome Formation. The observation wells were constructed to enable determination of grout sheet position and orientation. A gamma-sensitive probe was lowered down the observation wells to detect the presence of grout sheets at depth. Numerous grout sheets intercepted the 1982 borehole.

Construction Details. The TD of the borehole of Well 1982 is 1,152 ft bgs. The borehole logging and sample teams each measured the TD of the well to be 1,117 ft bgs. The well is cased with 2 $\frac{7}{8}$ -in. carbon steel and grouted to a depth of 1,117 ft. Figures 2.25–2.28 show the current wellhead configuration, well details, and proposed P&A.

Field Activities. Well 1982, tapped on July 24, 1995, was not under pressure, and the water level immediately after tapping was 10.61 ft bgs. A series of water level measurements were made through December 1995. Within two months after tapping, Well 1982 became flowing artesian. The wellhead was shut-in so pressure readings could be made. The pressure continued to increase up to 113 psig on December 7, 1995 (date of last reading). The tapping information and water level data are provided in Table 2.7.

The water column in Well 1982 was sampled at three depths (36, 581, and 1,094 ft bgs) in July 1995 as part of the field investigation.

Sample Analysis. Table 2.7 provides the results of the sample analysis for Well 1982. TDS are relatively low in the standing water column. The resistivity logs display a gradual decrease with a major step (increased conductivity) at 960 ft. The log data confirms the analytical results.

The water sampled from Well 1982 is basic (11.38 to 12.11 pH), fresh to brackish, and predominantly calcium bicarbonate type. The high pHs would indicate reaction with grout. Nitrate at a low concentration (18.7 mg/L) was detected in the bottom water sample. Nitrate was below detection limits in the upper two samples. No organics were detected at significant levels.

The gross beta activity is elevated in the bottom sample collected from this well (0.14 $\mu\text{Ci/L}$). The activity of ^{137}Cs and ^{90}Sr increase significantly with depth in the cased well. The maximum activities detected are ^{137}Cs 0.02 $\mu\text{Ci/L}$ and ^{90}Sr 0.28 $\mu\text{Ci/L}$. Cobalt-60 was not detected, and ^3H (3,213.5 pCi/L) is below normal background levels.

Geophysical Log Interpretation. The neutron log response is usable for lithology and picking formation tops over the whole drilled section. Interpretation of the log indicates that the well bottom is in the Rome Formation. The gamma ray log response, between 0 to 672 ft, is characteristic for the general area. The gamma counts increase dramatically below 672 ft and into the top of the Rome Formation due to influence of the grout sheets. The top of the first encountered grout sheet is at approximately 810 ft. Gamma counts through the grout sheets are > 15,000 cps.

The caliper log is featureless down to 1,072 ft. Some grout may be present within the casing below this depth. The casing is breached near 1,111 ft. The caliper, apparent density, and SPR indicates joints at 30 ft.

The VDL indicates surface casing set at 40 ft. Cement bonding is good to 514 ft, moderate to poor to 814 ft, and poor from 814 ft to TD. A washout is indicated at 40 ft. The amplitude response agrees with the interpreted bonding from the VDL. The construction grout behind casing from 790 to TD is probably low strength.

A temperature break at 565 ft indicates flow behind casing, with no corresponding change in resistivity. Breaks in measured temperature correlate with changes in resistivity—864 ft and 892 ft. Numerous breaks in temperature occur between 785 and 970 ft that would indicate flow behind casing. The log measures constant temperature from 970 ft to total logged depth. Resistivity is pegged out over the same zone. The interval probably indicates a zone of relatively major flow and mixing of waters.

The resistivities measured with the logging tool do not correlate with the laboratory TDS (1,646 mg/L) determined for the sample collected at 1,094 ft. The log response would indicate saline to briny water. Water of a composition similar to that collected and analyzed from other observation wells in the area would be expected at this depth.

Well Ranking. Well 1982 is an observation well and is cased to TD. There is evidence of casing leakage. Therefore, this well does not have EMI. The water in this well is contaminated (gross beta 0.14 $\mu\text{Ci/L}$) with radionuclides that mimic and were sourced from the grout sheets. The well is flowing artesian and presents a threat for the spread of radiological contamination uphole through the wellbore and/or annulus. The wellhead will require continual maintenance. The well should be P&A as soon as possible. Well 1982 is ranked high (8) for P&A.

General P&A Plan. Figures 2.25–2.28 show the surface and wellhead configuration, interpreted well detail, and a sketch of the proposed P&A well. The well details should be considered as best estimates based on poor historical records and evaluation and interpretation of the geophysical borehole logs.

Well 1982 will be brought to static equilibrium before P&A begins. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option for Well 1982 is presented below.

The casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. The lower 35 ft of casing will be cemented prior to pressure testing. Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well. Three 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out one below the upper Maryville Limestone (shallow freshwater zone, contact at 285 ft), another near the base of the Rutledge Limestone (contact at 742 ft), and a third near the top of the Rome Formation (contact at 1,092 ft, top of first plug at 1,057 ft).

After placement of the 35-ft initial cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the lower Pumpkin Valley Shale, the unit that overlies the Rome Formation, to maximize hydraulic separation. It is expected that the next cement stage will be set from approximately 742 to 1,027 ft. All cement stages will be placed at

less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone, the unit that overlies the upper Pumpkin Valley Shale (injection horizon). The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug will be tagged.

The next cement stage will be placed from 315 to 682 ft. After placement of this plug, a 30-ft casing interval will be perforated or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (285 to 315 ft). Ultrafine-grain, matrix-penetrating cement, and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged, and a final cement stage will be placed from 5 to 255 ft.

OBSERVATION WELL 1982 (4W-200W)

Fig. 2.25. Wellhead construction details.

Fig. 2.26. Well 1982 (4W-200W) acoustic variable density log.

Fig. 2.27. Characteristic log responses, observations, and summary chemical data for Well 1982 (4W-200W).

Fig. 2.28. Existing well construction and proposed P&A for Well 1982 (4W-200W).

Table 2.7. Well water measurements for Well 1982 (4W-200W)

Well Construction		
Original Date Well Completed =	1973	ORNL Grid Coordinates
Well Type =	Observation	Northing = 16504.8
Formation Penetration =	Rome Formation	Easting = 27975.23
Ground Surface Elev (ft) =	782.63	
Bottom Riser Casing Depth (ft bgs) =	1107	Historical Notes:
Bottom Riser Casing Elev (ft) =	-347.37	
Total Depth (ft bgs) =	1152	
Total Depth Elev (ft) =	-369.37	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	7/24/95	0	20.6	0.4	0	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
7/27/95	36	747	432
7/31/95	581	202	1,262
7/31/95	1094	-311	1,646

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Water Level	7/24/95	10.61	GS			772.02
Water Level	7/27/95	10.64	GS			771.99
Water Level	9/6/95	0.20	+ GS			782.83
Water Level	10/16/95	0.77	+ GS			783.40
Water Level	11/13/95	0.77	+ GS			783.40
Pressure	11/20/95		GS	89	207.11	989.74
Pressure	11/20/95		GS	84	195.57	978.20
Pressure	11/21/95		GS	101	232.97	1015.60
Pressure	11/21/95		GS	98	226.05	1008.68
Pressure	11/28/95		GS	104	241.71	1024.34
Pressure	11/29/95		GS	111	257.85	1040.48
Pressure	11/30/95		GS	112	260.16	1042.79
Pressure	12/7/95		GS	113	262.47	1045.10
Average						926.04
Minimum						771.99
Maximum						1045.10
						+ GS = Above Ground Surface
						GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.7 (continued). Well water sample analysis for Well 1982 (4W-200W)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	11.38	12.11	11.86
Lab pH	11.65	11.9	11.78
Temperature (C)	18.5	19.9	25.6
Specific Conductivity ($\mu\text{S} / \text{cm}$)	760	2330	2900
Eh (mV)	3.7	95.7	87.5
Alkalinity (mg CaCO_3 / L)	192	571	915
Total Dissolved Solids (mg / L)	432	1262	1646
Total Suspended Solids (mg / L)	7	25	153
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	88.6	233	378
Sodium	11.7	14.1	75.6
Magnesium	--	--	--
Potassium	4.2	6.8	25.9
Ammonium	3.4	12	106
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	6.8	20.9	131
Sulfate	49.2	15.4	96.7
HCO_3	7	2	9
CO_3	68	80	313
Bromide	--	--	--
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	18.7
Fluoride	2	5.6	23.8
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	2303.8	1210.6	141411.5
Gamma Activity	252	257	17500
Sr-90	--	--	283564.8
Cs-137	252	257	17500
H-3	--	201.8	3213.5
C-14	--	--	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	17	11	--
Dichloromethane	10	5	--
Xylenes (total)	--	6	8

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

2.8 SUMMARY OF WELL 1977 (4S-200W)—RANKED 8

Well Summary. Well 1977 (4S-200W) is one of six observation wells surrounding the NHF. Well 1977 was installed in 1973 and is 200 ft south of the NHF injection well (ORNL Well 1968). The well is cased throughout its length.

The observation wells were drilled through the injection zone (Pumpkin Valley Shale) to the top of the Rome Sandstone. This observation well does not appear to penetrate the Rome Formation. These wells were purposely constructed to enable determination of grout sheet position and orientation. A gamma sensitive probe was lowered down the observation wells to detect the presence after injection of grout sheets at depth. Numerous grout sheet intercepted Well 1977.

Construction Details. The total drilled depth of the borehole of Well 1977 is 1,200 ft. The well was reported to be cased with 2 $\frac{7}{8}$ -in. carbon steel to a depth of 1,102 ft. The borehole logging team measured the total logged depth of 1,147 ft bgs. While sampling Well 1977 in June 1995, the wireline sampler could not advance beyond 508 ft bgs due to an obstruction. Figures 2.29–2.32 show the current wellhead configuration, well details, and proposed P&A.

Field Activities. Well 1977 was tapped on June 12, 1995. The well was not under pressure, and the water level immediately after tapping was 3.50 ft bgs. A series of water level measurements were made through November 1995. The water level gradually dropped to 20.04 ft bgs in November 1995. The tapping information and water level data are provided in Table 2.8.

The water column in Well 1977 was also sampled at three depths (29, 256, and 483 ft bgs) in June 1995 as part of the WAG 10 field investigation. The deepest sample (483 ft) was collected well above the bottom depth (1,147 ft) of the well.

Analytical Results. Table 2.8 provides the results of the sample analysis for Well 1977. The pH of the standing water column in this well is basic (8.69 to 11.28 pH). The higher pHs of the lower two sample would indicate reaction with grout. To 483 ft, the water is low in TDS (fresh to slightly brackish) compared to the rock cover and DM wells, which are briny. The resistivity log, however, indicates increasing TDS to TD. The TDS content at the bottom of the well is most likely similar to Well 1975. The water sampled and logged in this well would not be representative of native formation water.

The top water sample has equal concentrations of calcium and sodium, and sulfate is the major anion. The bottom two water samples are predominantly calcium-bicarbonate type.

Nitrate was not detected in the samples (collected above 500 ft). Gross beta activity ranges from 1,062.5 to 4,766.1 pCi/L and ^{137}Cs ranges from 143 to 472 pCi/L in the three shallow samples. The radiological results for this well would not be representative of the whole standing water column. Dichloromethane was the only organic compound detected at levels above the SDWA MCL.

It is expected, based on historical information compiled on this well during NHF operations and field monitoring of geophysical logging cable and tools, that water in the lower portion of this well (below approximately 802 ft) will be contaminated with radionuclides sourced from the grout sheets.

Geophysical Log Interpretation. The neutron log response is usable for picking formation tops over the whole drilled section. Interpretation of the log indicates that the well bottoms in the lower Pumpkin Valley Shale. The gamma ray log response is characteristic for the general area down to approximately 682 ft. Below this depth, the gamma counts begin to increase due to influence of the grout sheets. The top of the first encountered grout sheet is at approximately 803 ft and is marked by an increase in temperature and a decrease in resistivity. Counts within the grout sheets are $> 15,000$ cps.

The caliper log was not functioning properly when run in this well (i.e., measuring diameter). Features on the log, however, if present would be detected by the tool. The caliper trace is featureless. The apparent density and SPR indicate that the well was constructed with 30-ft casing strings.

The VDL indicates good bonding from 0 to 440 ft, moderate to poor bonding from 440 to 790 ft, and poor bonding from 790 ft to logged TD. The construction grout behind casing from 790 ft to TD is probably low strength. Surface casing extends to 40 ft.

The temperature log measures an increase at 509 ft. No corresponding change in resistivity is noted at this depth. Possible flow behind casing is indicated at this depth. Numerous breaks in temperature occur starting at 803 ft and continue into the grout sheets. These temperature breaks correlate with resistivity shifts interpreted to indicate in borehole flow. The temperature log also displays a very interesting feature between 1,020 ft and TD; the temperature remains constant. Constant resistivity is also measured over the zone. The interval probably indicates a zone of relatively major flow and mixing of waters.

Well Ranking. Well 1977 is an observation well and is cased to TD. Water from the bottom of this well could not be collected because of an obstruction at approximately 500 ft; therefore, the results are not representative of the bottom of the well. Results for the sample collected at 483 ft indicates gross beta at $< 4,800$ pCi/L. The contamination in this well is indicative (mimics) of radiological contamination sourced from the grout sheets. The well presents a threat for the spread of radiological contamination uphole through the wellbore and/or annulus. The well should be P&A as soon as possible. Well 1977 is ranked high (8) for P&A.

General P&A Plan. Figures 2.29–2.32 show the surface and wellhead configuration, interpreted well detail, and a sketch of the proposed P&A well. The well details should be considered as best estimates based on poor historical records and evaluation and interpretation of the geophysical borehole logs.

Well 1977 will be brought to static equilibrium before P&A begin. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option for Well 1977 is presented below.

The casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. The lower 35 ft of casing will be cemented before pressure testing. Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well. Two 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out one below the upper Maryville Limestone (shallow freshwater zone, contact at 280 ft) and another near the base of the Rutledge Limestone (contact at approximately 817 ft).

It is expected that the second cement stage will be set from approximately 817 to 1,110 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone, the unit that overlies the upper Pumpkin Valley Shale (injection horizon), and maximize hydraulic separation. The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug will be tagged.

The next cement stage will be placed from 310 to 757 ft. After placement of this plug, a 30-ft casing interval will be perforated or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (250 to 310 ft). Ultrafine-grain, matrix-penetrating cement, and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged, and a final cement stage will be placed from 5 to 250 ft.

OBSERVATION WELL 1977 (4S-200W)

Fig. 2.29. Wellhead construction details.

Fig. 2.30. Well 1977 (4S-200W) acoustic variable density log.

Fig. 2.31. Characteristic log responses, observations, and summary chemical data for Well 1977 (4S-200W).

Fig. 2.32. Existing well construction and proposed P&A for Well 1977 (4S-200W).

Table 2.8. Well water measurements for Well 1977 (4S-200W)

Well Construction

Original Date Well Completed = 1973

Well Type = Observation

Formation Penetration = Rome Formation

Ground Surface Elev (ft) = 799.09

Bottom Riser Casing Depth (ft bgs) = 1102

Bottom Riser Casing Elev (ft) = -302.91

Total Depth (ft bgs) = 1200

Total Depth Elev (ft) = -400.91

ORNL Grid Coordinates

Northing = 16306.72

Easting = 28176.23

Historical Notes:

Tapping Details

	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	6/12/95	0	20.6	0	0	--
Casing Annulus	--	--	--	--	--	--

Sample Details

Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
6/20/95	29	770	212
6/21/95	256	543	333
6/21/95	483	316	1,382

Water Level Measurements

Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/12/95	3.50	GS			795.59	
Water Level	6/14/95	3.51	GS			795.58	
Water Level	6/20/95	3.52	GS			795.57	
Water Level	6/21/95	6.86	GS			792.23	
Water Level	9/6/95	18.06	GS			781.03	
Water Level	10/16/95	18.08	GS			781.01	
Water Level	11/13/95	20.04	GS			779.05	
Average						788.58	+ GS = Above Ground Surface
Minimum						779.05	GS = Ground Surface
Maximum						795.59	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.8 (continued). Well water sample analysis for Well 1977 (4S-200W)

General Parameters

Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	8.69	11.28	11
Lab pH	8.45	11.06	11.15
Temperature (C)	20.2	18.4	19.4
Specific Conductivity ($\mu\text{S} / \text{cm}$)	202	463	472
Eh (mV)	35.9	49	68.2
Alkalinity ($\text{mg CaCO}_3 / \text{L}$)	12	98	112
Total Dissolved Solids (mg / L)	212	333	1382
Total Suspended Solids (mg / L)	23	12	--

Cations, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	11.8	51	50.3
Sodium	10.3	11.1	10.6
Magnesium	.6	--	--
Potassium	3.3	3.4	3.6
Ammonium	1.7	2.7	3.5
Lithium	--	--	--

Anions, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	6.6	15.1	6.6
Sulfate	29.5	45.1	46.3
HCO_3	14	3	11
CO_3	0	23	42
Bromide	--	--	--
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	.9	1.9	2

Radionuclides, pCi/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	4766.1	1062.5	1222.7
Gamma Activity	220	143	472
Sr-90	--	--	--
Cs-137	220	143	472
H-3	538.7	--	426.1
C-14	--	--	--

Detected Organics, $\mu\text{g/L}$

Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	27	13	13
Benzene	2	3	3
Dichloromethane	9	16	17
Ethylbenzene	--	3	3
Naphthalene	--	3	3
Toluene	3	5	6
Xylenes (total)	4	9	11

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

2.9 SUMMARY OF WELL 2373 (DM1-RM)—RANKED 6

Well History. Well 2373 (DM1-RM) is one of seven deep-monitoring wells installed in the vicinity of the NHF after closure of waste injection operations. Well 2373 is located 1,050 ft east of the NHF injection well (Well 1968). Currently, Well 2373 is completed with an open interval in the Rome Formation.

Well 2373 was originally drilled (June 1984) to a depth of 1,487 ft bgs. Casing was installed to a depth of 550 ft bgs, and the remaining length of the borehole was open to five different formations. Two samplings (September 1984 and January 1985) of the standing water column were conducted by ORNL prior to modification of the well. Significant radiological contamination was confirmed from analytical results. After discovery of contamination, modifications were made (January 1986) so that Well 2373 is presently open only in the Rome Formation.

In February 1987, a computerized pressure monitoring system was installed in Well 2373. The system consisted of a pressure transducer, transducer carrier, tension-set packer, wireline cable, and landing nipple assembly. The equipment was installed on 2 $\frac{3}{8}$ -in. EUE steel tubing and allowed real-time monitoring of pressure in the well. No reports have been located at ORNL that present results from pressure monitoring of the Rome Formation in this well.

