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Prepared in cooperation with the U.S. Department of Energy

Completion Summary for Well NRF-16 near the Naval Reactors Facility, Idaho National Laboratory, Idaho

Scientific Investigations Report 2010–5101

U.S. Department of the Interior
U.S. Geological Survey

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By Brian V. Twining, Jason C. Fisher, and Roy C. Bartholomay

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**U.S. Department of the Interior
U.S. Geological Survey**

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors, Datums, Abbreviations and Acronyms

Conversion Factors

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
square foot (ft ²)	0.09290	square meter (m ²)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
gallon (gal)	3.785	liter (L)
cubic foot (ft ³)	28.32	cubic decimeter (dm ³)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
cubic yard (yd ³)	0.7646	cubic meter (m ³)
liter (L)	33.82	ounce, fluid (fl. oz)
Flow rate		
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per hour (ft/hr)	0.3048	meter per hour (m/hr)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
Pressure		
atmosphere, standard (atm)	101.3	kilopascal (kPa)
pound per square inch (lb/in ²)	6.895	kilopascal (kPa)
Radioactivity		
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

Conversion Factors, Datums, Abbreviations and Acronyms

Conversion Factors—Continued

Multiply	By	To obtain
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Hydraulic gradient		
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
Transmissivity*		
foot squared per day (ft ² /d)	0.09290	meter squared per day (m ² /d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft³/d)/ft²]ft. In this report, the mathematically reduced form, foot squared per day (ft²/d), is used for convenience.

Datums

Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations and Acronyms

BLS	below land surface
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFA	Central Facilities Area
SRP	Snake River Plain
INL	Idaho National Laboratory
LAS	Log ASCII Standard
LRL	laboratory reporting level
MSDS	Material Safety Data Sheet
NRF	Naval Reactors Facility
NRLFO/IBO	U.S. Department of Energy's Naval Reactors Laboratory Field Office, Idaho Branch Office
NWQL	USGS National Water Quality Laboratory
RL	reporting limits
SS	stainless steel
SSD	short-spaced density
LSD	long-spaced density
USGS	U.S. Geological Survey

Completion Summary for Well NRF-16 near the Naval Reactors Facility, Idaho National Laboratory, Idaho

By Brian V. Twining, Jason C. Fisher, and Roy C. Bartholomay

Abstract

In 2009, the U.S. Geological Survey in cooperation with the U.S. Department of Energy's Naval Reactors Laboratory Field Office, Idaho Branch Office cored and completed well NRF-16 for monitoring the eastern Snake River Plain (SRP) aquifer. The borehole was initially cored to a depth of 425 feet below land surface and water samples and geophysical data were collected and analyzed to determine if well NRF-16 would meet criteria requested by Naval Reactors Facility (NRF) for a new upgradient well. Final construction continued after initial water samples and geophysical data indicated that NRF-16 would produce chemical concentrations representative of upgradient aquifer water not influenced by NRF facility disposal, and that the well was capable of producing sustainable discharge for ongoing monitoring. The borehole was reamed and constructed as a Comprehensive Environmental Response Compensation and Liability Act monitoring well complete with screen and dedicated pump.

Geophysical and borehole video logs were collected after coring and final completion of the monitoring well. Geophysical logs were examined in conjunction with the borehole core to identify primary flow paths for groundwater, which are believed to occur in the intervals of fractured and vesicular basalt and to describe borehole lithology in detail. Geophysical data also were examined to look for evidence of perched water and the extent of the annular seal after cement grouting the casing in place. Borehole videos were collected to confirm that no perched water was present and to examine the borehole before and after setting the screen in well NRF-16.

Two consecutive single-well aquifer tests to define hydraulic characteristics for well NRF-16 were conducted in the eastern SRP aquifer. Transmissivity and hydraulic conductivity averaged from the aquifer tests were 4.8×10^3 ft²/d and 9.9 ft/d respectively. The transmissivity for well NRF-16 was within the range of values determined from past aquifer tests in other wells near NRF of 4.4×10^2 to 5.1×10^5 ft²/d.

Water samples were analyzed for metals, nutrients, total organic carbon, volatile organic compounds, semi-volatile organic compounds, herbicides, pesticides, polychlorinated biphenols, and radionuclides. All chloride, nitrate, and sulfate concentrations were less than background concentrations for the eastern SRP aquifer north of the NRF. Concentrations

in water samples for most of the organic compounds and radionuclides were less than the reporting limits and reporting levels.