Since modification, the well has been sampled twice; in January 1986 by ORNL and in 1995 by Bechtel.

Construction Details. The borehole of Well 2373 was originally drilled to a depth of 1,487 ft bgs, and 6-in. ID black carbon steel casing was installed to a depth of 550 ft bgs. The borehole had a 10-in. nominal diameter for the top 550 ft, and 6 in. for the rest of the well. The 6-in. casing was grouted in place.

During the January 1985 modifications, 30 ft of gravel was emplaced in the bottom of Well 2373. Bentonite pellets were placed on the gravel, and an 8-ft cement plug was set above the bentonite. Black carbon steel casing (4-in. ID) with a formation packer shoe attached was installed at 1,092 ft bgs. Cement grout was pumped into the annulus of the 4-in. casing; however, no cement returns to the surface were noted. It was found that cement had filled up the hole beneath the formation packer to a depth of 1,125 ft bgs (33 ft below the formation packer shoe). An attempt was made to under-ream the hole. An equipment failure occurred at 1,154 ft bgs, and it was decided to complete the well at that point. A plug of bentonite and cement was set to 1,149 ft bgs leaving only 57 ft of open hole.

The WAG 10 borehole logging team measured the TD of Well 2373 to be 1,143 ft bgs in November 1995. Figures 2.33–2.36 show the current wellhead configuration, well details, and proposed P&A.

Field Activities. Well 2373 was tapped on August 8, 1995. The annulus between the 4-in. wellhead casing and the 2 $\frac{3}{8}$ -in. steel tubing was not under pressure; however, the tubing had a pressure of 1.0 psig. A series of water level measurements were made through November 1995. Well 2373 is artesian and if left open would at times flow. The tapping information and water level data are provided in Table 2.9.

In order to sample the water in Well 2373 and prepare the well for possible P&A, the transducer and packer assembly had to be removed. On September 19–21, 1995, approximately

1,060 ft of steel tubing, a 4-in. diameter packer, and the transducer assembly was removed from the well. The tubing was cut up and placed in B-25 boxes for disposal.

The water column in Well 2373 was sampled at three depths (123, 624, and 1,124 ft bgs) in October 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.9 provides the results of the sample analysis for Well 2373. The water sampled from the recompleted well contains high TDS ($> 144,980$ mg/L) and would be classified as sodium chloride brine (Fig. 2.37). The pH of the upper two samples is basic (8.49 and 7.82, respectively). The bottom sample is very basic (pH 11.1), which would imply reaction with the construction grout. Nitrate was not detected in the 1995 sampling or in the 1985 sampling after well reconfiguration.

Prior to well recompletion in 1985, high levels of radionuclides of a composition that would mimic the grout waste were detected in historical samples (Fig. 2.38). After modification, ^{90}Sr [0.5 $\mu\text{Ci/L}$ (1986), 0.06 $\mu\text{Ci/L}$ (1995)], ^{60}Co [143.2 pCi/L (1986)], and minor ^{137}Cs [31.6 pCi/L (1995)] were detected at activities that were lower than the first two samplings. The highest level of ^{90}Sr activity (0.06 $\mu\text{Ci/L}$) was found in the top sample from the 1995 sampling. This result is probably due to the mixing of the water column while pulling the transducer assembly. No organic compounds were detected at significant levels.

The bottom water sample collected from Well 2373 contained high solids. A sample of the solid material was mounted on filter paper, glued to an SEM sample stub, coated with gold (Au) to provide a conductive layer, and examined in an ISI SEM equipped with an EDS system. The service was provided as a courtesy of Dr. S. Y. Lee and Dr. M. Elless of ORNL.

The SEM photomicrograph and EDS spectrum for the material collected from Well 2373 is shown on Fig. 2.39. The fibrous material seen in the photomicrograph is filter paper. The solids are amorphous and display no crystal form or recognizable shape (such as fly ash). No crystal form and elements detected would indicate that the solids are comprised of drilling debris (clay, drill cuttings, and casing and drilling component metal). No indication of solid waste grout was found.

Geophysical Log Interpretation. Well 2373 is doubly cased down to 550 ft causing suppression of both the neutron and gamma log responses. The neutron and gamma logs are usable for lithology below that depth. The gamma ray log appears normal down to 925 ft bgs.

Two uncharacteristically high gamma peaks (suppressed by casing and construction grout) are measured at 930 ft (100 cps) and 944 ft (185 cps). These behind casing peaks are attributable to contaminated grout filtrate that has flowed along either hydrofracture-induced or natural fractures within the Pumpkin Valley Shale. The upper peak at 930 ft correlates with a gamma high measured on openhole logs run in the well before casing was installed. No corresponding gamma highs on the old logs were observed for the 944-ft peak. This relationship would imply that the gamma contribution from the grout waste filtrate at 944 ft had not arrived at Well 2373 in 1984. Therefore, the filtrate causing the gamma peak at 944 ft arrived sometime after 1984.

The caliper log indicates that 20 ft lengths of casing were used to construct this well. Several changes in casing diameter measured by the caliper are noted in the well. The temperature log displays an erratic pattern throughout most of the cased interval. This pattern was caused by logging the well before the temperature was allowed to equilibrate following removal of tubing,

transducer, and packer. The change in temperature gradient at 1,087 ft, however, marks the transition into the Rome Formation.

The VDL indicates poor bonding over the doubly cased interval from 0 to 550 ft. Interpretation, however, is difficult because of the presence of double casing. It appears, based on the presence of some indications of rock signature, that the poor bond is between grout and formation.

Well Ranking. Well 2373 is a DM well. The well appears to have EMI. Recent water sampling results indicate radionuclide contamination. The contamination in this well, however, is a relic from when the well had a long openhole interval (through the injection horizon). It is not believed that the contamination has migrated into the Rome Formation. The well would be suitable for temporary monitoring of the Rome Formation. Well 2373 is ranked 6 for P&A.

General P&A Plan. The surface and wellhead configuration, well details, and a sketch of the proposed P&A well are shown on Figs. 2.33–2.36. The well details should be considered reliable and usable for P&A activities.

Well 2373 will be brought to static equilibrium before P&A begin. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option for Well 2373 is presented below.

An initial cement plug will be set from 1,050 ft to TD (1,142 ft) before pressure testing the casing. After setting the plug, the casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well. Three 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out, one below the upper Maryville Limestone (shallow freshwater zone, contact at 250 ft), another near the base of the Rutledge Limestone (contact at 747 ft), and a third at 1,050 ft within the lower Pumpkin Valley Shale above the Rome Formation.

After placement of the initial cement plug (1,050 ft to TD), a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the lower Pumpkin Valley Shale, the unit that overlies the Rome Formation to maximize hydraulic separation. The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug (990 to 1,050 ft) will be tagged.

It is expected that the next cement stage will be set from approximately 750 to 990 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone (720 to 750 ft), the unit that overlies the upper Pumpkin Valley Shale (injection horizon). The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug (690 to 750 ft) will be tagged.

The next cement stage will be placed from 280 to 690 ft. After placement of this plug, a 30-ft casing interval will be perforated or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (220 to

280 ft). Ultrafine-grain, matrix-penetrating cement, and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged, and a final cement stage will be placed from 5 to 220 ft.

DEEP MONITORING WELL 2373 (DM1-RM)

Fig. 2.33. Wellhead construction details.

Fig. 2.34. Well 2373 (DM1-RM) acoustic variable density log.

Fig. 2.35. Characteristic log responses, observations, and summary chemical data for Well 2373 (DM1-RM).

Fig. 2.36. Existing well construction and proposed P&A for Well 2373 (DM1-RM).

Table 2.9. Well water measurements for Well 2373 (DM1-RM)

Well Construction							
Original Date Well Completed = 1985				ORNL Grid Coordinates			
Well Type = Deep Monitoring				Northing = 16645.54			
Formation Penetration = Rome Formation				Easting = 29219.51			
Ground Surface Elev (ft) = 765.42				Historical Notes: Originally drilled to a depth of 1487 ft and later plugged back to 1149 ft with grout.			
Bottom Riser Casing Depth (ft bgs) = 1092							
Bottom Riser Casing Elev (ft) = -326.58							
Total Depth (ft bgs) = 1149							
Total Depth Elev (ft) = -383.58							
Tapping Details							
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments	
Riser Casing	8/8/95	1.0	20.6	1.8	1	Tubing tap - water present	
Casing Annulus	8/8/95	0	20.8	0.6	1	Casing/Tubing annulus tap - water present	
Sample Details							
	Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)			
	10/23/95	123	642	144,980			
	10/23/95	624	141	156,099			
	10/23/95	1124	-359	146,150			
Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft) Comments	
Pressure	9/6/95		GS	3.4	9.78	775.20	
Pressure	9/19/95		GS	2.2	7.01	772.43	
Pressure	9/19/95		GS		10.71	776.13	
Water Level	9/21/95	122.76	GS			642.66	
Water Level	10/16/95	101.43	GS			663.99	
Water Level	10/23/95	98.27	GS			667.15	
Water Level	11/13/95	91.22	GS			674.20	
					Average	710.25	+ GS = Above Ground Surface GS = Ground Surface
					Minimum	642.66	
					Maximum	776.13	

+ GS = Above Ground Surface
GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.9 (continued). Well water sample analysis for Well 2373 (DM1-RM)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	8.49	7.82	11.1
Lab pH	7.34	6.35	8.41
Temperature (C)	13.3	18.2	20.9
Specific Conductivity ($\mu\text{S} / \text{cm}$)	174300	180900	105800
Eh (mV)	-320	112	-244
Alkalinity (mg CaCO_3 / L)	24	38	31378
Total Dissolved Solids (mg / L)	144980	156099	146150
Total Suspended Solids (mg / L)	128	165	277140
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	14300	14600	26200
Sodium	42300	46100	55000
Magnesium	743	2160	3710
Potassium	263	274	231
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	85400	94700	131000
Sulfate	336	338	--
HCO_3	29	46	3263
CO_3	0	0	17194
Bromide	672	742	1110
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	22874.4
Gross Beta	272943.5	64254.3	53262.2
Gamma Activity	--	615	67.9
Sr - 90	61752.4	14995.2	
Cs - 137		31.6	
H - 3	--	--	--
C - 14	144666.7	35193.7	17540.5
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	594	527	24
Benzene	4	5	4
Chlorobenzene	2	4	5
Ethylbenzene	--	--	5
Naphthalene	3	2	18
Tetrachloroethene	--	--	4
Toluene	61	244	239
Xylenes (total)	8	8	24

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.9 (continued). Well water sample analysis for Well 2373 (DM1-RM)

pH, Alkalinity, TDS, and TSS

Analyte	Top Sample	Middle Sample	Bottom Sample
pH	7.34	6.35	8.41
Alkalinity (mg CaCO ₃ / L)	24	38	31378
Total Dissolved Solids (mg / L)	144980	156099	146150
Total Suspended Solids (mg / L)	128	165	277140

Cations, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	14300	14600	26200
Sodium	42300	46100	55000
Magnesium	743	2160	3710
Potassium	263	274	231
Ammonium	--	--	--
Lithium	--	--	--

Anions, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	85400	94700	131000
Sulfate	336	338	--
HCO ₃	29	46	3263
CO ₃	0	0	17194
Bromide	672	742	1110
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	22874.4
Gross Beta	272943.5	64254.3	53262.2
Gamma Activity	--	615	67.9
Sr-90	61752.4	14995.2	
Cs-137		31.6	
H-3	--	--	--
C-14	144666.7	35193.7	17540.5

Detected Organics, µg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	594	527	24
Benzene	4	5	4
Chlorobenzene	2	4	5
Ethylbenzene	--	--	5
Naphthalene	3	2	18
Tetrachloroethene	--	--	4
Toluene	61	244	239
Xylenes (total)	8	8	24

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

pH, alkalinity, and TDS

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Fig. 2.37. Chemistry of standing water column in NHF deep monitoring Well 2373.

Fig. 2.38. Historical radiological results in Well 2373.

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Fig. 2.39. Scanning electron microscopy and energy-dispersive x ray analyzer system images of solids from Well 2373.

Courtesy of Dr. S. Y. Lee and Dr. M. Ellies of ORNL

2.10 SUMMARY OF WELL 2374 (DM2-RM)—RANKED 6

Well History. Well 2374 (DM2-RM), one of seven deep-monitoring wells installed in the vicinity of the NHF, is located 1,100 ft west of the NHF injection well (Well 1968). This well was recompleted and currently has an open interval in the Rome Formation.

Well 2374 was originally drilled to a depth of 1,505 ft bgs (June 1984). Casing was installed to 550 ft bgs, and the remaining length (955 ft) of the borehole was left open to five different formations. Two samplings (September 1984 and January 1985) of the standing water column were conducted by ORNL prior to modification of the well. Significant radiological contamination was confirmed from analytical results acquired from samples collected during these samplings. Modifications were made to the well in January 1985 so that Well 2374 is now open only to the Rome Formation.

In February 1987, a computerized pressure monitoring system was installed in Well 2374. The system consisted of a pressure transducer, transducer carrier, tension-set packer, wireline cable, and landing nipple assembly. The equipment was installed on 2 $\frac{3}{8}$ -in. EUE steel tubing. The system allowed real-time monitoring of pressure in the well. No data or reports have been located at ORNL that present results from pressure monitoring of the Rome Formation at this location.

Well 2374 was sampled twice (September 1984 and January 1985) before the January 1986 well modification. The well was sampled again in January 1986 by ORNL after well modification, but before the pressure monitoring system was installed. The final sampling occurred in 1995 after removal of the pressure monitoring system.

Construction Details. Well 2374 was originally drilled to a depth of 1,505 ft and 6-in. black carbon steel casing was installed to 550 ft bgs. The borehole had a 10-in. nominal diameter for 0 to 550 ft and a 6-in. nominal diameter from 550 to 1505 ft. The 6-in. casing was grouted in place.

The original intent of the January 1986 well modification was to leave Well 2374 open to the Chickamauga Group; however, during the completion operations, a bailer was dropped down the borehole. After several unsuccessful attempts to fish out the bailer, it was decided to complete the well in the Rome Formation.

A rubber plug was driven to a depth of 1,300 ft bgs, and 25 ft of cement was placed on top of the plug. To correct the problem of cement filling up the open space while recompleting Well 2373, sand was placed above the cement plug up to depth of 1,093 ft, and another rubber plug was driven on top of the sand. Black carbon steel casing (4-in. ID) with a float shoe was lowered to a depth of 1,084 ft bgs at which point the casing became lodged. The casing was grouted in place. The 10-ft open space between the bottom of the casing and the rubber plug above the sand was also filled with cement. The float shoe and cement were drilled out, and the sand was blown out of the hole leaving an open interval between 1,094 and 1,275 ft bgs.

The borehole logging and sample teams each measured the TD of Well 2374 to be 1,250 ft bgs. The current configuration of the wellhead, well construction details, and proposed P&A are shown on Figs. 2.40–2.43.

Field Activities. Well 2374 was tapped on July 25, 1995. Neither the annulus between the 4-in. wellhead casing and the 2 $\frac{3}{8}$ -in. steel tubing and the tubing itself were under pressure. The

water level inside the tubing immediately after tapping was 135.11 ft bgs. A series of water level measurements were made through November 1995. The tapping information and water level data are provided in Table 2.10.

The transducer and packer assembly had to be removed from Well 2374 in order to sample the standing water and prepare the well for possible P&A. Approximately, 1,060 ft of steel tubing, a 4-in. diameter packer, and the transducer assembly was removed from the well (September 25–October 2, 1995). The tubing was cut up and placed in B-25 boxes for eventual disposal.

The water column in Well 2374 was sampled at three depths (262, 756, and 1,245 ft bgs) in October 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.10 provides the results of the sample analysis for Well 2374 after well reconfiguration. The water sampled from the recompleted well contains high TDS ($> 104,931$ mg/L), sodium chloride brine (Fig. 2.44). The pH of the lower two samples is acidic (6.53 and 6.16, respectively). The top sample is basic (pH 7.59). The pHs do not indicate reaction with the construction grout. Nitrate was not detected in the 1995 sampling and only a minor concentration was detected (9.2 mg/L) in the 1985 sampling,

Prior to well recompletion, high levels of radionuclides of a composition that would mimic the grout waste were detected in historical samples (Fig. 2.45). After modification, ^{90}Sr [0.4 $\mu\text{Ci/L}$ (1986), 0.09 $\mu\text{Ci/L}$ (1995)], ^{60}Co [1135.1 pCi/L (1986)], and minor ^{137}Cs [75.7 pCi/L (1986), 45 $\mu\text{Ci/L}$ (1995)] were detected at activities that were lower than the first two samplings. The highest level of ^{90}Sr activity ($0.09\mu\text{Ci/L}$) was found in the top sample from the 1995 sampling. This result is probably due to the mixing of the water column while pulling the transducer assembly. No organic compounds were detected at significant levels.

Geophysical Log Interpretation. The suppressed neutron and gamma log responses confirm that Well 2374 is doubly cased down to 550 ft. The neutron log is usable for lithology below that depth. The gamma ray log displays a gradual increase in counts to bottom of casing at 1,078 ft. This gamma response is abnormal for the area and would indicate that the waste grout filtrate is contributing to the response.

The new gamma log run in the cased interval of Well 2374 was compared to the old gamma ray log that was run in the openhole before casing. Several comparisons can be made. The gamma highs at 718 and 894 ft correlate with a gamma high at the same depths on the old logs. The intensities of these two peaks are also comparable. An additional gamma peak at 910 ft also correlates on the old log. The intensity of the peak, however, is different. On the new log the intensity of the peak is relatively higher. This observation implies that the gamma contribution from the waste grout filtrate is time dependent and continued to contribute contamination to the water from 1985 to 1995.

The caliper log indicates that 20 ft lengths of casing were used to construct this well. The casing appears corroded from 550 to 610 ft, and 745 to 850 ft. The temperature log displays a fairly erratic pattern throughout most of the cased interval. This pattern was caused by logging the well before the temperature was allowed to equilibrate following removal of tubing, transducer, and packer. There is, however, a change in temperature gradient from 1,010 ft to TD.

The VDL indicates poor bonding over the doubly cased interval from 0 to 550 ft. Interpretation, however, is difficult because of the presence of double casing. Bonding of the lower section of casing (below 550 ft) varies from moderate to good to bad. Numerous fractures or bedding plane features are noted on the VDL.

Well Ranking. Well 2374 is a DM well that is interpreted to have EMI. The recent round of water sampling results indicate radionuclide contamination. The contamination in this well, however, is believed to be relic from when the well had a long openhole interval (through the injection horizon). It is not believed that the contamination has migrated down into the Rome Formation. The well would be suitable for temporary monitoring of the Rome Formation. Well 2374 is ranked 6 for P&A.

General P&A Plan. The surface and wellhead configuration, well details, and a sketch of the proposed P&A well are shown on Figs. 2.40–2.43. The well details should be considered reliable and usable for P&A activities.

Well 2374 will be brought to static equilibrium before P&A begin. All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option for Well 2374 is presented below.

An initial cement plug will be set from 1,060 ft to TD before pressure testing the casing. After setting the plug, the casing will be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well. Three 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out; one below the upper Maryville Limestone (shallow freshwater zone, contact at 247 ft), another near the base of the Rutledge Limestone (contact at 738 ft), and a third at 1,060 ft within the lower Pumpkin Valley Shale above the Rome Formation.

After placement of the initial cement plug (1,060 ft to TD), a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the lower Pumpkin Valley Shale, the unit that overlies the Rome Formation to maximize hydraulic separation. The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug (1,000 to 1,060 ft) will be tagged.

It is expected that the next cement stage will be set from approximately 738 to 1000 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone (708 to 738 ft), the unit that overlies the upper Pumpkin Valley Shale (injection horizon). The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug (678 to 738 ft) will be tagged.

The next cement stage will be placed from 277 to 678 ft. After placement of this plug, a 30 ft casing interval will be perforated or a window will be milled out. Formation contact and hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units will be reestablished using perforating or milling and squeeze cementing (217 to 277 ft). Ultrafine-grain, matrix-penetrating cement, and a packer will be used to squeeze the perforated or milled window interval. After curing, the plug will be tagged, and a final cement stage will be placed from 5 to 217 ft.

C.

DEEP MONITORING WELL 2374 (DM2-RM)

Fig. 2.40. Wellhead construction details.

Fig. 2.41. Well 2374 (DM2-RM) acoustic variable density log.

Fig. 2.42. Characteristic log responses, observations, and summary chemical data for Well 2374 (DM2-RM).

Fig. 2.43. Existing well construction and proposed P&A for Well 2374 (DM2-RM).

Table 2.10. Well water measurements for Well 2374 (DM2-RM)

Well Construction

Original Date Well Completed = 1985

Well Type = Deep Monitoring

Formation Penetration = Rome Formation

Ground Surface Elev (ft) = 757.78

Bottom Riser Casing Depth (ft bgs) = 1084

Bottom Riser Casing Elev (ft) = -326.22

Total Depth (ft bgs) = 1275

Total Depth Elev (ft) = -517.22

ORNL Grid Coordinates

Northing = 16456.59

Easting = 27075.2

Historical Notes:

Originally drilled to a depth of 1505 ft and later plugged back to 1275 ft with grout.

Tapping Details

	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	7/25/95	0	3.7	0	50	Tubing tap
Casing Annulus	7/25/95	0	20.5	0.2	3	Casing/Tubing annulus tap

Sample Details

Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
10/26/95	262	496	104,931
10/26/95	756	2	266,015
10/26/95	1245	-487	277,376

Water Level Measurements

Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	7/25/95	135.11	GS			622.67	Inside tubing
Water Level	9/6/95	130.78	GS			627.00	
Water Level	9/25/95	129.09	GS			628.69	Immediately before tubing removed
Water Level	10/2/95	245.67	GS			512.11	Immediately after tubing removed
Water Level	10/16/95	240.15	GS			517.63	
Water Level	10/26/95	237.07	GS			520.71	
Water Level	11/13/95	233.31	GS			524.47	
Average						564.75	+ GS = Above Ground Surface
Minimum						512.11	GS = Ground Surface
Maximum						628.69	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.10 (continued). Well water sample analysis for Well 2374 (DM2-RM)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	7.59	6.53	6.16
Lab pH	7.6	5.28	5.19
Temperature (C)	17.9	18.8	18.1
Specific Conductivity ($\mu\text{S} / \text{cm}$)	121400	219000	226000
Eh (mV)	85	-48	-58
Alkalinity (mg CaCO_3 / L)	65	28	21
Total Dissolved Solids (mg / L)	104931	266015	277376
Total Suspended Solids (mg / L)	46	108	125
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	11100	27200	28300
Sodium	28300	65100	71300
Magnesium	732	3870	3510
Potassium	210	360	341
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	61700	153000	163000
Sulfate	--	--	--
HCO_3	79	34	26
CO_3	0	0	0
Bromide	530	1410	1510
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	150077.6	122064.8	54388.4
Gamma Activity	35.5	2060	--
Sr - 90	91510.9	15329.6	4472.1
Cs - 137	35.5	37.7	45
H - 3	2827	--	--
C - 14	--	79175.7	33153.2
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	385	620	383
Benzene	2	--	--
Chlorobenzene	4	--	--
Toluene	2	--	--
Xylenes (total)	3	--	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.10 (continued). Historical sample analysis for Well 2374 (DM2-RM)

pH, Alkalinity, and TDS		Analyte		Alkalinity (mg HCO ₃ /L)		Total Dissolved Solids (mg/L)		Cations, mg/L		September 1984		September 1984		January 1985		January 1985		January 1986		January 1986	
	640 ft bgs	6.1	72	13415	125	154	122	98.8	23.5	12400	640 ft bgs	filtered	1120	3760	17500	1400	70.5	32.3	79.5	78.5	352
	840 ft bgs	5.6	15	74182	821	568	568	568	568	568	840 ft bgs	filtered	7390	14300	12900	5140	5920	1400	1120	982	2850
	960 ft bgs	5.7	27	71988	568	568	568	568	568	568	960 ft bgs	filtered	12900	12900	8800	14000	2500	170	110	1600	20000
	1040 ft bgs	5.8	27	51669	568	568	568	568	568	568	1040 ft bgs	filtered	14000	14000	15000	35000	2600	140	140	2200	5200
	1400 ft bgs	5.2	7	92450	180	310	320	320	320	320	1400 ft bgs	filtered	14000	14000	15000	35000	2600	140	140	2200	5200
	640 ft bgs	5.4	5.4	139170	320	320	320	320	320	320	640 ft bgs	filtered	14000	14000	15000	35000	2600	140	140	2200	5200
	840 ft bgs	5.2	5.2	130340	320	320	320	320	320	320	840 ft bgs	filtered	14000	14000	15000	35000	2600	140	140	2200	5200
	960 ft bgs	5.2	5.2	120640	320	320	320	320	320	320	960 ft bgs	filtered	14000	14000	15000	35000	2600	140	140	2200	5200
	1040 ft bgs	4.6	4.6	295830	320	320	320	320	320	320	1040 ft bgs	filtered	14000	14000	15000	35000	2600	140	140	2200	5200
	1250 ft bgs	10.3	366	141500	28	69	100	100	100	100	1250 ft bgs	unfiltered	15000	57000	2300	890	32	47	430	2300	890
	1250 ft bgs	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6	1250 ft bgs	unfiltered	130000	163000	108	1400	680	1300	46	19	12
	1250 ft bgs	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	1250 ft bgs	unfiltered	130000	163000	108	1400	680	1300	46	19	12
	1250 ft bgs	1135.1	1135.1	1135.1	1135.1	1135.1	1135.1	1135.1	1135.1	1135.1	1250 ft bgs	unfiltered	999999	405405	75.7	1135.1	1135.1	1135.1	1135.1	1135.1	1135.1

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Fig. 2.44. Chemistry of standing water column in NHF deep monitoring Well 2374.

2.11 SUMMARY OF WELL 1981 (4W-190RC)—RANKED 5

Well History. Well 1981 (4W-190RC) is one of eight rock-cover wells constructed in 1980 surrounding the NHF. The well is located 190 ft west of the injection well (Well 1968) and had an open interval in the Rogersville Shale and Rutledge Limestone formations. The open interval is presently packed with sand containing geophones and cable. This equipment had been abandoned in the well after cessation of operations at NHF.

Pressure and permeability monitoring were the primary functions of the rock cover wells. Pressure was measured from gauges that were installed on the wellheads. Permeability was determined by pressurizing each well to 75 psi and measuring the rate at which the formation would accept water. An increase in the permeability over a period of time would indicate the isolation of the disposal zone was reduced (ORNL 1984). The openhole interval continued to accept a low volume of water during all water acceptance tests run. These results would imply low but consistent effective permeability in the area of the well.

Four historical water samples were collected by ORNL from Well 1981 (4W-190RC) (October 1983, January 1985, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was not purged before the other sample events. The well was sampled in July 1995 as part of the WAG 10 field investigation.

Construction Details. Well 1981 was drilled to a TD of 650 ft bgs and is cased to a depth of 550 ft. The bottom 100 ft of the well is open to the Rogersville Shale and Rutledge Limestone formations. The well was equipped with geophones and packed within sand. In 1986, an attempt was made to remove the geophones; however, the cable continuously broke causing the decision to be made to abandon the equipment in the hole. Geraghty and Miller (1986) report the top of the sand pack, cable, and the geophones at a depth of 535 ft bgs.

While attempting to measure the total well depth during the sampling on June 28, 1995, the wire-line sampler stopped at 526 ft bgs and could not go any further. The geophysical logging probes stopped at a depth of 525 ft bgs. Therefore, it is concluded that the actual depth to sand is 525 ft. Figures 2.46–2.50 show the current configuration of the wellhead, well details, and proposed P&A.

Field Activities. Well 1981 was vented, so it was unnecessary to tap the well. The earliest water level measurement was 27.38 ft bgs on July 24, 1995. A series of water level measurements were made through November 1995. A list of the water level data is provided in Table 2.11.

The water column in Well 1981 was sampled at three depths (52, 339, and 510 ft bgs) in July 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.11 provides the results of the sample analysis for Well 1981. The water sampled from this well is near neutral to acidic (pH 5.94–7.46). The TDS results indicate that all three samples are brine ($> 185,729$ mg/L). The water appears to be native brine composed predominantly of sodium with lesser amounts of calcium, and the major anion is chloride. No nitrate was detected in the recent sampling. Minor amounts of nitrate, however, were detected in the historical sampling (maximum 48 mg/L, bottom sample, May 1986). Cesium-137 (≤ 48.8 pCi/L) was detected in the two lower samples. Cesium-137 (≤ 27 pCi/L) and ^{90}Sr (351.4 pCi/L) were detected in the historical samples. No organics were detected at significant levels.

The analytical results from the historical samples collected from Well 1981 are reported in Table 2.11.

Geophysical Log Interpretation. Formation tops were picked using the gamma and neutron logs. The caliper log shows the 30 ft casing. The casing wall appears to be corroded. The SPR log is shorted out confirming laboratory results indicative of brine composition. The apparent density log from 0 to 210 ft correlates with interpreted bad bonding to this depth. The temperature displays break at 232 ft (joint), 265 ft (joint), and 300 ft (joint) with erratic breaks from 490 to 512 ft.

The VDL indicates bad bonding from 0 to 300 ft and good bonding from 300 to bottom of casing (525 ft bgs). Bonding in this well may have been disturbed during past operations conducted in an attempt to remove geophones from the well.

Well Ranking. There is evidence of leakage at couplings in Well 1981. The well is classified as not having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. In the past, the well was equipped with cable and geophones. An attempt was made to retrieve the equipment but failed after the cable broke. The equipment (cabling and geophones) was sanded in and abandoned in the openhole interval of the well. This well is unsuitable for temporary monitoring. Well 1981 is ranked low (5) for future P&A.

General P&A Plan. The surface and wellhead configuration, interpreted well details, and proposed P&A are shown on Figs. 2.46–2.50. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs. Casing bonding, based on log interpretation, varies from poor to good. The casing appears to be corroded. Breaks in temperature response may indicate leakage.

Well 1981 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (to approximately 490 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h above the casing shoe (at approximately 522 ft) by either shutting in the well or placing a packer.

If the as expected casing does not maintain pressure, cement will be placed between approximately 280 and 490 ft (initial plug 490 to TD). This plug will be squeezed using a packer and tagged. A 30-ft (approximately 250 to 280 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 250 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 220 to 280 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 220 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

C.

ROCK COVER WELL 1981 (4W-190RC)

Fig. 2.46. Wellhead construction details.

Fig. 2.47. Well 1981 (4W-190RC) acoustic variable density log.

Fig. 2.48. Characteristic log responses, observations, and summary chemical data for Well 1981 (4W-190RC).

Fig. 2.49. Existing well construction and proposed P&A for Well 1981 (4W-190RC).

Table 2.11. Well water measurements for Well 1981 (4W-190RC)

Well Construction	
Original Date Well Completed = 1980	ORNL Grid Coordinates
Well Type = Rock Cover	Northing = 16472.85
Formation Penetration = Rutledge Limestone	Easting = 27984.56
Ground Surface Elev (ft) = 783.28	
Bottom Riser Casing Depth (ft bgs) = 550	Historical Notes:
Bottom Riser Casing Elev (ft) = 233.28	
Total Depth (ft bgs) = 650	
Total Depth Elev (ft) = 133.28	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	--	--	11	7	30	Existing riser was vented
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
7/26/95	52	731	185,726
7/26/95	339	444	189,219
7/27/95	510	273	193,268

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Water Level	7/24/95	27.38	GS			755.90
Water Level	7/26/95	27.40	GS			755.88
Water Level	9/6/95	30.55	GS			752.73
Water Level	10/16/95	30.74	GS			752.54
Water Level	11/13/95	30.20	GS			753.08
Average						754.03
Minimum						752.54
Maximum						755.90
						+ GS = Above Ground Surface
						GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.11 (continued). Well water sample analysis for Well 1981 (4W-190RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	7.46	6.06	5.94
Lab pH	4.85	3.98	4.33
Temperature (C)	20.1	24.3	18.6
Specific Conductivity ($\mu\text{S} / \text{cm}$)	189700	172200	197900
Eh (mV)	-140.7	58.2	97.8
Alkalinity (mg CaCO_3 / L)	--	--	--
Total Dissolved Solids (mg / L)	185726	189219	193268
Total Suspended Solids (mg / L)	192	168	105

Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	20300	21200	21400
Sodium	48100	49300	49200
Magnesium	3820	4190	4220
Potassium	145	136	130
Ammonium	--	--	--
Lithium	20	20	20

Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	117000	116000	122000
Sulfate	--	--	--
HCO_3	--	--	--
CO_3	--	--	--
Bromide	939	996	983
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	1837.3	4484.5	1819.9
Gamma Activity	--	48.8	45.9
Sr - 90			
Cs - 137		48.8	45.9
H - 3	--	--	--
C - 14	227	--	--

Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	16	13	7

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.11 (continued). Historical sample analysis for Well 1981 (4W-190RC)

pH, Alkalinity, and TDS

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
pH		6.8	3.9	
Alkalinity (mg HCO ₃ /L)	19.2	--		--
Total Dissolved Solids (mg/L)	99611	195000	187786	190947

Cations, mg/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Calcium	7410	20000	18000	19000
Sodium	21200	48000	40000	42000
Magnesium	1110	3400	3200	3300
Potassium	8830		210	180
Manganese	1.5	31	36	37
Iron	--	130	190	170
Lithium	37.4	--	--	--
Barium	302	650	620	630
Strontium	890	2000	2000	2100
Titanium	2.6	--	--	--

Anions, mg/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Chloride	68200	120000		122000
Sulfate	--	--		--
Bromide	499	950		1300
Phosphate				--
Nitrate	--	48		.8
Fluoride		.56		230
Iodide		15		--

Radionuclides, pCi/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Gross Alpha		--		--
Gross Beta		729.7		--
Sr-90	--	351.4		--
Cs-137	--	27		--
Co-60	--	--		--
H-3	--			--
Tc-99	--			--
Th-232		--		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The October 1983 sample was collected at a depth of 640 ft bgs, the May 1986 sample was from 400 ft bgs, and the December 1986 sample was from 405 ft bgs.

Fig. 2.50. Chemistry of standing water column in NHF rock cover Well 1981.

2.12 SUMMARY OF WELL 1979 (4SE-280RC)—RANKED 5

Well History. Well 1979 (4SE-280RC) constructed in 1980 is one of eight rock-cover wells surrounding the NHF. The well is located 280 ft southeast of the injection well (Well 1968) and is open to the Rogersville and Rutledge Formations.

Rock-cover wells were constructed to continually monitor pressure and periodically monitor for changes in the permeability in the rock cover overlying the disposal horizon. The permeability was determined by pressurizing each well to 75 psi and measuring the rate at which the formation would accept water. A significant increase in water acceptance would imply increased permeability caused by waste grout injection(s). Results for tests conducted at this location indicate "moderate" permeability in the rock cover with no increase due to injection.

Four historical samples were collected from Well 1979 (4SE-280RC) (October 1983, January 1985, May 1986, and December 1986). The October 1983 and January 1985 samples were collected from the unpurged standing water column. The well was purged five months before the May 1986 sample event, but was not purged before the other sample events. The latest sampling was conducted in July 1995 as part of the WAG 10 field investigation.

Construction Details. Well 1979 is drilled to a TD of 700 ft bgs. This depth was confirmed by both the borehole logging and sample teams. The well is cased to a depth of 582 ft bgs (confirmed by logging), and the bottom 118 ft of the well is open to the formation. The current configuration of the wellhead, wellhead details, and proposed P&A are shown on Figs. 2.51–2.54.

Field Activities. Well 1979, which was tapped on June 14, 1995, is not under pressure. The water level was 96.91 ft bgs immediately after tapping. A series of water level measurements were made through November 1995. The well is not flowing artesian. A list of the water level data is provided in Table 2.12.

The water column in Well 1979 was sampled at three depths (122, 398, and 675 ft bgs) on June 29 and July 5, 1995, as part of the field investigation.

Analytical Results. Table 2.12 provides the results of the sample analysis for Well 1979. The water sampled from this well is acidic (pH 5.54–6.52). The TDS results indicate saline water in the upper sample (54,838 mg/L) and brine (> 141,989 mg/L) in the lower two samples. The water appears to be native brine composed predominantly of sodium with lesser amounts of calcium, and the major anion was chloride (Fig. 2.55). No nitrate was detected in the recent sampling. Minor amounts of nitrate, however, was detected in the historical sampling (maximum 24 mg/L, bottom sample, May 1986). Minor amounts of ^{90}Sr (< 297.3 pCi/L) and ^{137}Cs (29.7 pCi/L) were also detected in the historical sampling. Dichloromethane was the only organic compound detected above the SDWA MCL.