Introduction

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy, has collected drill hole information at the Idaho National Laboratory (INL) since 1949 to provide baseline data concerning the migration and disposition of radioactive and chemical wastes in the eastern Snake River Plain (SRP) aquifer. The USGS is developing models for the movement of water in the eastern SRP aquifer and more geohydrologic and corehole information near the Naval Reactors Facility (NRF) is needed. Geohydrologic information is needed to help understand flow-system response to large recharge events to the north and east of the NRF in the Big Lost River and its playas and sinks ([fig. 1](#)) and corehole information will help define the basalt and sediment stratigraphy for that region of the aquifer.

In 2008, in response to a request from the U.S. Department of Energy's Naval Reactors Laboratory Field Office, Idaho Branch Office (NRLFO/IBO) to drill a replacement well for NRF-13, the USGS INL Project Office cored a borehole (NRF-15) about 0.25 mi north of well NRF-13 to a depth of about 425 ft. After coring, the water from NRF-15 was sampled to see if aquifer conditions were conducive to installing a replacement monitoring well for the NRF groundwater monitoring program ([fig. 2](#)). The NRF criteria for a new replacement monitoring well included: (1) the well is unaffected by NRF facility operations, (2) the well is capable of producing a sustained pumping rate of 15 gal/min or higher, and (3) sampled water has low turbidity levels (Kelly Willie, Bechtel/Bettis Corporation, written commun., April 6, 2009). Water samples collected from well NRF-15 on November 20, 2008, and December 10, 2008, indicated larger than background concentrations of chloride and sulfate. After reviewing the data, NRF determined that NRF-15 would not meet their needs as an upgradient monitoring well (Kelly Willie, Bechtel/Bettis Corporation, oral commun., August 27, 2009) and it was decided to drill a second monitoring well farther north, NRF-16.

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Figure 1. Location of selected facilities and monitoring well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

Figure 2. Location of monitoring wells, Naval Reactors Facility and vicinity, Idaho National Laboratory, Idaho.

During summer 2009, a new well (NRF-16) about 1 mi north of NRF-15 ([fig. 2](#)) was continuously cored and water samples collected to determine if this location would meet the needs for the NRF Program. Analysis of water samples collected August 26, 2009, indicated that well NRF-16 would meet NRF criteria for an upgradient monitoring well (Kelly Willie, Bechtel/Bettis Corporation, oral commun., August 27, 2009), and the USGS proceeded to complete the borehole as a Comprehensive Environmental Response Compensation and Liability Act monitoring well.

Purpose and Scope

The purpose of this report is to present information collected during the drilling, completion, and testing of NRF-16, a new upgradient monitoring well for the NRF groundwater monitoring program. Geophysical data collected during drilling and after final completion of the well are presented and analyzed. The production results of two consecutive hydraulic pumping tests, performed after completion of the monitoring well, are presented. Water samples were collected and analyzed for common ions, selected trace elements, and nutrients prior to well completion to obtain preliminary information on local water chemistry of the eastern SRP aquifer. Samples also were collected and analyzed for a comprehensive suite of chemical constituents selected by the NRF (Kelly Willie, Bechtel/Bettis Corporation, written communication, October 21, 2009) after completion of the well.

Geohydrologic Setting

The INL is in the west-central part of the eastern SRP ([fig. 1](#)). The eastern SRP is a northeast-trending structural basin about 200 mi long and 50–70 mi wide. The basin, bounded by faults on the northwest and by downwarping and faulting on southeast, has been filled with basaltic lava flows interbedded with terrestrial sediments. The basaltic rocks and sedimentary deposits combine to form the eastern SRP aquifer, which is the main source of groundwater for the eastern SRP.

The eastern SRP aquifer is one of the most productive aquifers in the United States (U.S. Geological Survey, 1985, p. 193). Movement of water in the aquifer generally is from northeast to southwest, and it eventually discharges to springs along the Snake River downstream from Twin Falls, Idaho—about 100 mi southwest of the INL. Water moves horizontally

through basalt interflow zones and vertically through joints and interfingering edges of interflow zones. Infiltration of surface water, heavy pumpage, geologic conditions, and seasonal fluxes of recharge and discharge locally affect the movement of groundwater (Garabedian, 1986). Recharge to the eastern SRP aquifer is primarily from infiltration of applied irrigation water, streamflow, precipitation, and groundwater inflow from adjoining mountain drainage basins (Ackerman and others, 2006).