The analytical results from the historical samples collected from Well 1979 are reported in Table 2.12.

Geophysical Log Interpretation. The neutron and gamma ray log responses are normal for the area and are useful for lithology and picking formation tops. The caliper log shows the casing (30 ft) and bottom of casing at 582 ft bgs. The SPR log is shorted out and would confirm laboratory results indicative of brine composition. The resistivity log indicates a transition from

saline water in the upper section of the well to brine at the bottom. Apparent density is noisy and erratic but shows location of joints and couplings.

The temperature displays an unusual "stepped" pattern from 378 ft bgs to the bottom of the well. Three very distinct temperature breaks, within casing, are measured at 378, 478, and 581 ft (near bottom of casing). These anomalous breaks in temperature gradient may reflect the physical impact of waste grout injection. Uplift and subsidence caused by emplacement of grout may have broken the formation-construction grout-casing bond allowing for flow.

The VDL indicates good casing bonding to bottom of casing at 582 ft bgs. Rock signature is strong as seen behind casing.

Well Ranking. There is evidence of leakage at couplings in Well 1979. Therefore, the well is classified as not having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. The well is not recommended for temporary site monitoring. If left inactive and because of the threat of flow of brine (201,000 mg/L) uphole this well should be P&A. Well 1979 is ranked 5 for P&A.

General P&A Plan. The surface and wellhead configuration, well details, and proposed P&A are shown on Figs. 2.51–2.54. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs. Casing bonding, based on log interpretation, is good. The casing condition also appears to be good. The temperature response, however, may indicate leakage caused by response to repeated uplift and subsidence.

Well 1979 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (to approximately 550 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h above the casing shoe (at approximately 582 ft) by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Three cement plugs (5 to approximately 275 ft, approximately 275 to 550 ft, and 550 to TD) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 365 and 550 ft (initial plug 550 to TD). This plug will be squeezed using a packer and tagged. A 30-ft (approximately 335 to 365 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 335 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 305 to 365 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 305 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

ROCK COVER WELL 1979 (4SE-280RC)

Fig. 2.51. Wellhead construction details.

Fig. 2.52. Well 1979 (4SE-280RC) acoustic variable density log.

Fig. 2.53. Characteristic log responses, observations, and summary chemical data for Well 1979 (4SE-280RC).

Fig. 2.54. Existing well construction and proposed P&A for Well 1979 (4SE-280RC).

Table 2.12. Well water measurements for Well 1979 (4SE-280RC)

Well Construction	
Original Date Well Completed = 1980	ORNL Grid Coordinates
Well Type = Rock Cover	Northing = 16303.52
Formation Penetration = Rutledge Limestone	Easting = 28382.46
Ground Surface Elev (ft) = 814.18	
Bottom Riser Casing Depth (ft bgs) = 600	Historical Notes:
Bottom Riser Casing Elev (ft) = 214.18	
Total Depth (ft bgs) = 700	
Total Depth Elev (ft) = 114.18	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	6/14/95	0	20.9	0	0	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
6/29/95	122	692	54,838
6/29/95	398	416	141,989
7/5/95	675	139	200,919

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Water Level	6/14/95	96.91	GS			717.27
Water Level	6/29/95	96.86	GS			717.32
Water Level	7/13/95	99.26	GS			714.92
Water Level	9/6/95	99.33	GS			714.85
Water Level	10/16/95	99.09	GS			715.09
Water Level	11/13/95	98.90	GS			715.28
Average						715.79
Minimum						714.85
Maximum						717.32
						+ GS = Above Ground Surface
						GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.12 (continued). Well water sample analysis for Well 1979 (4SE-280RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	6.52	5.97	5.54
Lab pH	5.41	4.36	6.1
Temperature (C)	19.9	21.9	21.4
Specific Conductivity ($\mu\text{S} / \text{cm}$)	79500	163500	177700
Eh (mV)	18.7	63.8	111.2
Alkalinity (mg CaCO_3 / L)	--	--	21
Total Dissolved Solids (mg / L)	54838	141989	200919
Total Suspended Solids (mg / L)	52	60	223

Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	4670	13400	21800
Sodium	16700	39000	51100
Magnesium	78	2190	4320
Potassium	89	144	138
Ammonium	--	--	--
Lithium	--	--	--

Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	34000	87800	125000
Sulfate	--	--	--
HCO_3	--	--	26
CO_3	--	--	0
Bromide	230	668	1060
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	1589.2	--	--
Gamma Activity	--	--	--
Sr - 90	--	--	--
H - 3	161.3	--	--
C - 14	--	--	--

Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	113	15	--
Benzene	7	--	--
Dichloromethane	530	--	--
Ethylbenzene	309	3	2
Naphthalene	3	--	--
Toluene	63	--	--
Xylenes (total)	1294	7	8

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.12 (continued). Historical sample analysis for Well 1979 (4SE-280RC)

pH, Alkalinity, and TDS					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986 unfiltered	December 1986 filtered
pH		6.3	6.2	5.5	
Alkalinity (mg HCO ₃ /L)	.3	2	--		6
Total Dissolved Solids (mg/L)	165265	164177	171020	195731	198887

Cations, mg/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986 unfiltered	December 1986 filtered
Calcium	12400	14100	20000	19000	20000
Sodium	33700	44100	49000	44000	46000
Magnesium	3320	2790	3300	3300	3400
Potassium	8460	180		180	180
Manganese	16.7	12.3	11	28	28
Iron	25.3	--	--	47	--
Lithium	51	30	--	--	--
Barium	516	547	670	640	660
Strontium	1490	1740	2100	2000	2100
Titanium	1.9	--	--	15	13
Zinc	5.9	--	--	15	15

Anions, mg/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986 unfiltered	December 1986 filtered
Chloride	113000	100000	95000		125000
Sulfate	--	--	--		--
Bromide	839	90	950		1200
Phosphate		--			--
Nitrate	--	5	24		.4
Fluoride		.21	.14		300
Iodide		--	10		--

Radionuclides, pCi/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986 unfiltered	December 1986 filtered
Gross Alpha		--	--		--
Gross Beta		--	1189.2		--
Sr-90	--	--	297.3		25.9
Cs-137	14.1	--	29.7		--
Co-60	--	--	--		--
H-3	--	--			--
Tc-99	22.4	--			--
Th-232			25.9		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The October 1983, May 1986, and December 1986 samples were collected at a depth of 690 ft bgs.

The January 1985 sample was collected at 685 ft bgs.

Fig. 2.55. Chemistry of standing water column in NHF rock cover Well 1979.

2.13 SUMMARY OF WELL 2952 (DM1-RT)—RANKED 4

Well History. Well 2952 (DM1-RT) is one of seven deep-monitoring wells installed in the vicinity of the NHF. This well, located 1,070 ft east of the injection well (Well 1968), has an open interval within the Rutledge Limestone. The well was completed to a depth of 721 ft bgs in January 1986.

In February 1987 (after a January 1986 sampling by ORNL), a computerized pressure monitoring system was installed in Well 2952. The system consisted of a pressure transducer, transducer carrier, tension-set packer, wireline cable, and landing nipple assembly. The equipment was installed on 2 $\frac{3}{8}$ -in. EUE steel tubing. The system was designed to allow real-time monitoring of pressure in the well. No results or reports that document pressure data collected from this well were located at ORNL.

Construction Details. A 10 $\frac{3}{4}$ -in. surface casing was installed in the top 50 ft of Well 2952. The surface casing was grouted in place in a nominal 15-in. diameter borehole. A nominal 8 $\frac{1}{4}$ -in. hole was drilled from 50 to 615 ft bgs, and 6-in. ID black steel casing was grouted in place. An interval was then drilled from a depth of 615 to 721 ft bgs. This section of the well was left openhole within the Rutledge Limestone.

The borehole logging team measured the bottom of Well 2952 to be at 721 ft bgs. The current configuration of the wellhead, construction details, and proposed P&A are shown in Figs. 2.56–2.59.

Field Activities. Well 2952 was tapped on August 8, 1995. Neither the annulus between the 6-in. well casing and the 2 $\frac{3}{8}$ -in. steel tubing, nor the tubing itself were under pressure. The water level immediately after tapping was 161.36 ft bgs. A series of water level measurements were made through November 1995. The tapping information and water level data are provided in Table 2.13.

Prior to sampling the standing water in Well 2952, the transducer and packer assembly had to be removed. On September 12-13, 1995, approximately 580 ft of steel tubing, a 6-in. diameter packer, and the transducer assembly were removed from the well. The tubing was cut up and placed in B-25 boxes for disposal. The water column in Well 2952 was then sampled at three depths (200, 449, and 696 ft bgs) in October 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.13 provides the results of the sample analysis for Well 2952. Two of the water samples collected (middle and bottom) are acidic (pH 6.06 and 5.55, respectively). The top sample is very basic (pH 11.26) and would indicate reaction with well construction grout. The top sample has a low TDS (15,402 mg/L) indicative of saline water. It appears that an influx of fresh water from an uphole zone has diluted the water in the top sample. The other two samples are high saline brine (TDS, > 221,933 mg/L). This water appears to be native brine composed predominantly of sodium chloride (Fig. 2.60). Nitrate was not detected in the recent round of sampling. A minor amount of nitrate, however, was detected in the historical sampling (18 mg/L). Strontium-90 (6,756.8 pCi/L) was reported in the historical sampling, and trace amounts of ¹³⁷Cs [27 pCi/L (1986) and 53.4 pCi/L (1995)] were reported in the recent and past sampling. No organics were detected at significant levels.

The analytical results of the historical samples collected from Well 1974 are reported in Table 2.13.

Geophysical Log Interpretation. The neutron and gamma ray log responses are characteristic for the area and are useful for lithology and picking formation tops. The caliper log indicates that the well was constructed using 20 ft casing string. The casing appears to be corroded over the entire length. No fractures are noted in the openhole interval. The VDL indicates good casing bonding to bottom of casing.

Well Ranking. Well 2952 appears to be in fair condition. There is an indication that the casing is corroded but there is no evidence of one casing leakage. The well is classified as having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. The well would be suitable for temporary monitoring of the Rutledge Limestone. If left inactive, however, the well should be P&A. Well 2952 is ranked 4 for P&A.

General P&A Plan. Figures 2.56–2.59 show the surface and wellhead configuration, well details, and proposed P&A. The well details are from published ORNL reports and are considered accurate. Casing bonding, based on log interpretation, is good. The casing condition, however, appears to be poor.

Well 2952 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (to approximately 600 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Three cement plugs (5 to approximately 300 ft, approximately 300 to 600 ft, and 600 to TD) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 270 and 600 ft (initial plug 600 ft to TD). This plug will be squeezed using a packer and tagged. A 30-ft (approximately 240 to 270 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 240 ft) after placement of the cement plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 210 to 270 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 210 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

C.

DEEP MONITORING WELL 2952 (DM1-RT)

Fig. 2.56. Wellhead construction details.

Fig. 2.57. Well 2952 (DM1-RT) acoustic variable density log.

B = Gross Beta

Fig. 2.58. Characteristic log responses, observations, and summary chemical data for Well 2952 (DM1-RT).

WELL 2952 (DM1-RT)
EXISTING WELL CONDITION

WELL 2952 (DM1-RT)
PROPOSED PLUGGING AND ABANDONMENT

Fig. 2.59. Existing well construction and proposed P&A for Well 2952 (DM1-RT).

Table 2.13. Well water measurements for Well 2952 (DM1-RT)

Well Construction						
Original Date Well Completed = 1985			ORNL Grid Coordinates			
Well Type = Deep Monitoring			Northing = 16649.77			
Formation Penetration = Rutledge Limestone			Easting = 29238.29			
Ground Surface Elev (ft) = 765.52			Historical Notes:			
Bottom Riser Casing Depth (ft bgs) = 615						
Bottom Riser Casing Elev (ft) = 150.52						
Total Depth (ft bgs) = 721						
Total Depth Elev (ft) = 44.52						
Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	8/8/95	0	16.5	8.6	13	Tubing tap
Casing Annulus	8/8/95	0	20.7	2.8	1	Casing/Tubing annulus tap
Sample Details						
	Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)		
	10/18/95	200	566	15,402		
	10/19/95	449	317	221,933		
	10/19/95	696	70	237,648		
Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft) Comments
Water Level	9/6/95	161.36	GS			604.16
Water Level	9/12/95	161.09	GS			604.43 Immediately before tubing removed
Water Level	9/13/95	180.85	GS			584.67 Immediately after tubing removed
Water Level	10/16/95	177.73	GS			587.79
Water Level	10/18/95	177.50	GS			588.02
Water Level	11/13/95	176.46	GS			589.06
Average					593.02	+ GS = Above Ground Surface
Minimum					584.67	GS = Ground Surface
Maximum					604.43	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.13 (continued). Well water sample analysis for Well 2952 (DM1-RT)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	11.26	6.06	5.55
Lab pH	10.74	5.07	4.2
Temperature (C)	17.7	14.7	20.1
Specific Conductivity ($\mu\text{S} / \text{cm}$)	23800	190500	191500
Eh (mV)	35	79.3	119.3
Alkalinity (mg CaCO_3 / L)	121	15	--
Total Dissolved Solids (mg / L)	15402	221933	237648
Total Suspended Solids (mg / L)	24	147	193
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	866	25000	27300
Sodium	4620	53800	55800
Magnesium	--	5390	5870
Potassium	741	316	171
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	8190	136000	134000
Sulfate	117	--	--
HCO_3		18	--
CO_3		0	--
Bromide	52.5	1220	1320
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	522	--	--
Gamma Activity	--	53.4	--
Sr - 90			
Cs - 137		53.4	
H - 3	1693.7	--	--
C - 14	--	--	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	123	16	11
Benzene	3	--	--
Ethylbenzene	2	--	--
Xylenes (total)	9	9	2

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.13 (continued). Historical sample analysis for Well 2952 (DM1-RT)

pH, Alkalinity, and TDS

Analyte	January 1986 unfiltered
pH	6.8
Alkalinity (mg HCO ₃ /L)	3
Total Dissolved Solids (mg/L)	145740

Cations, mg/L

Analyte	January 1986 unfiltered
Calcium	13000
Sodium	30000
Magnesium	2700
Potassium	740
Manganese	3.4
Iron	5.3
Lithium	28
Barium	89
Strontium	1300
Phosphorus	9.2

Anions, mg/L

Analyte	January 1986 unfiltered
Chloride	98000
Sulfate	--
Bromide	840
Phosphate	28
Nitrate	18
Fluoride	.6
Iodide	0

Radionuclides, pCi/L

Analyte	January 1986 unfiltered
Gross Beta	1513.5
Sr-90	6756.8
Cs-137	27
Co-60	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.
The January 1986 sample was collected at a depth of 700 ft bgs.

Fig. 2.60. Chemistry of standing water column in NHF deep monitoring Well 2952.

2.14 SUMMARY OF WELL 1969 (4E-200RC)—RANKED 4

Well History. Well 1969 (4E-200RC) is one of eight rock-cover wells (constructed in 1980) surrounding the NHF. Well 1969 is 200 ft east of the NHF injection well (ORNL Well 1968 [4-INJECT]). The well has an open interval within the Rogersville Shale and Rutledge Limestone formations.

Rock-cover wells were constructed to periodically monitor pressure and changes in permeability, as measured by water acceptance, within the relatively impermeable sections that overlie the disposal zone (Pumpkin Valley Shale). The permeability was determined by pressurizing each well to 75 psi for 2 hours and measuring the rate at which the formation would accept water. Results of the tests indicate that Well 1969 accepted the second most largest volume of water. This would imply that in a relative sense the permeability of the rock cover is second highest in 1969.

Four historical samples were collected from Well 1969 (4E-200RC) (October 1983, January 1985, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was sampled, unpurged, in July 1995 as part of the WAG 10 NHF field investigation.

Well Construction. Well 1969 (4E-200RC) was drilled to a TD of 650 ft. The well is cased to a depth of 530 ft, and the bottom 120 ft of the well is open to the formation. The TD of the well was measured to be 650 ft bgs during the sampling and borehole logging. Figures 2.61–2.64 show the current configuration of the wellhead, well construction details, and proposed P&A.

Recent Field Activities. Well 1969 was tapped on June 13, 1995. The well was not under pressure, and the water level immediately after tapping was 70.84 ft bgs. A series of water level measurements were made through November 1995. A list of the tapping information and water level data is provided in Table 2.14.

The water column in Well 1969 was also sampled at three depths (96, 339, and 625 ft bgs) in July 1995 as part of the field investigation.

Analytical Results. Table 2.14 provides the results of the analysis of the three recent samples from Well 1969. All three samples are acidic (pH 5.12 to 6.00) and had high levels of TDS ($\geq 147,355$ mg/L, shallowest sample). The water is native brine composed predominantly of sodium with lesser amounts of calcium, and the major anion was chloride (Fig. 2.65). No nitrate was detected in the recent sampling. Minor amounts of nitrate were detected in the historical sampling (maximum 32 mg/L, bottom sample, May 1986). Cesium-137 was the only radionuclide detected in the 1995 sampling. It was found at depths of 339 (293 pCi/L) and 625 ft bgs (29.3 pCi/L). Minor amounts of ^{90}Sr (64.9 pCi/L) and ^{60}Co (maximum 3.5 pCi/L) were reported in the historical sampling. Dichloromethane was the only organic compound detected at levels above the SDWA MCL (40 *Code of Federal Regulations* 141.61).

The analytical results of the historical samples collected from Well 1969 are reported in Table 2.14.

Geophysical Log Interpretation. The neutron and gamma ray log responses are characteristic for the area and are useful for picking formation tops. The caliper log shows the casing to be featureless, except for joints at 30-ft intervals. The apparent density confirms 30-ft joints. The openhole shows minor enlargement at 555 ft and from 560 to 568 ft. These

enlargements may be indicative of fractures. The temperature log displays a negative deviation from 560 to 570 ft indicative of flow in the openhole interval at the depth. The temperature anomaly correlates with hole enlargement.

The VDL indicates good casing bonding. No other construction details are apparent on the VDL. The TDS results would confirm this interpretation. Low velocity, saprolithic material appears to extend from 0 to approximately 120 ft (bgs).

Well Ranking. Well 1969 appears to be in good condition and there is no apparent evidence of behind casing flow. The well is classified as having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. There is evidence of a hydraulic fracture in the openhole interval (Rogersville Shale). The well would be suitable for temporary monitoring of the brine (181,000 mg/L) water. If left inactive, however, the well should be P&A. Well 1969 is ranked 4 for P&A.

General P&A Plan. Figures 2.61–2.64 show the surface and wellhead configuration, interpreted well details, and proposed P&A. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs.

Casing bonding, based on log interpretation, is good. The casing condition also appears to be good.

Well 1969 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. The casing will be pressure tested [≤ 100 psi (surface gauge pressure) for 1 h] above/near the casing shoe (at 530 ft) by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Two cement stages (5 to approximately 300 ft and approximately 300 to 650 ft) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 310 and 650 ft. This plug will be squeezed using a packer and tagged. A 30-ft (approximately 280 to 310 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 280 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 250 to 310 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 250 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

C.

ROCK COVER WELL 1969 (4E-200RC)

Fig. 2.61. Wellhead construction details.

Fig. 2.62. Well 1969 (4E-200RC) acoustic variable density log.

Fig. 2.63. Characteristic log responses, observations, and summary chemical data for Well 1969 (4E-200RC).

Fig. 2.64. Existing well construction and proposed P&A for Well 1969 (4E-200RC).

Table 2.14. Well water measurements for Well 1969 (4E-200RC)

Well Construction							
Original Date Well Completed = 1980			ORNL Grid Coordinates				
Well Type = Rock Cover			Northing = 16487.09				
Formation Penetration = Rutledge Limestone			Easting = 28376.61				
Ground Surface Elev (ft) = 788.59			Historical Notes: 				
Bottom Riser Casing Depth (ft bgs) = 550							
Bottom Riser Casing Elev (ft) = 238.59							
Total Depth (ft bgs) = 650							
Total Depth Elev (ft) = 138.59							
Tapping Details							
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments	
Riser Casing	6/13/95	0	20.9	60	34	--	
Casing Annulus	--	--	--	--	--	--	
Sample Details							
	Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)			
	7/5/95	96	693	147,355			
	7/6/95	339	450	167,258			
	7/7/95	625	164	180,688			
Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/13/95	70.84	GS			717.75	
Water Level	6/14/95	70.84	GS			717.75	
Water Level	7/5/95	70.90	GS			717.69	
Water Level	7/13/95	72.05	GS			716.54	
Water Level	9/6/95	72.71	GS			715.88	
Water Level	10/16/95	72.56	GS			716.03	
Water Level	11/13/95	72.45	GS			716.14	
Average					716.83	+ GS = Above Ground Surface	
Minimum					715.88	GS = Ground Surface	
Maximum					717.75		

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.14 (continued). Well water sample analysis for Well 1969 (4E-200RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	6	5.69	5.12
Lab pH	4.44	4.62	4.45
Temperature (C)	20.9	24.2	18
Specific Conductivity ($\mu\text{S} / \text{cm}$)	149400	156200	173000
Eh (mV)	3.4	108	79.8
Alkalinity (mg CaCO_3 / L)	--	--	--
Total Dissolved Solids (mg / L)	147355	167258	180688
Total Suspended Solids (mg / L)	200	70	210

Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	14000	15200	18700
Sodium	43000	46700	48800
Magnesium	2170	3480	3910
Potassium	164	131	126
Ammonium	--	--	--
Lithium	--	--	--

Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	91000	102000	114000
Sulfate	--	--	--
HCO_3	--	--	--
CO_3	--	--	--
Bromide	722	866	959
Phosphate	--	--	--
Nitrate- Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	--	293	29.3
Sr-90	--	--	--
Cs-137	--	293	29.3
H-3	--	--	--
C-14	--	--	--

Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	148	11	15
Benzene	2	--	--
Dichloromethane	269	--	8
Ethylbenzene	64	--	2
Toluene	4	--	--
Xylenes (total)	256	--	8

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.14 (continued). Historical sample analysis for Well 1969 (4E-200RC)

pH, Alkalinity, and TDS

Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
pH		4.7	4.1	unfiltered 4.9	filtered
Alkalinity (mg HCO ₃ /L)	--	6	--		2
Total Dissolved Solids (mg/L)	147091	182549	193840	195060	188459

Cations, mg/L

Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
Calcium	13400	12200	19000	unfiltered 19000	filtered 17000
Sodium	26600	44500	48000	46000	42000
Magnesium	3040	2880	3300	3400	3100
Potassium	11400	160		180	170
Manganese	17.7	13.7	30	33	30
Iron	23	5.12	39	73	32
Lithium	40.6	58.8	--	--	--
Barium	498	599	660	660	610
Strontium	1620	1540	2000	2000	1800
Chromium	--	.94	--	--	--
Zinc	28.8	12	--	--	--
Titanium	203	--	--	14	15

Anions, mg/L

Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
Chloride	101000	120000	120000	unfiltered	filtered 122000
Sulfate	--	--	--		--
Bromide	933	830	880		1300
Phosphate		--			--
Nitrate	--	5	32		2
Fluoride		.46	.33		400
Iodide		--	18		--

Radionuclides, pCi/L

Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
Gross Alpha		--	--	unfiltered	filtered --
Gross Beta		--	--		--
Sr-90	--	--	64.9		--
Cs-137	--	--	27		--
Co-60	2.7	--	3.5		--
H-3	--	--			--
Tc-99	5.7	--			--
Th-232			--		--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The October 1983, January 1985, and May 1986 samples were collected at a depth of 640 ft bgs.

The December 1986 sample was collected at 635 ft bgs.

Fig. 2.65. Chemistry of standing water column in NHF deep monitoring Well 1969.

2.15 SUMMARY OF WELL 1971 (4N-200RC)—RANKED 4

Well History. Well 1971 (4N-200RC) is one of eight rock-cover wells constructed in 1980 surrounding the NHF. Well 1971 is 215 ft north of the NHF injection well (ORNL Well 1968). The well is open to the Rogersville and Rutledge Formations.

The rock-cover wells were constructed to monitor pressure and changes in the permeability (water acceptance tests) above the disposal zone. The permeability was determined by pressurizing each well to 75 psi and measuring the rate at which the formation would accept water. Results from the last test conducted (June 1983) indicate that the well did not accept water. The rock cover at this location appears to be impermeable.

Three historical samples were collected from Well 1971 (4N-200RC) (October 1983, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was not purged before the other sample events. The well was also sampled in July 1995 as part of the WAG 10 field investigation.

Well Construction. Well 1971 was drilled to a reported TD of 580 ft bgs. The well is cased to a depth of 480 ft bgs, and the bottom 100 ft of the well is reported to be open to the formation. The well was equipped with geophones and packed with sand. In 1986, an attempt was made to remove the geophones; however, the cable continued to break. The geophones were left in the hole. Geraghty and Miller (1986) report the top of the sand pack containing the geophones is at a depth of 485 ft bgs.

While attempting to measure the total well depth during the sampling on June 19, 1995, the wire-line sampler stopped at 413 ft bgs and could not go any further. The geophysical logging probes stopped at a depth of 410 ft bgs. It is assumed based on these results that the top of sand is at 410 ft (bgs). Figures 2.66–2.69 show the current wellhead configuration, well construction details, and the proposed P&A.

Field Activities. Well 1971 was tapped on June 12, 1995. The well was not under pressure, and the water level immediately after tapping was 37.50 ft bgs. A series of water level measurements were made through November 1995. A list of the tapping information and water level data is provided in Table 2.15.

The water column in Well 1971 was also sampled at three depths (62, 261, and 387 ft bgs) in June 1995 as part of the field investigation.

Analytical Results. Table 2.15 provides the results of the sample analysis for Well 1971. The water is acidic (pH 5.48 to 5.70) and of native brine composition ($\geq 144,940$ mg/L). The water is of sodium chloride composition, with lesser concentrations of calcium (Fig. 2.70). Nitrate was not detected in the recent sampling. Minor concentrations of nitrate, however, were detected in historical sampling (maximum 28 mg/L). No radionuclides or organics were detected at significant levels in Well 1971 in the recent sampling. Minor concentrations of ^{90}Sr (73 pCi/L), ^{137}Cs (27 pCi/L), and ^{60}Co (70.3 pCi/L) were detected during historical samplings.

The historical analytical results are presented in Table 2.15.

Geophysical Log Interpretation. Well 1971 is plugged at a depth of 410 ft (bgs). This depth probably marks the top of the sanded-in geophones and is not a true obstruction in the well.

The neutron and gamma ray log responses are characteristic for the area and are useful for picking formation tops. The caliper log shows some possible casing corrosion and joints at 30-ft intervals. The apparent density confirms 30-ft joints. The openhole was not logged and presently contains sanded-in geophones. No significant deviations are shown on the temperature log.

The VDL indicates good casing bonding with no other apparent construction details. The TDS results indicate that water is flowing to the wellbore through the sanded-in geophones. The signature of the rock section on the VDL seems to imply possible deformation/fracturing of the section.

Well Ranking. Well 1971 appears to be in good condition with no direct evidence of behind casing flow. The well is classified as having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. In the past, the well was equipped with cable and geophones. An attempt was made to retrieve the equipment but failed after the cable broke. The equipment was sanded in and abandoned in the openhole interval of the well. This well is unsuitable for temporary monitoring. Well 1971 is ranked low (4) for future P&A.

General P&A Plan. Figures 2.66–2.69 show the surface and wellhead configuration, interpreted well details, and proposed P&A. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs. It is believed that 410 ft bgs marks the top of the sanded-in geophones. The recommendation is made that these downhole components be left in place and not drilled out of the well.

The casing bonding is interpreted to be good. The casing condition also appears to be generally good with some indication of corrosion.

Well 1971 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. The casing will be pressure tested [≤ 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer after placement of the first cement stage to approximately 380 ft (bgs). The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Two cement stages (5 to approximately 380 ft and approximately 380 to 410 ft) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 280 and 380 ft. This plug will be squeezed using a packer and tagged. A 30-ft (approximately 250 to 280 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 250 ft) after placement of the plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 220 to 280 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 220 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

ROCK COVER WELL 1971 (4N-200RC)

Fig. 2.66. Wellhead construction details.

Fig. 2.67. Well 1971 (4N-200RC) acoustic variable density log.

Fig. 2.68. Characteristic log responses, observations, and summary chemical data for Well 1971 (4N-200RC).

Fig. 2.69. Existing well construction and proposed P&A for Well 1971 (4N-200RC).

Table 2.15. Well water measurements for Well 1971 (4N-200RC)

Well Construction	
Original Date Well Completed = 1980	ORNL Grid Coordinates
Well Type = Rock Cover	Northing = 16716.33
Formation Penetration = Rutledge Limestone	Easting = 28168.74
Ground Surface Elev (ft) = 767.99	
Bottom Riser Casing Depth (ft bgs) = 480	Historical Notes:
Bottom Riser Casing Elev (ft) = 287.99	
Total Depth (ft bgs) = 580	
Total Depth Elev (ft) = 187.99	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	6/12/95	0	20.6	0.8	3	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
6/19/95	62	706	144,940
6/19/95	261	507	160,794
6/20/95	387	381	162,616

Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/12/95	37.50	GS			730.49	
Water Level	6/13/95	37.48	GS			730.51	
Water Level	6/14/95	37.47	GS			730.52	
Water Level	6/15/95	37.44	GS			730.55	
Water Level	6/19/95	37.40	GS			730.59	
Water Level	7/13/95	41.77	GS			726.22	
Water Level	9/6/95	40.81	GS			727.18	
Water Level	10/16/95	39.16	GS			728.83	
Water Level	11/13/95	38.58	GS			729.41	
Average						729.37	+ GS = Above Ground Surface
Minimum						726.22	GS = Ground Surface
Maximum						730.59	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.15 (continued). Well water sample analysis for Well 1971 (4N-200RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	5.48	5.7	5.58
Lab pH	4.67	4.77	4.24
Temperature (C)	19.9	18.9	18.3
Specific Conductivity ($\mu\text{S} / \text{cm}$)	168600	178000	180000
Eh (mV)	-55.2	-24.5	-5.9
Alkalinity (mg CaCO_3 / L)	--	--	--
Total Dissolved Solids (mg / L)	144940	160794	162616
Total Suspended Solids (mg / L)	122	95	140
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	13500	15000	15000
Sodium	36500	40600	41300
Magnesium	2570	3100	3080
Potassium	90	96	93
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	91400	99600	99600
Sulfate	--	--	--
HCO_3	--	--	--
CO_3	--	--	--
Bromide	714	776	782
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	--	--	--
Sr - 90	--	--	--
H - 3	200.9	4561.3	1156.8
C - 14	--	--	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	129	16	10

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.15 (continued). Historical sample analysis for Well 171 (4N-200RC)

pH, Alkalinity, and TDS

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
pH		5.2	1.7	
Alkalinity (mg HCO ₃ /L)	47.1	--		--
Total Dissolved Solids (mg/L)	6408	162770	166206	168275

Cations, mg/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Calcium	717	16000	14000	15000
Sodium	2180	44000	40000	41000
Magnesium	168	2900	2800	2800
Potassium	954		150	140
Manganese	1.4	20	20	20
Iron	--	25	70	42
Lithium	4	--	--	--
Barium	18.9	500	470	480
Strontium	79	1600	1500	1600
Cadmium	--	--	3.4	--
Titanium	.4	--	13	13

Anions, mg/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Chloride	3200	97000		106000
Sulfate	--	--		--
Bromide	45	770		900
Phosphate				--
Nitrate	--	28		3.01
Fluoride		.03		280
Iodide		15		--

Radionuclides, pCi/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Gross Alpha		--		--
Gross Beta		--		1621.6
Sr-90	10.8	73		--
Cs-137	--	22.2		27
Co-60	--	2.2		70.3
H-3	--			--
Tc-99	--			--
Th-232		15.1		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The October 1983 sample was collected at a depth of 640 ft bgs; the May 1986 sample at 400 ft bgs; and the December 1986 sample at 635 ft bgs.

Fig. 2.70. Chemistry of standing water column in NHF rock cover Well 1971.

2.16 SUMMARY OF WELL 1973 (4NE-280RC)—RANKED 4

Well History. Well 1973 (4NE-280RC) is one of eight rock-cover wells constructed in 1980 surrounding the NHF. Well 1973 is 300 ft northeast of the NHF injection well (ORNL Well 1968). The well is open to the Rogersville Shale and Rutledge Limestone.

The rock-cover wells were constructed to monitor pressure during grout injections and periodically run water-acceptance tests to check for changes in the permeability of the rock cover. Very little water was accepted into the openhole interval of this well. These results would indicate no increase in permeability attributable to grout injection.

Four historical samples were collected from Well 1973 (4NE-280RC) (October 1983, January 1985, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was not purged before the other sample events. The well was also sampled in July 1995 as part of the WAG 10 field investigation.

Well Construction. Well 1973 was drilled to a TD of 582 ft bgs. The geophysical logging team measured the TD of the well to be 590 ft bgs, and the sample team measured 588 ft bgs in July 1995. The well is cased to a depth of 480 ft bgs, and the bottom 110 ft of the well is open to the Rogersville Shale/Rutledge Limestone. Figures 2.71–2.74 show the present wellhead configuration, well construction details, and proposed P&A.

Field Activities. Well 1973 was tapped on July 17, 1995. The well was not under pressure, and the water level immediately after tapping was 52.80 ft bgs. A series of water level measurements were made through November 1995. A list of the tapping information and water level data is provided in Table 2.16.

The water column in Well 1973 was also sampled at three depths (76, 317, and 557 ft bgs) in June 1995 as part of the field investigation.

Analytical Results. Table 2.16 provides the results of the sample analysis for Well 1973. The standing water column in Well 1973 is acidic (pH 6.76) and the TDS of the native brine is $\geq 146,345$ mg/L. The water is of sodium chloride composition (Fig. 2.75). Nitrate was not detected by the recent sampling. Historical results indicate minor concentrations of nitrate (maximum 34 mg/L). Cesium-137 (107 to 234 pCi/L, respectively) was detected in the two lower samples. Strontium-90 (2,351 pCi/L) was detected in an historical sample collected before well purging. The concentration detected after purging (^{90}Sr 29.7 pCi/L) was substantially lower. Dichloromethane was the only organic compound detected above the SDWA MCL.

The analytical results of the historical samples collected from Well 1973 are reported in Table 2.16.

Geophysical Log Interpretation. The neutron and gamma ray log responses are characteristic for the area and are useful for picking formation tops. The caliper log shows the casing to be featureless, except for joints at 30-ft intervals. The apparent density measures a decrease between 296 and 309 ft that may be indicative of a void behind casing. The openhole shows an enlargement at 488 ft. This enlargement may be indicative of a bedding plane. No temperature log was run in Well 1973.

The VDL indicates good casing bonding to 480 ft (bgs). No other construction details are apparent on the VDL. The TDS results would confirm this interpretation. The disrupted rock signature shown on the VDL may be indicative of intense deformation/fracturing/folding.

Well Ranking. Well 1973 appears to be in good condition and there is no apparent evidence of behind casing flow. The well is classified as having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. There is a possible void behind casing at 300 ft bgs. The well is not recommended for temporary site monitoring. If left inactive, and because of the threat of flow of brine uphole, this well should be P&A. Well 1973 is ranked 4 for P&A.

General P&A Plan. Figures 2.71–2.74 show the surface and wellhead configuration, interpreted well details, and proposed P&A. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs.

Casing bonding and casing condition, based on log interpretation, appear to be good.

Well 1973 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. The casing will be pressure tested [≤ 100 psi (surface gauge pressure) for 1 h] above/near the casing shoe (at 480 ft) by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Two cement stages (5 to approximately 300 ft and approximately 300 to 590 ft) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 265 and 590 ft. This plug will be squeezed using a packer and tagged. A 30-ft (approximately 235 to 265 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 232 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 205 to 265 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 205 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

ROCK COVER WELL 1973 (4NE-280RC)

Fig. 2.71. Wellhead construction details.

Fig. 2.72. Well 1973 (4NE-280RC) acoustic variable density log.

Fig. 2.73. Characteristic log responses, observations, and summary chemical data for Well 1973 (4NE-280RC).

Fig. 2.74. Existing well construction and proposed P&A for Well 1973 (4NE-280RC).