The eastern SRP aquifer is comprised mostly of olivine tholeiite basalt flows, erupted as tube-fed, inflated pahoehoe flows that comprise more than 85 percent of the subsurface volume of the eastern SRP at the INL (Anderson and Liszewski, 1997). [Figure 3](#) illustrates a typical eastern SRP basalt flow showing vesicular zones and cooling fractures on the top and sides, with vesicle sheets, pipe vesicles, interior mega-vesicles, and a diktytaxitic to massive core. Near-vent flows are thinner than distal flows, and accumulations of thin flows have a larger volume of high conductivity zones than the same volume of thick flows; therefore, spaces occupied by vents tend to have more fractured, high-conductivity volume than spaces distal to vents (Anderson and others, 1999). The distribution of basalt flows is controlled by topography, rate of effusion, and duration of eruption.

Across the INL, the water table altitude in boreholes ranges from about 4,560 to 4,400 ft ([fig. 4](#)); near NRF the altitude of the water table is about 4,470 ft. Depth to water ranges from about 200 ft north of the INL to more than 900 ft in the southeastern area; depth to water near the NRF is about 360 ft below land surface (BLS). A significant proportion of the groundwater moves through the upper 200–800 ft of basaltic rocks (Mann, 1986, p. 21). A range of transmissivity of basalt in the upper part of the aquifer of 1.1 to 760,000 ft²/d was reported by Ackerman (1991, p. 30) and Bartholomay, Tucker, and others (1997b, table 3). The hydraulic gradient at the INL ranges from 2 to 10 ft/mi, with an average of about 4 ft/mi (Davis, 2008, fig. 11). Horizontal flow velocities of 2 to 20 ft/d have been calculated based on the movement of various chemical/radiochemical constituents in different areas of the eastern SRP aquifer at the INL (Robertson and others, 1974; Mann and Beasley, 1994; Cecil and others, 2000; Busenberg and others, 2001). These flow rates equate to a travel time of about 70–700 years for water beneath the INL to travel to springs that discharge at the terminus of the eastern SRP aquifer near Twin Falls, Idaho ([fig. 1](#)). Localized tracer tests at the INL have shown vertical and horizontal transport rates as high as 60 to 150 ft/d (Nimmo and others, 2002; Duke and others, 2007).

Figure 3. Idealized typical olivine tholeiitic pahoehoe basalt flow (modified from Self and others, 1998, fig. 3, p. 90). The basalt flow is divided into three sections on the basis of vesicle characteristics and fracture frequency. Hydraulic conductivity is highest for the Fractured Upper Crust, moderate for the Lower Crust, and lowest for the Diktytaxitic to Massive Interior. The photograph of the pahoehoe lobe surface is courtesy of Scott Hughes, Idaho State University, Pocatello, Idaho.

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Figure 4. Water-table contours, measured during March–May 2008, and monitoring wells at and near the Idaho National Laboratory, Idaho.

Drilling and Borehole Construction Methodology

The location and final design for the new monitoring well, NRF-16, was determined by NRF (Kelly Willie, Bechtel/Bettis Corp., written commun., July 15, 2008). Drilling, well construction, and hydraulic testing by the USGS INL Project Office took place August 3, 2009, through November 24, 2009. All activities were performed in accordance with the USGS INL Site Safety Plan and the NRF monitoring well specification document(s) (Kelly Willie, Bechtel/Bettis Corp., written commun(s), July 15, 2008). Additionally, the USGS performed and documented regular safety inspections and safety briefings. Material Safety Data Sheet (MSDS) files for all chemicals used during drilling are included in [appendix A](#).

Prior to drilling startup, a staging area was established for cleaning and decontamination of equipment. All drill stem, casing components, stainless pipe, screen(s), pump, and drilling equipment were cleaned using a Hotsy™ HSS-80389E diesel pressure washer. Protective tarps were placed under the drill rig and equipment was checked on a daily basis for signs of hydraulic leaks. No reportable spills or leaks occurred while drilling at this location.