Table 2.16. Well water measurements for Well 1973 (4NE-280RC)

Well Construction	
Original Date Well Completed = 1980	ORNL Grid Coordinates
Well Type = Rock Cover	Northing = 16661.52
Formation Penetration = Rutledge Limestone	Easting = 28434.92
Ground Surface Elev (ft) = 764.77	
Bottom Riser Casing Depth (ft bgs) = 480	Historical Notes:
Bottom Riser Casing Elev (ft) = 284.77	
Total Depth (ft bgs) = 582	
Total Depth Elev (ft) = 182.77	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	7/17/95	0	20.6	4	1	--
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
7/17/95	76	689	73,436
7/19/95	317	448	140,146
7/19/95	557	208	155,621

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Water Level	7/17/95	52.80	GS			711.97
Water Level	9/6/95	37.16	GS			727.61
Water Level	10/16/95	51.83	GS			712.94
Water Level	11/13/95	50.98	GS			713.79

Average   716.58
 Minimum   711.97
 Maximum   727.61

+ GS = Above Ground Surface
 GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.16 (continued). Well water sample analysis for Well 1973 (4NE-280RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	6.76		
Lab pH	4.36	4.08	4.32
Temperature (C)	19.1	18.2	20.4
Specific Conductivity ($\mu\text{S} / \text{cm}$)	101200	166600	175000
Eh (mV)	7.4		
Alkalinity (mg CaCO_3 / L)	--	--	--
Total Dissolved Solids (mg / L)	73436	140146	155621
Total Suspended Solids (mg / L)	46	84	110

Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	5280	12400	14300
Sodium	21700	38600	42100
Magnesium	1410	2930	3300
Potassium	56	207	96
Ammonium	--	--	--
Lithium	--	--	--

Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	48000	85800	94900
Sulfate	--	--	--
HCO_3	--	--	--
CO_3	--	--	--
Bromide	134	680	2170
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	--	107	234
Sr - 90			
Cs - 137		107	234
H - 3	--	--	--
C - 14	--	--	--

Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	60	--	--
Dichloromethane	10	--	--
Ethylbenzene	2	--	--
Naphthalene	2	--	--
Xylenes (total)	8	5	2

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.16 (continued). Historical sample analysis for Well 173 (4NE-280RC)

pH, Alkalinity, and TDS					
Analyte	October 1983	January 1985	May 1986	December 1986	
	filtered	filtered	unfiltered	unfiltered	filtered
pH		4.7	5.9	4.6	
Alkalinity (mg HCO ₃ /L)	.2	4	--		--
Total Dissolved Solids (mg/L)	166779	159363	160920	147490	146345

Cations, mg/L					
Analyte	October 1983	January 1985	May 1986	December 1986	
	filtered	filtered	unfiltered	unfiltered	filtered
Calcium	15500	12200	16000	12000	12000
Sodium	27700	41600	44000	34000	33000
Magnesium	3120	2770	3000	2500	2400
Potassium	17300	130		160	160
Manganese	10.9	25.5	33	30	29
Iron	--	13.6	47	110	49
Lithium	53.2	25.7	--	--	--
Barium	478	463	530	450	450
Strontium	1880	1530	1600	1400	1400
Chromium	--	.95	--	--	--
Titanium	4.9	--	--	--	17

Anions, mg/L					
Analyte	October 1983	January 1985	May 1986	December 1986	
	filtered	filtered	unfiltered	unfiltered	filtered
Chloride	117000	100000	95000		95700
Sulfate	--	--	--		--
Bromide	1101	800	790		950
Phosphate		--			--
Nitrate	--	4	34		2.6
Fluoride		.29	.3		190
Iodide		--	16		--

Radionuclides, pCi/L					
Analyte	October 1983	January 1985	May 1986	December 1986	
	filtered	filtered	unfiltered	unfiltered	filtered
Gross Alpha		--	--		--
Gross Beta		--	973		--
Sr-90	59.5	2351.3	29.7		7
Cs-137	--	--	21.9		--
Co-60	--	--	--		--
H-3		--			--
Tc-99	--	--			--
Th-232			--		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The October 1983 and December 1986 samples were collected at a depth of 570 ft bgs.

The January 1985 and May 1986 samples were collected at a depth of 580 ft bgs.

Fig. 2.75. Chemistry of standing water column in NHF deep monitoring Well 1973.

2.17 SUMMARY OF WELL 1974 (4NW-340RC)—RANKED 4

Well History. Well 1974 (4NW-340RC), constructed (1980) as one of eight rock-cover wells surrounding the NHF is located 350 ft northwest of the injection well (Well 1968). The well is open to the Rogersville and Rutledge Formations.

The rock-cover wells were constructed to monitor pressure and to periodically monitor for changes in the permeability in the rock cover (Rogersville Shale/Rutledge Limestone) overlying the disposal zone. Pressures were measured during and after injections to track the probable direction of grout flow. The permeability was determined by pressurizing each well to 75 psi and measuring the rate at which the formation would accept water. Results of the water acceptance tests indicate that the rock cover at this location accepted the largest volume of water, compared to the other rock cover wells, during the test conducted after SI-3. The last acceptance test conducted after SI-6 indicated that the amount of water accepted was third when compared to the other wells. These results would indicate that the permeability at this location is moderate. No permeability increase caused by grout injection is noted.

Three historical samples were collected from Well 1974 (4NW-340RC) (October 1983, January 1985, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was not purged before the other sample events. The well was sampled in July 1995 as part of the WAG 10 field investigation.

Construction Details. Well 1974 was reportedly drilled to a TD of 580 ft bgs. The geophysical logging and sample teams, however, measured the TD of the well to be 591 ft bgs. The well is cased to a depth of 484 ft bgs (measured by logging), and the bottom 107 ft of the well is open to the formation. The present configuration of the wellhead, well construction details, and proposed P&A are shown in Figs. 2.76–2.79.

Field Activities. Well 1974 was vented, so it was unnecessary to tap the well. The earliest water level measurement was 20.16 ft bgs on June 27, 1995. A series of water level measurements were made through November 1995. A list of the water level data is provided in Table 2.17.

The water column in Well 1974 was sampled at three depths (45, 300, and 555 ft bgs) in July 1995 as part of the field investigation.

Analytical Results. Table 2.17 provides the results of the sample analysis for Well 1974. The water sampled from this well is acidic (pH 5.04–6.22), except for the top sample which is near neutral (pH 7.39). All three samples are brine (TDS > 149,714 mg/L). The water appears to be native brine composed predominantly of sodium with lesser amounts of calcium, and the major anion was chloride (Fig. 2.80). Nitrate was not detected in the recent round of sampling. A minor amount of nitrate, however, was detected in the historical sampling (maximum 54 mg/L, bottom sample, May 1986). Minor amounts of ^{90}Sr (< 118.9 pCi/L), ^{137}Cs (18.6 pCi/L), and ^{60}Co (15.1 pCi/L) were reported in the historical sampling. No organics were detected at significant levels.

The analytical results of the historical samples collected from Well 1974 are reported in Table 2.17.

Geophysical Log Interpretation. The neutron and gamma ray log responses are characteristic for the area and are useful for lithology and picking formation tops. The caliper log

shows the casing (30 ft) to be featureless except for construction grout in casing near the shoe. A temperature log was not run in this well. The SPR log is shorted out and would confirm laboratory results indicative of brine composition. Apparent density shows joints and a possible centralizer at 380 ft.

The VDL indicates good casing bonding to bottom of casing at 484 ft bgs and surface casing to 40 ft bgs. Rock signature is strong as seen behind casing.

Well Ranking. Well 1974 appears to be in fairly good condition, with no apparent evidence of behind-casing flow. The well is classified as having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. The well is not recommended for temporary site monitoring. If left inactive, and because of the threat of flow of brine (163,000 mg/L) uphole, this well should be P&A. Well 1974 is ranked 4 for P&A.

General P&A Plan. Figures 2.76–2.79 show the surface and wellhead configuration, interpreted well details, and proposed P&A. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs. Casing bonding, based on log interpretation, is good. The casing condition also appears to be good.

Well 1974 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (to approximately 454 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h above the casing shoe (at approximately 484 ft) by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Three cement plugs (5 to approximately 230 ft, approximately 230 to 454 ft, and 454 to TD) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 270 and 454 ft (initial plug 454 to TD). This plug will be squeezed using a packer and tagged. A 30-ft (approximately 24 to 270 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 240 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 210 to 270 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 210 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

ROCK COVER WELL 1974 (4NW-340RC)

Fig. 2.76. Wellhead construction details.

Fig. 2.77. Well 1974 (4NW-340RC) acoustic variable density log.

Fig. 2.79. Existing well construction and proposed P&A for Well 1974 (4NW-340RC).

Table 2.17. Well water measurements for Well 1974 (4NW-340RC)

Well Construction							
Original Date Well Completed = 1980			ORNL Grid Coordinates				
Well Type = Rock Cover			Northing = 16695.8				
Formation Penetration = Rutledge Limestone			Easting = 27884.13				
Ground Surface Elev (ft) = 769.33			Historical Notes:				
Bottom Riser Casing Depth (ft bgs) = 480							
Bottom Riser Casing Elev (ft) = 289.33							
Total Depth (ft bgs) = 580							
Total Depth Elev (ft) = 189.33							
Tapping Details							
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments	
Riser Casing	--	--	20.9	0	0	Existing riser was vented	
Casing Annulus	--	--	--	--	--	--	
Sample Details							
	Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)			
	7/7/95	45	724	152,848			
	7/7/95	300	469	149,714			
	7/10/95	555	214	162,658			
Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/27/95	20.16	GS			749.17	
Water Level	7/7/95	20.21	GS			749.12	
Water Level	7/13/95	22.54	GS			746.79	
Water Level	9/6/95	20.83	GS			748.50	
Water Level	10/16/95	20.79	GS			748.54	
Water Level	11/13/95	20.43	GS			748.90	
Average						748.50	+ GS = Above Ground Surface
Minimum						746.79	GS = Ground Surface
Maximum						749.17	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.17 (continued). Well water sample analysis for Well 1974 (4NW-340RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	7.39	6.22	5.04
Lab pH	4.92	4.51	4.1
Temperature (C)	18.2	19.8	21.6
Specific Conductivity ($\mu\text{S} / \text{cm}$)	152000	152700	159200
Eh (mV)	-156	9.9	52.8
Alkalinity ($\text{mg CaCO}_3 / \text{L}$)	--	--	--
Total Dissolved Solids (mg / L)	152848	149714	162658
Total Suspended Solids (mg / L)	107	146	150
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	13200	13200	14900
Sodium	43000	42800	45200
Magnesium	3080	3130	3450
Potassium	102	98	99
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	92300	89800	99400
Sulfate	--	--	--
HCO_3	--	--	--
CO_3	--	--	--
Bromide	697	696	791
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	--	--	--
Sr - 90	--	--	--
H - 3	--	--	--
C - 14	--	--	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	424	27	45
Benzene	3	--	--
Naphthalene	3	--	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.17 (continued). Historical sample analysis for Well 1974 (4NW-340RC)

pH, Alkalinity, and TDS

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
pH		4.9	4.5	
Alkalinity (mg HCO ₃ /L)	16.3	--		2
Total Dissolved Solids (mg/L)	37646	169220	168886	169974

Cations, mg/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Calcium	2820	17000	15000	15000
Sodium	8890	46000	42000	43000
Magnesium	1930	3200	2900	3000
Potassium	1430		140	140
Manganese	--	19	22	22
Iron	--	69	99	77
Lithium	13.4	--	--	--
Barium	119	550	520	530
Strontium	297	1700	1600	1600
Titanium	.4	--	13	13

Anions, mg/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Chloride	23400	100000		10600
Sulfate	--	--		--
Bromide	190	770		450
Phosphate				--
Nitrate	--	54		.71
Fluoride		.44		140
Iodide		11		--

Radionuclides, pCi/L

Analyte	October 1983	May 1986	December 1986	
	filtered	unfiltered	unfiltered	filtered
Gross Alpha		1648.6		--
Gross Beta		1945.94		2567.6
Sr-90	--	118.9		19.7
Cs-137	--	18.6		--
Co-60	--	15.1		--
H-3	--			--
Tc-99	17.3			--
Th-232		--		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.
 The October 1983 and December 1986 samples were collected at a depth of 570 ft bgs,
 and the May 1986 sample at 580 ft bgs.

A.

B.

C.

D.

- ▲ Top interval
- Middle interval
- Bottom interval
- + Samples from all other rock cover wells (1995 sample event)

Fig. 2.80. Chemistry of standing water column in NHF deep monitoring Well 1974.

2.18 SUMMARY OF WELL 1976 (4S-200RC)—RANKED 4

Well History. Well 1976 (4S-200RC) is one of eight rock-cover wells constructed in 1980 surrounding the NHF. This well is located 200 ft south of the NHF injection well (ORNL Well 1968). The well is open to the Rogersville and Rutledge Formations.

The rock-cover wells were specifically constructed to monitor pressure (to track implied grout sheet movement) and periodically monitor for changes in the permeability (water acceptance tests) in units overlying the disposal zone. The permeability was determined by pressurizing each well to 75 psi and measuring the rate at which the formation would accept water. Well 1976 accepted a low volume of water during these tests. No significant increase in permeability was measured in the rock cover at this location.

Four historical samples were collected from Well 1976 (4S-200RC) (October 1983, January 1985, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was not purged before the other sample events. The well was sampled in July 1995 as part of the WAG 10 field investigation.

Construction Details. Well 1976 is drilled to a TD of 700 ft bgs. The sample team in June 1995 measured the TD to be 699 ft bgs. The well is cased to a depth of 600 ft bgs (checked by logs), and the bottom 99 ft of the well is open to the formation. The well was constructed using 30-ft casing. Figures 2.81–2.84 show the present wellhead configuration, well details, and the proposed P&A.

Field Activities. Well 1976 was tapped on June 8, 1995, and was not under pressure. The water level was 80.01 ft bgs immediately after tapping. A series of water level measurements were made through November 1995. A list of the water level data is provided in Table 2.18.

The water column in Well 1976 was sampled at three depths (105, 390, and 674 ft bgs) in June 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.18 provides the results of the sample analysis for Well 1976. All three samples are acidic (pH 5.36 to 6.16). The top sample is saline (TDS, 45,092 mg/L) and the lower two samples are high saline brine (TDS, < 200,000 mg/L). The water appears to be native brine composed predominantly of sodium with lesser amounts of calcium, and the major anion was chloride (Fig. 2.85). Nitrate was not detected in the recent round of sampling. Minor amounts of nitrate, however, were detected in the historical sampling (maximum 120 mg/L, bottom sample, October 1986). Cesium-137 was the only radionuclide reported in the 1995 sampling. The activities were less than 37.1 to 293 pCi/L in all three samples. Minor amounts of ^{90}Sr (< 175.7 pCi/L) and ^{137}Cs (< 29.7 pCi/L) were reported in the historical sampling. No organics were detected at significant levels.

The analytical results of the historical samples collected from Well 1969 are reported in Table 2.18.

Geophysical Log Interpretation. All of the logging tools “hung-up” at 600 ft bgs (some type of obstruction in casing) except for the sonic tool. Therefore, these comments are based on log data collected in the cased portion of the well. The obstruction in casing should not hamper P&A operations.

The gamma ray and neutron log responses are characteristic for the area and are useful for lithology and picking formation tops. The caliper log shows the casing to be featureless except for joints at 30-ft intervals. The temperature log indicates possible behind casing uphole flow from 335 ft to bottom of casing. Flow could be occurring in microchannels within the construction grout. There is a zone of constant temperature (off gradient) from 550 to 584 ft. Temperature increase appears normal below this depth.

The VDL indicates good casing bonding to bottom of casing at 600 ft bgs. The temperature, however, does imply behind casing flow. The VDL also indicates a fracture or cavity at 130 ft bgs. No other construction details are apparent on the VDL.

Well Ranking. Well 1976 appears to have a leak at a coupling. The well does not have EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. The well is not recommended for temporary site monitoring. If left inactive, and because of the threat of flow of brine (222,000 mg/L) uphole, this well should be P&A. Well 1976 is ranked 4 for P&A.

General P&A Plan. Figures 2.81–2.84 show the surface and wellhead configuration, interpreted well details, and proposed P&A. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs. Casing bonding, based-on log interpretation, is good. The casing condition also appears to be good.

Well 1976 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed before pressure testing casing. The casing will be pressure tested [≤ 100 psi (surface gauge pressure) for 1 h] above/near the casing shoe (at approximately 570 ft) by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Three cement stages (5 to approximately 300 ft, approximately 300 to 570 ft, and 570 to TD) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 330 and 570 ft. This plug will be squeezed using a packer and tagged. A 30-ft (approximately 300 to 330 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 300 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 270 to 330 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 270 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

ROCK COVER WELL 1976 (4S-200RC)

Fig. 2.81. Wellhead construction details.

Fig. 2.82. Well 1976 (4S-200RC) acoustic variable density log.

Fig. 2.83. Characteristic log responses, observations, and summary chemical data for Well 1976 (4S-200RC).

Fig. 2.84. Existing well construction and proposed P&A for Well 1976 (4S-200RC).

Table 2.18. Well water measurements for Well 1976 (4S-200RC)

Well Construction							
Original Date Well Completed = 1980				ORNL Grid Coordinates			
Well Type = Rock Cover				Northing = 16305.45			
Formation Penetration = Rutledge Limestone				Easting = 28204.99			
Ground Surface Elev (ft) = 800.51				Historical Notes: 			
Bottom Riser Casing Depth (ft bgs) = 600							
Bottom Riser Casing Elev (ft) = 200.51							
Total Depth (ft bgs) = 700							
Total Depth Elev (ft) = 100.51							
Tapping Details							
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments	
Riser Casing	6/8/95	0	20.6	0	0.1	--	
Casing Annulus	--	--	--	--	--	--	
Sample Details							
Date Sampled		Sample Depth (ft)		Sample Elev. (ft msl)		TDS (mg/L)	
6/22/95		105		696		45,092	
6/22/95		390		411		207,380	
6/27/95		674		127		221,949	
Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	6/8/95	80.01	GS			720.50	
Water Level	6/12/95	79.74	GS			720.77	
Water Level	6/14/95	79.79	GS			720.72	
Water Level	6/22/95	79.62	GS			720.89	
Water Level	7/13/95	82.93	GS			717.58	
Water Level	9/6/95	82.91	GS			717.60	
Water Level	10/16/95	82.59	GS			717.92	
Water Level	11/13/95	82.29	GS			718.22	
				Average	719.28	+ GS = Above Ground Surface	
				Minimum	717.58	GS = Ground Surface	
				Maximum	720.89		

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.18 (continued). Well water sample analysis for Well 1976 (4S-200RC)

General Parameters

Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	6.16	5.37	5.36
Lab pH	4.58	3.61	3.79
Temperature (C)	16.7	29.5	22.1
Specific Conductivity ($\mu\text{S} / \text{cm}$)	56100	180000	183500
Eh (mV)	-36.4	9.5	61.6
Alkalinity (mg CaCO_3 / L)	--	--	--
Total Dissolved Solids (mg / L)	45092	207380	221949
Total Suspended Solids (mg / L)	79	139	252

Cations, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	4110	23300	25200
Sodium	11100	49800	53500
Magnesium	827	4430	4710
Potassium	36	134	119
Ammonium	--	--	--
Lithium	--	--	--

Anions, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	27100	134000	138000
Sulfate	--	--	--
HCO_3	--	--	--
CO_3	--	--	--
Bromide	208	1230	1260
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	32.4	36.9	37.1
Sr - 90	--	--	--
Cs - 137	32.4	36.9	37.1
H - 3	--	--	--
C - 14	--	--	--

Detected Organics, $\mu\text{g/L}$

Analyte	Top Sample	Middle Sample	Bottom Sample
1,1,1 - Trichloroethane	--	--	131
Acetone	262	14	--
Benzene	2	--	--
Dichloromethane	6	--	--
Naphthalene	4	--	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.18 (continued). Historical sample analysis for Well 1976 (4S-200RC)

pH, Alkalinity, and TDS					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	October 1986	
pH		5.3	4.9	unfiltered 5.4	filtered .5
Alkalinity (mg HCO ₃ /L)	14.3	--	--		
Total Dissolved Solids (mg/L)	51597	31876	195000	87051	87822

Cations, mg/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	October 1986	
Calcium	4810	2370	13000	unfiltered 7500	filtered 8300
Sodium	11400	8630	27000	20000	20000
Magnesium	736	331	2200	1500	1500
Potassium	5190	50		81	81
Manganese	1.6	1.49	26	14	16
Iron	--	26.3	46	120	70
Lithium	18.7	--	--	12	12
Barium	162	58.7	410	210	240
Strontium	551	266	1300	910	900
Aluminum	6.8	--	--	--	--
Cobalt	--	--	--	.32	.31
Titanium	1.5	--	--	.68	.66

Anions, mg/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	October 1986	
Chloride	33700	20000	71000	unfiltered	filtered 55900
Sulfate	--	--	--		40
Bromide	238	220	580		480
Phosphate		--			--
Nitrate	--	--	20		120
Fluoride		.04	.39		162
Iodide		--	11		--

Radionuclides, pCi/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	October 1986	
Gross Alpha		--	--	unfiltered	filtered --
Gross Beta		--	1216.2		--
Sr-90	--	94.6	124.3		175.7
Cs-137	3.2	--	14.6		--
Co-60	--	--	--		--
H-3	--	--			--
Tc-99	--	--			--
Th-232			--		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The samples were collected at the following depths:

October 1983 -- 690 ft bgs	May 1986 -- 597 ft bgs
January 1985 -- 590 ft bgs	October 1986 -- 610 ft bgs

Fig. 2.85. Chemistry of standing water column in NHF rock cover Well 1976.

2.19 SUMMARY OF WELL 1980 (4SW-280RC)—RANKED 4

Well History. Well 1980 (4SW-280RC, constructed 1980) is one of eight rock-cover wells surrounding the NHF. The well is located 280 ft southwest of the injection well (Well 1968). The well has an open interval in the Rutledge Formation.

Rock-cover wells were constructed to monitor both pressure as an indicator of grout flow direction and the permeability of the strata overlying disposal zone. The permeability was determined by pressurizing each well to 75 psi and measuring the rate at which the formation would accept water. Results of the water acceptance test imply a reduction in effective permeability with successive injections.

Four historical samples were collected from Well 1980 (4SW-280RC) (October 1983, January 1985, May 1986, and December 1986). The well was purged five months before the May 1986 sample event. The well was not purged before the other sample events. The well was sampled, unpurged, in July 1995 as part of the WAG 10 field investigation.

Construction Details. Well 1980 was drilled to a TD of 700 ft bgs. The borehole logging team measured the TD to be 699 ft bgs, and the sample team measured the TD to be 704 ft bgs. The well is cased to a depth of 599 ft bgs, and the bottom 100 ft of the well is open to the Rutledge Limestone. Figures 2.86–2.89 show the present wellhead configuration, well details, and proposed P&A.

Field Activities. Well 1980 was vented, so it was unnecessary to tap the well. The earliest water level measurement was 16.20 ft bgs on June 12, 1995. A series of water level measurements were made through November 1995. A list of the water level data is provided in Table 2.19.

The water column in Well 1980 was sampled at three depths (41, 358, and 675 ft bgs) in June 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.19 provides the results of the sample analysis for Well 1980. The water sampled from this well is acidic (pH 4.09–6.68) and the TDS results indicate briny water ($> 159,623$ mg/L). The water appears to be native brine and is composed predominantly of sodium with lesser amounts of calcium, and the major anion was chloride (Fig. 2.90). No nitrate was detected in the recent sampling. Minor amounts of nitrate, however, were detected in the historical sampling (maximum 31 mg/L, bottom sample, 5/86). Minor amounts of ^{90}Sr (< 245.9 pCi/L) and ^{137}Cs (17.3 pCi/L), however, were detected in historical samples. No organics were detected at significant levels.

The analytical results of the historical samples collected from Well 1980 are reported in Table 2.19.

Geophysical Log Interpretation. Formation tops were picked using the neutron and gamma ray log responses, which are normal for the area. The caliper log shows the casing (30 ft) and possible separation of casing caused by uplift/subsidence (grout injection). The SPR log is shorted out and would confirm laboratory results indicative of brine composition. Apparent density shows the location of joints and couplings.

The temperature displays two distinct breaks: at 262, and from 520 to 530 ft. These deeper breaks in temperature gradient may reflect waste grout injection. Uplift and subsidence caused by emplacement of grout may have caused separation at joints.

The VDL indicates poor bonding to bottom of casing at 599 ft bgs. The sonic amplitude log confirms this interpretation.

Well Ranking. There is evidence of leakage at several couplings in Well 1980. The well appears to be in poor condition. Therefore, the well is classified as not having EMI. Historical and recent water sampling results indicate minor radionuclide contamination. The radionuclide contamination may be indicative of migration of contaminated filtrate from the grout sheets or imply cross contamination during monitoring and NHF injection operations. The well is not recommended for temporary site monitoring. If left inactive, and because of the threat of flow of brine (247,000 mg/L) uphole, this well should be P&A. Well 1980 is ranked 4 for P&A.

General P&A Plan. The surface and wellhead configuration, interpreted well details, and the proposed P&A of Well 1980 are shown in Figs. 2.86–2.89. The well details should be considered as best estimates based on historical records and evaluation and interpretation of the geophysical logs. Casing bonding, based on log interpretation, is poor. The temperature response may indicate leakage caused by separation and leakage at joints.

Well 1980 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (to approximately 570 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h above the casing shoe (at approximately 599 ft) by either shutting in the well or placing a packer. The casing in this well is not expected to maintain pressure based on the log interpretation.

If the casing does not maintain pressure, cement will be placed between approximately 290 and 570 ft (initial plug 570 to TD). This plug will be squeezed using a packer and tagged. A 30-ft (approximately 260 to 290 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 260 ft) after placement of the first-stage plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 230 to 290 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 230 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

ROCK COVER WELL 1980 (4SW-280RC)

Fig. 2.86. Wellhead construction details.

Fig. 2.87. Well 1980 (4SW-280RC) acoustic variable density log.

Fig. 2.88. Characteristic log responses, observations, and summary chemical data for Well 1980 (4SW-280RC).

Fig. 2.89. Existing well construction and proposed P&A for Well 1980 (4SW-280RC).

Table 2.19. Well water measurements for Well 1980 (4SW-280RC)

Well Construction	
Original Date Well Completed = 1980	ORNL Grid Coordinates
Well Type = Rock Cover	Northing = 16372.21
Formation Penetration = Rutledge Limestone	Easting = 27922.1
Ground Surface Elev (ft) = 785.23	
Bottom Riser Casing Depth (ft bgs) = 600	Historical Notes:
Bottom Riser Casing Elev (ft) = 185.23	
Total Depth (ft bgs) = 700	
Total Depth Elev (ft) = 85.23	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing		--	20.6	0	0	Existing riser was vented
Casing Annulus	--	--	--	--	--	--

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
6/28/95	41	744	159,623
6/28/95	358	427	237,858
6/29/95	675	110	246,504

Water Level Measurements						
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)
Water Level	6/12/95	16.20	GS			769.03
Water Level	6/14/95	16.21	GS			769.02
Water Level	6/28/95	16.13	GS			769.10
Water Level	9/6/95	18.07	GS			767.16
Water Level	10/16/95	18.25	GS			766.98
Water Level	11/13/95	17.87	GS			767.36
Average						768.11
Minimum						766.98
Maximum						769.10
						+ GS = Above Ground Surface
						GS = Ground Surface

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.19 (continued). Well water sample analysis for Well 1980 (4SW-280RC)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	6.68	5.65	4.09
Lab pH	8.18	4.83	4.18
Temperature (C)	18.6	22.2	20.6
Specific Conductivity ($\mu\text{S} / \text{cm}$)	165900	186400	192400
Eh (mV)	-199.4	25.8	91.1
Alkalinity (mg CaCO_3 / L)	144	10	--
Total Dissolved Solids (mg / L)	159623	237858	246504
Total Suspended Solids (mg / L)	810	192	135
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	19500	28500	28700
Sodium	41200	57800	56300
Magnesium	1520	5580	5840
Potassium	123	140	137
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	101000	155000	151000
Sulfate	--	--	--
HCO_3	176	12	--
CO_3	0	0	--
Bromide	901	1390	1450
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	--	--	--
Sr-90	--	--	--
H-3	211.7	535.1	153.2
C-14	--	--	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	298	11	--
Benzene	3	--	--
Dichloromethane	7	--	--
Ethylbenzene	2	--	--
Toluene	4	--	--
Xylenes (total)	12	--	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.19 (continued). Historical sample analysis for Well 1980 (4SW-280RC)

pH, Alkalinity, and TDS					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
pH		4.4	4.8	4	
Alkalinity (mg HCO ₃ /L)	20.9	1	--		--
Total Dissolved Solids (mg/L)	90798	251090	198650	221493	248032

Cations, mg/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
Calcium	6950	25200	23000	23000	31000
Sodium	18300	60500	48000	45000	61000
Magnesium	1270	5300	3600	4000	5400
Potassium	3520	180		210	210
Manganese	1.6	21.3	35	29	39
Iron	--	21.88	21	93	72
Lithium	25.7	42	--	--	--
Barium	277	770	650	680	930
Strontium	841	3020	2300	2500	3400
Chromium	--	2.74	--	--	--
Titanium	1.1	--	--	11	11

Anions, mg/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
Chloride	62700	155000	120000		144000
Sulfate	--	--	--		--
Bromide	460	1300	1100		1700
Phosphate		--			--
Nitrate	--	7	31		.9
Fluoride		.31	.41		270
Iodide		--	18		--

Radionuclides, pCi/L					
Analyte	October 1983 filtered	January 1985 filtered	May 1986 unfiltered	December 1986	
Gross Alpha		--	--		--
Gross Beta		--	--		--
Sr-90	--	245.9	51.4		--
Cs-137	--	--	17.3		--
Co-60	--	--	--		--
H-3	--	--			--
Tc-99	--	--			--
Th-232			27		

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

The October 1983 sample was collected at a depth of 690 ft bgs, and the January 1985 sample was from 590 ft bgs.

The January 1985 and May 1986 samples were collected at a depth of 600 ft bgs.

Fig. 2.90. Chemistry of standing water column in NHF deep monitoring Well 1980.

2.20 SUMMARY OF WELL 2953 (DM3-RT)—RANKED 4

Well History. Well 2953 (DM3-RT), one of seven deep-monitoring wells installed in the vicinity of the NHF, is located 1,080 ft east of the injection well (Well 1968). This well has an open interval within the Rutledge Limestone.

Well 2953 was originally drilled to a depth of 552 ft and abandoned in 1984. In late 1985, it was decided to recomple the abandoned borehole with an open interval in the Rutledge Limestone. The well was recomple in January 1986.

In February 1987 (sampled by ORNL in January 1986), a computerized pressure monitoring system was installed in Well 2953. The system consisted of a pressure transducer, transducer carrier, tension-set packer, wireline cable, and landing nipple assembly. The equipment was installed on 2 $\frac{3}{8}$ -in. EUE steel tubing. The system allowed real-time monitoring of pressure in the well. No results or reports that document pressure data collected from this well were located at ORNL.

Construction Details. A 10 $\frac{3}{4}$ -in. surface casing was installed in the top 50 ft of Well 2953 during the drilling of the borehole in 1984. The surface casing was grouted in place in a nominal 15-in. diameter borehole. A nominal 8-in. hole was drilled from 50 to 552 ft bgs. In January 1986, the abandoned borehole was recomple by grouting 4-in. ID black steel casing in place to a depth of 550 ft. An open interval (4-in. nominal diameter) was then extended from 552 to 615 ft bgs.

The borehole logging and sampling teams each measured the TD of the well to be 610 ft bgs. Figures 2.91–2.94 show the present wellhead configuration, well details, and proposed P&A.

Field Activities. Well 2953 was tapped on August 2, 1995. No pressure was encountered. The water level immediately after tapping was 39.90 ft bgs. A series of water level measurements were made through November 1995. The tapping information and water level data are provided in Table 2.20.

The transducer and packer assembly were removed to allow for sampling of water and in preparation for possible future P&A. On September 14, 1995, approximately 540 ft of steel tubing, a 4-in. diameter packer, and the transducer assembly were removed from the well. The tubing was cut up and placed in B-25 boxes for disposal.

The water column in Well 2953 was sampled at three depths (65, 328, and 580 ft bgs) in October 1995 as part of the WAG 10 field investigation.

Analytical Results. Table 2.20 provides the results of the sample analysis for Well 2953. Two of the water samples collected (middle and bottom) are acidic (pH 6.35 and 5.53, respectively). The top sample is slightly basic (pH 7.67). All of the samples are saline brine (TDS, > 145,648 mg/L). This water appears to be native brine composed predominantly of sodium chloride (Fig. 2.95). Nitrate was not detected in the recent or historic sampling. Strontium-90 (1,243.2 pCi/L) and ^{60}Co (178.4 pCi/L) were reported in the historical sampling. Minor ^{137}Cs (< 45.2 pCi/L) and ^{40}Co (111 pCi/L) were detected in the recent sampling. No organics were detected at significant levels.

The analytical results of the historical samples collected from Well 1974 are reported in Table 2.20.

Geophysical Log Interpretation. The neutron and gamma ray log responses are characteristic for the area and are useful for lithology and picking formation tops. The caliper log indicates that the well was constructed using 20 ft casing string. The casing appears to be corroded over the entire length. No fractures are noted in the openhole interval. The VDL indicates good casing bonding to bottom of casing.

Well Ranking. Well 2953 appears to be in fair condition. There is an indication that the casing is corroded and there is evidence of casing leakage. The well does not have EMI. Historical and recent water sampling results indicate minor radionuclide contamination. It may, however, imply cross contamination during past sampling. The well would not be suitable for temporary monitoring of the Rutledge Limestone. If left inactive, the well should be P&A. Well 2953 is ranked 4 for P&A.

General P&A Plan. Figures 2.91–2.94 show the surface and wellhead configuration, well details, and proposed P&A for Well 2953. The well details are from published ORNL reports and are considered accurate. Casing bonding, based on log interpretation, is good. The casing condition, however, appears to be poor.

Well 2953 will be brought to static equilibrium before P&A activities begin. All of the water purged from the well will be diverted and contained for future treatment. A bottom plug will be placed (to approximately 530 ft) before pressure testing casing to ≤ 100 psi (surface gauge pressure) for 1 h by either shutting in the well or placing a packer. The bradenhead method will be used to squeeze cement plugs if pressure is maintained during the test. Three cement plugs (5 to approximately 265 ft, approximately 265 to 530 ft, and 530 to TD) will be placed; each will be squeezed and tagged.

If the casing does not maintain pressure, cement will be placed between approximately 200 and 530 ft (initial plug 530 to TD). This plug will be squeezed using a packer and tagged. A 30-ft (approximately 170 to 200 ft) casing interval will either be perforated [2 perforations/ft (60 perforations/interval)] or milled out below the upper Maryville Limestone (shallow freshwater zone) contact (approximately 170 ft) after placement of the cement plug. Perforating or milling will reestablish contact with the formation and restore hydraulic separation between the shallow freshwater zone (upper Maryville Limestone) and underlying units. The perforated/milled window interval will be squeezed (approximately 140 to 200 ft) using matrix-penetrating cement and a packer. After curing, the plug will be tagged and a final cement stage will be placed from 5 to approximately 140 ft. The well will be closed using the established procedure for finishing from ground surface to 5 ft bgs.

C.

DEEP MONITORING WELL 2953 (DM3-RT)

Fig. 2.91. Wellhead construction details.

Fig. 2.92. Well 2953 (DM3-RT) acoustic variable density log.

Fig. 2.93. Characteristic log responses, observations, and summary chemical data for Well 2953 (DM3-RT).