NRF-16 Drilling Methods

Well NRF-16 was continuously cored using a Christensen™ CS 1500 rotary drilling rig and PQ-size coring system, where PQ refers to core rod sizing (pipe size about 4.6 in. outside diameter and drill bit size about 4.8 in.). The coring system uses Crisdrill™ diamond drill bit(s), core catchers, latch assembly, and dual retrieval systems ([fig. 5](#)). Core was retrieved in 5-ft long sections using a wireline latching mechanism (quadlatch) located at the top of the core barrel assembly. Once removed from the borehole, core was marked for vertical direction and depth in the field before boxing. Core was photographed and archived at the INL Lithologic Core Storage Library (Davis and others, 1997), operated by the USGS INL Project Office, located at Central Facilities Area (CFA).

Reaming and setting the surface casing was performed using a rotary drill rig mounted to a Peterbilt™ diesel truck. A hydraulically operated downhole hammer was used to advance the surface casing through surficial alluvium. Tricone drill bits were used to ream out sections of the borehole prior to setting the casing and screen. To straighten deviated and fractured borehole sections, a 21-ft stabilizer was run with a tri-cone reaming bit. This technique prevented ledges in fractured sections from hanging the casing during lowering.

The cementing technique requested by NRF was used to pressure a grout slurry down the inside of the 7 in. casing with return coming up the outside of the casing. Bridging problems

prevented the grout slurry from moving up the outside of the casing. After several attempts to move the casing, an alternate approach using a 1 in. tremie line to pump the grout slurry between the annular space was successful based on examination of geophysical information. Displaced cement grout inside of the 7 in. casing had to be drilled out using a rotary tri-cone bit before advancing the borehole.

Drilling fluids included water and pressurized air, which were supplied using a Sullair™ diesel air-compressor, equipped with an air filtration system. Air and water mist were continuously used during coring and reaming of NRF 16. Drill water was transported from well USGS 17 using a 3,000 gal capacity water truck. Water from well USGS 17 was used because the well is upgradient from the NRF, the water has small cation and anion concentrations (Bartholomay, Knobel, Tucker, and others 1997a), and because the water shows no constituents of concern. During drilling, the rate of water usage ranged from 2 to 4 gal/min and air pressures ranged from 105 to 350 lb/in².

NRF-16 Construction

Well NRF-16 was continuously cored to a depth of 425 ft BLS from August 10, 2009, through August 25, 2009; the local water table is near 360 ft BLS. No perched water was encountered during coring and sediment layers that were recovered were described as mostly dry.

After coring was completed, geophysical logs were collected through drill rod and water samples were collected. Core, geophysical, and water chemistry data indicated the aquifer at this location was favorable for installation of a replacement monitoring well. Core material and geophysical data were used to approximate aquifer productivity and to determine the location for setting the screen material. Water samples were collected at about 408 ft BLS on August 26, 2009. Final construction of well NRF-16 began on September 1, 2009.

Prior to reaming, a 10-in. diameter surface casing was set at about 15 ft BLS. Attempts to drill a 12-in. borehole and lower the casing failed, so a hydraulically operated casing hammer was mounted to the Peterbilt™ drill rig to drive the casing through surficial sediment. Once the casing was set, the casing hammer was removed and drilling continued.

Borehole NRF-16 was reamed using a 9.25-in. tungsten and carbide tricone bit with 4.75-in. tungsten and carbide pilot bit from about 15 to 341 ft BLS from September 2, 2009, through September 23, 2009. A second attempt to ream the borehole using a 9.25 in. tricone equipped with a 21-ft stabilizer bit took place September 28, 2009, through October 5, 2009. Additional time was spent running a large stabilizer bit because the first attempt to set 7-in. casing was problematic and the borehole had to be re-reamed due to borehole collapsing conditions.

Figure 5. PQ-size coring system, similar to one used for coring well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

A 7-in. outside diameter carbon steel casing was butt-welded and placed 341 ft BLS October 6, 2009, to October 8, 2009, then a pre-mixed grout slurry was used to seal the annular space between the 7-in. casing and 9.25-in. borehole October 13, 2009 to October 20, 2009. The grout slurry could not be continuously injected because transportation to borehole NRF-16 was limited to one load per day due to poor weather and road conditions. Initial attempts to pressure grout slurry inside of the 7-in. casing with grout return coming up the outside of the casing were limited to approximately 2 yd³ before the grout slurry began filling the inside of the 7-in. casing due to bridging between the annular space. A decision was made to halt the grouting once the grout slurry level inside of the 7-in. casing reached about 100 ft BLS. Attempts were made to unbridge the grout slurry by moving the casing; however, the casing was raised to approximately 339 ft BLS before grout slurry cured and locked the casing in place at about 339 ft BLS. A second method using a 1-in. tremie line to pump grout slurry between the annular space and seal the 7-in. casing in place was successful. Approximately 29 yd³ of grout slurry was pumped through tremie line until grout reached the top of the 7-in. casing. A total of 31 yd³ of Portland Type II grout slurry (20 parts cement 1 part bentonite) were used to seal the annular space between the casing and borehole.

Cured grout slurry inside the 7-in. casing was drilled out from 100 to 339 ft BLS using 6-in. tungsten and carbide tricone bit from October 26 to October 28, 2009. Drilling was halted near 339 ft BLS and cuttings and debris were flushed with air and water to land surface from near the bottom of the 7-in. casing for several hours before advancing. The borehole was reamed from 339 to 425 ft BLS using the same 6-in. tungsten and carbide tricone bit on October 29, 2009. A downhole video log taken of the borehole on October 30, 2009 revealed a rock bridge near 381 ft BLS and a second attempt was made to ream the borehole.

A larger, 6.25-in. tungsten and carbide tri-cone drill bit was run November 2, 2009 from 339 to 425 ft BLS. After removing the reaming bit, a downhole video log was run and revealed the borehole was in good condition and open to 422 ft BLS (appendix B, [NRF16_OpenHole.flv](#)), with sluff from 422 to 425 ft BLS. Open hole geophysical logs were run on November 4, 2009 prior to setting the final screen. Screen, casing, and components used for hydraulic pump testing were pressure washed on November 12, 2009.

A wire-wrap well screen and screen blank were placed in well NRF-16 on November 13, 2009 using the Christensen™ CS 1500 core rig ([fig. 6](#)). Drill rod was used to lower the screen assembly to the bottom of the borehole on a reverse threaded casing adapter. The casing adapter was equipped with rubber wipers to seal the screen and prevent movement. After the drill rod was removed from the well a borehole video was run to examine the screen (appendix B, [NRF16_Screen.flv](#)). The final monitoring well configuration includes: (1) 6.5-in.

figure k-packer with rubber wipers by 5-in. pipe size from 300 to 302 ft BLS, (2) 5-in. pipe size (PS) 304 stainless steel (SS) casing extending from 302 to 362 ft BLS, and (3) 5-in. PS 304 SS wire wrap well screen equipped with a bottom plug extending from 362 to 422 ft BLS ([fig. 6](#)). Sluff from 422 to 425 ft BLS, prevented setting the screen deeper than 422 ft BLS. The final monitoring well completion for NRF-16 is summarized in [table 1](#).

A temporary pump, discharge line, and water level measuring line were set in order to run hydraulic pumping tests during November 16 to 17, 2009. Once hydraulic testing was complete, the temporary pump and measurement line were removed and a final downhole video log was run to examine the condition of the well prior to setting the final pump and water level measuring line.

The final monitoring well was configured with a Grundfos™ 5-horse power submersible pump, 4-wire 7 gauge pump wire, 1.25-in. SS discharge line, and 1-in. SS water level line on November 23, 2009 ([fig. 6](#)). The pump intake was set at about 402 ft BLS and the 1-in. measuring line was capped at about 390 ft BLS. Surface completion consisted of a 4-ft concrete pad complete with a brass-survey marker, steel impingement guard posts around the well, and a locking well head. Well drilling equipment was removed on November 24, 2009.