Table 2.20. Well water measurements for Well 2953 (DM3-RT)

Well Construction	
Original Date Well Completed = 1985	ORNL Grid Coordinates
Well Type = Deep Monitoring	Northing = 16983.95
Formation Penetration = Rutledge Limestone	Easting = 27214.53
Ground Surface Elev (ft) = 753.51	
Bottom Riser Casing Depth (ft bgs) = 553	Historical Notes:
Bottom Riser Casing Elev (ft) = 200.51	
Total Depth (ft bgs) = 615	
Total Depth Elev (ft) = 138.51	

Tapping Details						
	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	8/2/95	0	20.2	0.7	19	Tubing tap
Casing Annulus	8/2/95	0	20.2	0.6	1	Casing/Tubing annulus tap

Sample Details			
Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
10/25/95	65	689	145,686
10/25/95	328	426	153,229
10/25/95	580	174	156,265

Water Level Measurements							
Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Water Level	9/6/95	39.90	GS			713.61	
Water Level	9/14/95	39.91	GS			713.60	Immediately before tubing removed
Water Level	9/14/95	97.38	GS			656.13	Immediately after tubing removed
Water Level	10/16/95	40.61	GS			712.90	
Water Level	10/25/95	40.35	GS			713.16	
Water Level	11/13/95	40.00	GS			713.51	Measured by logging crew
Average						703.82	+ GS = Above Ground Surface
Minimum						656.13	GS = Ground Surface
Maximum						713.61	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.20 (continued). Well water sample analysis for Well 2953 (DM3-RT)

General Parameters

Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	7.67	6.35	5.53
Lab pH	6.64	6.05	5.22
Temperature (C)	12.9	13.7	14.9
Specific Conductivity ($\mu\text{S} / \text{cm}$)	152500	160600	164400
Eh (mV)	-340	-11	22
Alkalinity ($\text{mg CaCO}_3 / \text{L}$)	31	30	16
Total Dissolved Solids (mg / L)	145686	153229	156265
Total Suspended Solids (mg / L)	138	96	426

Cations, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	14100	14900	15800
Sodium	39800	41200	42600
Magnesium	3060	3290	3820
Potassium	100	94.1	97.4
Ammonium	--	--	--
Lithium	--	--	--

Anions, mg/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	91000	94700	99600
Sulfate	--	--	--
HCO_3	38	37	20
CO_3	0	0	0
Bromide	694	738	773
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--

Radionuclides, pCi/L

Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	37.8	45.2	560
Sr - 90	--	--	--
Cs - 137	37.8	45.2	28.8
Co - 60	--	--	111
H - 3	--	--	--
C - 14	--	--	--

Detected Organics, $\mu\text{g/L}$

Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	132	6	--
Benzene	3	--	--
Chlorobenzene	3	--	--
Ethylbenzene	3	--	--
Naphthalene	3	--	--
Toluene	3	3	--
Xylenes (total)	8	7	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.20 (continued). Historical sample analysis for Well 2953 (DM3-RT)

pH, Alkalinity, and TDS

Analyte	January 1986
	unfiltered
pH	4.6
Alkalinity (mg HCO ₃ /L)	--
Total Dissolved Solids (mg/L)	143340

Cations, mg/L

Analyte	January 1986
	unfiltered
Calcium	11000
Sodium	35000
Magnesium	2900
Potassium	140
Manganese	7
Iron	100
Lithium	33
Barium	290
Strontium	1300
Phosphorus	9.5
Zinc	1

Anions, mg/L

Analyte	January 1986
	unfiltered
Chloride	93000
Sulfate	--
Bromide	950
Phosphate	20
Nitrate	--
Fluoride	.59
Iodide	12

Radionuclides, pCi/L

Analyte	January 1986
	unfiltered
Gross Beta	1081.1
Sr-90	1243.2
Cs-137	--
Co-60	178.4

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.
 The January 1986 sample was collected at a depth of 550 ft bgs.

Fig. 2.95. Chemistry of standing water column in NHF deep monitoring Well 2953.

2.21 SUMMARY OF WELL 2375 (DM3A-PV)—RANKED 4

Well History. Well 2375 (DM3A-PV) is one of seven deep-monitoring wells installed in the vicinity of the NHF. The well is located 1,250 ft northwest of the injection well (Well 1968) and is currently open in the lower Pumpkin Valley Formation.

Well 2375 was originally drilled to a depth of 1,166 ft bgs (June 1984). The well was sampled by ORNL twice (September 1984 and January 1985) before well modification. In June 1985, attempts were made to isolate specific zones in the well. These attempts failed, and it was decided to complete the well to be open only to the lower Pumpkin Valley Formation. The well modification was completed in January 1986.

In February 1987, a computerized pressure monitoring system was installed in Well 2375. The system consisted of a pressure transducer, transducer carrier, tension-set packer, wireline cable, and landing nipple assembly. The equipment was installed on 2 $\frac{3}{8}$ -in. EUE steel tubing. The system was designed to allow real-time monitoring of pressure in the well. No reports or results from pressure monitoring were located at ORNL.

Well 2375 was sampled (September 1984 and January 1985) before the January 1986 modifications. The well was sampled once again in January 1986 after modification and before the pressure monitoring system was installed. The final sampling, after pressure monitoring system removal, was conducted in 1995 by the WAG 10 sampling team.

Construction Details. Well 2375 was originally drilled to a depth of 1,166 ft bgs and cased to a depth of 550 ft with 6 $\frac{5}{8}$ -in. carbon steel.

In January 1986 a rubber plug was driven to 931 ft bgs, and 9 ft of cement grout was placed on top of the plug. There is no report that cement was placed from 931 ft to TD. A layer of bentonite and a cement plug was placed up to a depth of 910 ft. Well 2375 is open from 550 to 910 ft bgs.

The borehole logging team measured the TD of Well 2375 to be 910 ft bgs. The current configuration of the wellhead, well construction details, and the proposed P&A plan are shown in Figs. 2.96–2.99.

Field Activities. Well 2375 was tapped on August 1, 1995. The annulus between the 6-in. wellhead casing and the 2 $\frac{3}{8}$ -in. steel tubing had a pressure of 1.1 psig. The tubing interior was already vented, so it was unnecessary to tap the tubing. A series of water level measurements were made through November 1995. Results indicate that the well is artesian and at times would be flowing artesian. The well is presently shut-in. The tapping information and water level data are provided in Table 2.21.

In order to sample the standing water in Well 2375, the transducer and packer assembly had to be removed. On September 18, 1995, approximately 540 ft of steel tubing, a 4-in. diameter packer, and the transducer assembly were removed from the well. The tubing was cut up and placed in B-25 boxes for eventual disposal.

The water column in Well 2375 was sampled at three depths (52, 469, and 880 ft bgs) in October 1995 as part of the field investigation.

Analytical Results. Table 2.21 provides the results of the sample analysis for Well 2375 after well reconfiguration. The water sampled from the recompleted well contains a TDS ($> 23,014$ mg/L) of a concentration and composition that would classify it as sodium chloride saline water (Fig. 2.100). The salinity of the water in this well is lower than the six other DM wells. The pH of the lower two samples is acidic (6.86 and 6.51, respectively). The top sample is basic (pH 8.45). The pHs do not indicate reaction with the construction grout. Nitrate was not detected in either the 1985 (ORNL) or 1995 sampling (Table 2.21).

Low levels of radionuclides (maximum gross beta, 1,027 pCi/L, ^{90}Sr , 405.4 pCi/L and ^{137}Cs , 183.8 pCi/L) were detected in Well 2375 prior to well recompletion. After modification, ^{90}Sr (2,702.7 pCi/L) and minor ^{137}Cs (23.8 pCi/L) were detected in the ORNL 1986 sampling. Minor ^{137}Cs (< 45.2 pCi/L) was also detected in the 1995 sampling. No organic compounds were detected at significant levels.

Geophysical Log Interpretation. The neutron and gamma log responses were used to pick formation tops. The responses displayed by both of these logs are normal for the area. The caliper indicates that 20 ft casing strings were used to construct the well. The casing appears to be corroded at approximately 360 ft bgs. In the openhole, the caliper indicates numerous bedding plane features.

The VDL indicates a good bond from ground surface to bottom of casing. The rock signature behind casing is strong and shows good lithology. Several breaks in the temperature log within the openhole are measured: at 588, 660, and 808 ft. The temperature break at 588 ft correlates with a shift in resistivity (higher conductivity).

Well Ranking. Well 2375 appears to be in fairly good condition. The well appears to have EMI. Historical and recent water sampling results indicate no radionuclide contamination. The well would be suitable for temporary monitoring. If left inactive, however, the well should be P&A. Well 2375 is ranked low (4) for P&A.

General P&A Plan. Figures 2.96–2.99 show the surface and wellhead configuration, interpreted well detail, and a sketch of the proposed P&A well.

A plug was set in this well from 910 to 931 ft to complete the reconfiguration of the well. There is no report that the openhole interval from 931 to 1,166 ft below the plug was filled with cement. It is recommended that this plug be drilled out before initiating P&A activities for this well.

All of the purged water and circulation fluids will be diverted and contained for treatment. The P&A option is presented below.

Prior to pressure testing, the existing plug (910 to 931 ft) will be drilled out and a “new” plug will be set from 530 to 1,166 ft (drilled TD). The casing will then be pressure tested [approximately 100 psi (surface gauge pressure) for 1 h] by either shutting in the well or placing a packer. Subsequent plugs will be placed by squeezing, using the bradenhead method, and tagged if pressure is maintained in the well.

If pressure is not maintained, two 30-ft casing intervals will be perforated [2 perforations/ft (60 perforations/interval)] or milled out: one below the upper Maryville Limestone (shallow

freshwater zone, contact at 134 ft) and another near the base of the Rutledge Limestone (contact at 538 ft).

After placement of the initial cement plug (top at 530 ft), a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the Rutledge Limestone and maximize hydraulic separation. It is expected that the next cement stage will be set from approximately 164 to 470 ft. All cement stages will be placed at less than 70 percent (0.7 psi/ft) of the assumed fracture gradient (1 psi/ft). Each cement stage will be squeezed using a retrievable mechanical or inflatable packer and tagged after curing. After placement of the cement plug, a 30-ft casing interval will be perforated or a window will be milled out to establish contact with the lower Maryville Limestone (134 to 164 ft). The perforated/milled window interval will be squeezed using matrix penetrating cement. After curing, the plug will be tagged. A final cement stage will be placed from 5 to 134 ft, and the well will be finished to grade.

C.

DEEP MONITORING WELL 2375 (DM3A-PV)

Fig. 2.96. Wellhead construction details.

Fig. 2.97. Well 2375 (DM3A-PV) acoustic variable density log.

Fig. 2.98. Characteristic log responses, observations, and summary chemical data for Well 2375 (DM3A-PV).

Fig. 2.99. Existing well construction and proposed P&A for Well 2375 (DM3A-PV).

Table 2.21. Well water measurements for Well 2375 (DM3A-PV)

Well Construction

Original Date Well Completed = 1985

Well Type = Deep Monitoring

Formation Penetration = Pumpkin Valley Shale

Ground Surface Elev (ft) = 768.89

Bottom Riser Casing Depth (ft bgs) = 550

Bottom Riser Casing Elev (ft) = 218.89

Total Depth (ft bgs) = 910

Total Depth Elev (ft) = -141.11

ORNL Grid Coordinates

Northing = 17413.8

Easting = 27311.94

Historical Notes:

Originally drilled to a depth of 1166 ft and later plugged back to 910 ft with grout.

Tapping Details

	Date Tapped	Tap Pressure (psig)	Oxygen %	Organic Vapor (ppm)	LEL %	Comments
Riser Casing	8/1/95	--	20.7	2	4	Existing tubing was vented
Casing Annulus	8/1/95	1.1	20.2	0.2	3	Casing/Tubing annulus tap

Sample Details

Date Sampled	Sample Depth (ft)	Sample Elev. (ft msl)	TDS (mg/L)
10/24/95	52	717	23,014
10/24/95	469	300	24,132
10/24/95	880	-111	59,120

Water Level Measurements

Data Type	Date Measured	Depth (ft, bgs)	Depth Reference	Pressure (psig)	Pressure Head (ft)	Water Elev (ft)	Comments
Pressure	8/28/95		GS		2.24	771.13	Casing/Tubing annulus
Pressure	8/29/95		GS		2.24	771.13	Casing/Tubing annulus
Water Level	9/6/95	14.47	GS			754.42	
Water Level	9/18/95	14.52	GS			754.37	Immediately before tubing removed
Water Level	9/18/95	76.15	GS			692.74	Immediately after tubing removed
Water Level	10/16/95	29.38	GS			739.51	
Water Level	10/24/95	26.88	GS			742.01	
Water Level	11/13/95	23.44	GS			745.45	
Average						746.34	+ GS = Above Ground Surface
Minimum						692.74	GS = Ground Surface
Maximum						771.13	

Hydrograph

NOTE: Hydrograph includes only "water level" data types

Table 2.21 (continued). Well water sample analysis for Well 2375 (DM3A-PV)

General Parameters			
Analyte	Top Sample	Middle Sample	Bottom Sample
Field pH	8.45	6.86	6.51
Lab pH	6.24	5.94	5.6
Temperature (C)	15.2	16.2	16
Specific Conductivity ($\mu\text{S} / \text{cm}$)	37100	35700	84100
Eh (mV)	-87	-49	-58
Alkalinity (mg CaCO_3 / L)	14	21	21
Total Dissolved Solids (mg / L)	23014	24132	59120
Total Suspended Solids (mg / L)	35	89	203
Cations, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Calcium	896	676	3930
Sodium	7820	6220	18000
Magnesium	186	143	822
Potassium	21.8	17.7	49
Ammonium	--	--	--
Lithium	--	--	--
Anions, mg/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Chloride	13100	10100	33700
Sulfate	1070	827	602
HCO_3	17	26	26
CO_3	0	0	0
Bromide	71.7	59.8	221
Phosphate	--	--	--
Nitrate - Nitrogen	--	--	--
Fluoride	--	--	--
Radionuclides, pCi/L			
Analyte	Top Sample	Middle Sample	Bottom Sample
Gross Alpha	--	--	--
Gross Beta	--	--	--
Gamma Activity	45.2	28.8	34.6
Sr - 90	--	--	--
Cs - 137	45.2	28.8	34.6
H - 3	--	--	--
C - 14	--	--	--
Detected Organics, $\mu\text{g/L}$			
Analyte	Top Sample	Middle Sample	Bottom Sample
Acetone	23	24	23
Benzene	--	--	4
Naphthalene	3	--	--
Tetrachloroethene	--	--	5
Toluene	27	19	5
Trichloroethene	--	--	2
Xylenes (total)	7	6	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Table 2.21 (continued). Historical sample analysis for Well 2375 (DM3A-PV)

pH, Alkalinity, and TDS	September 1984				January 1985				January 1986
	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	875 ft bgs unfiltered
pH	8.9	8.1	8.3	6.8	8.7	8.5	8.3	7.8	6.9
Alkalinity (mg HCO ₃ /L)	113	123	115	90	114	135	136	128	60
Total Dissolved Solids (mg/L)	341	414	392	5919	620	804	816	29695	39347
Cations, mg/L	September 1984				January 1985				January 1986
	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	875 ft bgs unfiltered
Calcium	.85	1.09	2.2		6.3	1.9	2.5	1200	2800
Sodium	179	211	198	2100	280	350	370	9000	12000
Magnesium	.24	.24	.4	73.9	1.4	.44	.65	340	260
Potassium	1.08	1.41	1.67	27.1	1.4	1.7	2.4	77	77
Manganese					.04	.01	.01	3.9	3
Iron					--	--	--	98	23
Lithium					--	--	--	--	11
Barium				.26	.02	--	--	--	1.5
Strontium	.02	.03	.04	18.1	.44	.08	.09	78	210
Aluminum					--	--	--	--	2.4
Boron					.14	.22	.27	--	--
Chromium					--	--	--	3.8	.54
Nickel					--	--	--	14	--
Phosphorus					--	--	.32	--	--
Silicon					.78	1.5	1.6	--	5.6
Anions, mg/L	September 1984				January 1985				January 1986
	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	875 ft bgs unfiltered
Chloride	160	200	190	3700	330	450	440	19000	24000
Sulfate	34	34	43	85	40	100	153	230	522
Bromide	--	--	--	28	2	2	2	140	210
Phosphate	--	--	--	--	--	--	--	--	22
Fluoride					1.4	1.9	2	.81	.08
Radionuclides, pCi/L	September 1984				January 1985				January 1986
	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	610 ft bgs filtered	850 ft bgs filtered	940 ft bgs filtered	1100 ft bgs filtered	875 ft bgs unfiltered
Gross Alpha	--	--	--	--	--	--	945.9	--	--
Gross Beta	--	--	--	--	945.9	1027	1054.1	891.9	--
Sr-90	4.3	4.1	6.8	--	405.4	135.1	--	86.5	2702.7
Cs-137	--	--	--	--	183.8	151.4	62.2	227	23.8
Co-60	--	--	--	--	--	--	5.1	--	--
H-3	--	--	--	--	--	--	--	--	--
Tc-99	--	15.7	--	--	--	--	--	--	--
Ru-106	--	--	--	--	--	--	--	--	--

Note: "--" indicates analyte was not detected. A blank indicates no analysis was performed.

Fig. 2.100. Chemistry of standing water column in NHF deep monitoring Well 2375.

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Appendix

UNIT OF MEASUREMENT

HOW BIG IS A PICOCURIE?

This appendix will explain a unit of measurement called the curie. The curie is a standard measure for the intensity of radioactivity contained in a sample of radioactive material. It was named after French scientists Marie and Pierre Curie for their landmark research into the nature of radioactivity.

The basis for the curie is the radioactivity of 1 g of radium. Radium decays at a rate of about 2.2 trillion disintegrations (2.2×10^{12}) per minute. A picocurie is one trillionth of a curie. Thus, a picocurie represents 2.2 disintegrations per minute.

To put the relative size of 1 trillionth into perspective, consider that if the Earth were reduced to 1 trillionth of its diameter, the "pico earth" would be smaller in diameter than a speck of dust. In fact, it would be six times smaller than the thickness of a human hair.

The difference between the curie and the picocurie is so vast that other metric units are used between them. These are as follows:

Millicurie	=	1/1,000 of a curie
Microcurie	=	1/1,000,000 of a curie
Nanocurie	=	1/1,000,000,000 of a curie
Picocurie	=	1,000,000,000,000 of a curie

Table A.1 shows the relative differences between the units and gives analogies in dollars. It also gives examples of where these various amounts of radioactivity could typically be found. The number of disintegrations per minute has been rounded off for the table.

Table A.1. Relative differences between curie units

Unit of radioactivity	Symbol	Disintegrations per minute	Dollar analogy	Examples of radioactive materials
1 curie	Ci	2×10^{12} or 2 trillion	2 times the annual federal budget	Nuclear medicine generator
1 millicurie	mCi	2×10^9 or 2 billion	Cost of new interstate highway from Atlanta to San Francisco	Amount used for a brain or liver scan
1 microcurie	μ Ci	2×10^6 or 2 million	All-star baseball player's salary	Amount used in thyroid tests
1 nanocurie	nCi	2×10^3 or 2 thousand	Annual home energy costs	Consumer products
1 picocurie	pCi	2	Cost of a hamburger and drink	Background environmental levels

Figure A.1 gives a graphical representation of curie units and a comparison of the half-life for four isotopes and their decay rate in years.

Fig. A.1. Graphical representation of curie units and comparison of the half-lives of four isotopes and their decay rates in years.

Many household products contain a small amount of radioactivity. Examples include gas lantern mantles, smoke detectors, dentures, camera lenses, and antistatic brushes. The radioactivity is added to the products either specifically to make them work, or as a result of using compounds of elements like thorium and uranium in producing them. The amount of radiation the products give off is not considered significant. However, with today's sensitive equipment, it can be detected.

About 20 million gas lantern mantles are used by campers each year in the United States. Under today's standards, the amount of natural radioactivity found in a lantern mantle would require precautions in handling it at many government or industry sites. The radioactivity present would contaminate 15 lb of dirt to above allowable levels. This is because the average mantle contains 1/3 g of thorium oxide, which has a specific activity (a measure of radioactivity) of approximately 100,000 pCi per gram. The approximately 35,000 pCi of radioactivity in the mantle would, if thrown onto the ground, be considered low-level radioactive contamination.

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