Table 1. Location and completion information for monitoring well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

[Location of well shown in [figure 1](#); diagram of well shown in figure 6. **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifier used to access well data (<http://waterdata.usgs.gov/nwis>). **Abbreviations:** NAD 27, North American Datum of 1927; NGVD 29, National Geodetic Vertical Datum of 1929; NRF, Naval Reactors Facility]

Local name	NRF-16
Site identifier	434018112545101
Longitude	112°54'51.8" (NAD 27)
Latitude	43°40'18.5" (NAD 27)
Land surface elevation	4,833 feet (NGVD 29)
Aquifer thickness	847 feet, estimated distance between land surface and bedrock
Drilled borehole depth	425 feet below land surface
Completion depth	422 feet below land surface
Borehole diameter	6.25 inches
Casing diameter	5 inch inside diameter
Top of screen	362 feet below land surface
Bottom of screen	422 feet below land surface
Depth to water	359.96 feet below land surface, measured November 16, 2009, at 10:25 AM pre-pumping

Figure 6. Final design of monitoring well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

Geologic and Geophysical Descriptions

Analysis of core material collected during coring of NRF-16 was used to provide a general geologic description along with geophysical data that were collected after completion of coring and completion of the final borehole.

Borehole geophysics included natural gamma, neutron, gamma-gamma dual density, and caliper logs. Gyroscopic deviation surveys were run to determine direction and magnitude of borehole deviation. Borehole video surveys were run to look at the condition of the drilled borehole and final monitoring well. Geophysical data were displayed using WellCAD™ software and data were used to describe geologic and hydrologic features.

Geologic Descriptions

Sparsely vegetated eolian deposits were detected in the uppermost geologic unit in NRF-16. Surficial sediments were 9.6 ft thick and were composed of silt to fine sand loess deposits, yellowish brown in color.

Five sediment layers, excluding surficial sediment, were detected in NRF-16. Sediment layers primarily are composed of fine to coarse alluvial sand; layers range from 0.2 to 6 ft thick. Top of sediment layers occur near 15, 65, 122, 209, and 336 ft BLS. No sediment was detected within the screened interval (362–422 ft BLS).

Olivine tholeiite basalt comprised 96 percent of the unsaturated zone and 100 percent of the saturated zone in NRF-16. Approximately 22 individual basalt flows were observed at NRF-16 ranging in thickness from 2 to 65 ft, based on visual inspection of core and geophysical data. Basalt varied from highly fractured to dense, with high-to-low vesiculation and aphanitic-to-fine grained texture, and was medium to-dark gray in color.

Geophysical Logging

Wireline geophysical logs were run during several phases of the NRF-16 construction; logs were collected by the USGS after completion of coring and completion of the final borehole ([table 2](#)). Geophysical data were collected using Century™ logging equipment and data files were processed using WellCAD™ analytical software. Additionally, borehole video logs were recorded using a Laval™ R-2000 downhole video system. Digital video files are included in [appendix B](#). Raw borehole geophysical data for NRF-16 are available upon request in Log ASCII Standard (LAS) format by contacting the USGS INL Project Office.

Natural gamma, caliper, neutron, gamma-gamma dual density, temperature, specific conductivity, gyroscopic deviation, and borehole video logs were all collected during various drilling stages at NRF-16. Temperature and conductivity logs were collected but are not presented in this report because they were collected following drilling and were not representative of in situ aquifer conditions. A composite of natural gamma, caliper, neutron, and gamma-gamma dual density logs along with general lithology from land surface to total depth are included in [figure 7](#).

Table 2. Summary of geophysical and video logs collected at well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

[**Abbreviations:** NRF, Naval Reactors Facility; BLS, below land surface; PQ, core rod sizing (pipe size about 4.6 in. outside diameter and drill bit size about 4.8 in. diameter)]

U.S. Geological Survey geophysical logging files								
Log type	Logging tool identifier	Depth (feet BLS)		Date	Hole Condition	Log direction	File format	Comments
		Top	Bottom					
Natural gamma	9057A	0	424	08-27-09	PQ casing	Up	LOG	Run after coring
	9057A	0	422	11-19-09	Cased/screen	Up	LOG	Run after screen installed
Caliper	9074A	344	424	08-26-09	Open	Up	LOG	Run after coring
	9074A	9	424	11-04-09	Cased/open	Up	LOG	Run before setting 5-inch screen
Neutron	9057A	0	424	08-27-09	PQ casing	Up	LOG	Run after coring – no grout
	9057A	0	422	11-19-09	Cased/screen	Up	LOG	Run after screen installed – grout
Gamma-gamma dual density	0024A	0	424	08-27-09	PQ casing	Up	LOG	Run after coring – no grout
	0024A	0	422	11-19-09	Cased/screen	Up	LOG	Run after screen installed – grout
Temperature and specific conductance	9042A	360	420	11-04-09	Open	Down	LOG	Run before setting 5-inch screen
	9042A	360	420	11-19-09	Screen	Down	LOG	Run after pump test
Gyro deviation	9095	0	424	08-31-09	PQ casing	Down	LOG	Run after coring
	9095	0	424	08-31-09	PQ casing	Up	LOG	Run after coring
Borehole video	R-2000	0	240	9-29-09	Open hole	Up	FLV	Run after coring – bridge near 240 feet BLS
	R-2000	0	422	11-13-09	Cased/open	Down	FLV	Run before setting 5-inch screen
	R-2000	0	422	11-19-09	Cased/screen	Down	FLV	Run after setting 5-inch screen

Figure 7. Geophysical and lithologic logs run from total depth to land surface for borehole NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

Natural Gamma Logs

Natural gamma logs record gamma radiation emitted by naturally occurring radioisotopes and commonly are used at the INL to identify sedimentary layers in boreholes and distinguish between basalt flows that have differences in potassium-40. Some examples of naturally occurring radioisotopes in the eastern SRP basalts are potassium-40, bismuth-214, lead-214, actinium-228, thorium-232, and uranium-238 (Barracough and others, 1976). The gamma detector measures total gamma radiation without distinguishing between individual contributions of the various isotopes.

Natural gamma logs were collected after coring and after completion of the final monitoring well. The natural gamma log taken after completion of coring on August 27, 2009, is shown in [figure 7](#). The log depicts a 9.6 ft surficial sediment layer and confirms the tops of five sediment layers identified from the borehole core. Several zones show an increase in natural gamma radiation, which may be indicative of clay deposits within fractures. A borehole video survey taken November 13, 2009 displays this phenomenon near 395 ft BLS (appendix B, [NRF16_OpenHole.flv](#)).

Caliper Logs

The caliper tool provides a continuous log of the drill-hole diameter by using three extendable spring loaded arms, capable of detecting changes in borehole diameter of 0.15 in. or greater. Changes in borehole diameter, detected by the amount of deflection of the caliper arms, are recorded as the caliper tool is brought up from the bottom of the borehole. Caliper data was used to depict fractured and dense sections within NRF-16.

Caliper logging was done after coring and again after reaming NRF-16 in open borehole conditions from approximately 340 to 424 ft BLS. Unstable conditions prevented a continuous caliper profile for the entire borehole. [Figure 7](#) shows the caliper trace taken November 4, 2009 following reaming. The caliper log, along with visual inspection of the core, depicts fracture and vesiculated sections extending from about 362 to 366 ft BLS, 375 to 387 ft BLS, 392 to 398 ft BLS, and 403 to 406 ft BLS.

Neutron Logs

Neutron measurements are used as a general indicator of hydrogen content, and when combined with natural gamma logs for sediment location, can be used to identify perched water zones in the unsaturated zone. The neutron log records the continuous measurement of the induced radiation produced by bombarding surrounding media (casing, formation, and fluid) with fast neutrons (energies greater than 10^5 eV) from a sealed neutron source, which collide with surrounding atomic nuclei until they are captured (Keys, 1990, section 5, p. 95). The neutron tool used by the USGS INL Project Office has an americium/beryllium neutron source, and a Helium-3 detector that counts slow (thermal) neutrons (those that have energies less than 0.025 eV).

Neutron logs were run after completion of coring and after the final monitoring well screen was placed in NRF-16. A neutron trace ([fig. 7](#)) was made on August 27, 2009, immediately following the initial coring to 425 ft BLS and was examined for evidence of perched water. The neutron log shows elevated hydrogen near 55 ft BLS, just above a sediment layer about 65 ft BLS; however, borehole video logs run after removing the drill rod revealed no evidence of perched water (appendix B, [NRF16_PerchedWater.flv](#)). This zone, near 55 ft BLS, may have been influenced by drilling water or antecedent moisture conditions.

Neutron logs, examined for the section of aquifer extending from 360 to 424 ft BLS, were used to identify areas of higher and lower hydrogen content in NRF-16 ([fig. 8](#)). A horizontal gradient, ranging from red (higher hydrogen content) to white (lower hydrogen content), was applied to neutron logs in WellCAD™ and used to infer areas of fractured and dense basalt; the neutron log shows excellent correlation with the drill core lithology log ([fig. 8](#)). Areas of low hydrogen correlate with areas of dense and massive basalt and areas of higher hydrogen content correlate with areas of fractured and vesicular basalt. Based on basalt-hydrogen correlations, neutron logs show evidence for fractured and vesicular basalt, indicative of water producing zones, from 362 to 365 ft BLS, 375 to 388 ft BLS, 392 to 398 ft BLS, and 403 to 406 ft BLS in NRF-16.

Figure 8. Geophysical and lithologic logs with focus on depths 360–424 feet below land surface for NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

Gamma-Gamma Dual Density Logs

The gamma-gamma dual density log, also known as the induced gamma-density log, measures bulk density of the formation in the immediate vicinity of the borehole. Two separately-spaced detectors record induced gamma-radiation intensity from an encapsulated radioactive source after it is backscattered or absorbed in a drill hole, borehole fluid, or surrounding media (Chase and others, 1964). Very dense materials increase scatter, and cause increased absorption of gamma radiation; the increased absorption of gamma radiation results in fewer particles returning to the detector. The opposite is true for fractured and low density materials. The induced gamma signal is attenuated in direct proportion to the bulk density of a formation.

Gamma-gamma dual density logs were run after completion of coring and after completion of the final monitoring well. The gamma-gamma trace taken August 27, 2009, immediately following the initial coring to 425 ft BLS is shown in [figure 7](#). Density logs were used to reference areas of dense as opposed to fractured basalt and show excellent correlation with the lithology log ([fig. 7](#)). Density logs confirm that fractured basalt occurred between the intervals 362 to 365 ft BLS, 375 to 388 ft BLS, 392 to 398 ft BLS, and 403 to 406 ft BLS in NRF-16.

Gamma-gamma dual density logs also were used to investigate the effects of grouting. Logs taken August 27, 2009, and November 19, 2009, were examined to determine the extent of the grout seal from land surface to 339 ft BLS ([fig. 9](#)). A slight drop in density response occurs near 301 ft BLS where the top of the well screen lies inside of the 7 in. casing. Both gamma short-spaced density (SSD) and gamma long-spaced density (LSD) detectors show consistent readings which indicate the annular seal is present from land surface to 339 ft BLS ([fig. 9](#)).

Gyroscopic Deviation Survey

A borehole gyroscopic-deviation survey was run after completion of coring on August 31, 2009. The gyroscopic-deviation survey was done to determine whether well NRF-16 would meet NRF specification(s): (1) vertical projection of the borehole from land surface to bottom of the borehole does not deviate more than 20 ft in any direction, and (2) measured length of the borehole does not exceed the vertical distance between the top and bottom of the well by more than 2 percent (NRLFO/IFO, written commun., July 25, 2008). A summary of borehole deviation listings referenced to 400 ft BLS is presented in [table 3](#). Data indicate a 11.45 ft horizontal deviation from vertical with 1.6 degree deviation from vertical, which are within NRLFO/IFO monitoring well specifications.

Table 3. Gyroscopic deviation survey summary from well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

[Survey performed using 9095 Century™ logging tool. Reference sighting azimuth was set to 20 degrees, magnetic declination 13.9 degrees, and sighting and drift stations were taken from top of 4.9-inch casing. **Abbreviations:** NRF, Naval Reactors Facility; BLS, below land surface]

Borehole name	Horizontal deviation from vertical taken at 400 feet BLS (feet)	Degrees deviation from vertical taken at 400 feet BLS	True drillhole length at 400 feet BLS (feet)	Drillhole azimuth at 400 feet BLS (degrees)
NRF-16	11.45	1.6	399.82	76

Figure 9. Geophysical log traces run before and after placing cement grout in borehole NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho.

Hydrologic Description

The pre- and post-pumping test data were collected and relative trends were analyzed. Prolonged pumping tests confirmed that well NRF-16 met or exceeded sustained discharge rates of 15 gal/min. The pumping also removed any effects of drilling fluid introduced during construction of NRF-16.

Perched Water

No perched water was encountered during drilling activities and this was further confirmed through examination of geophysical and video logs. One area of elevated moisture was noted near 55 ft BLS, but the source could not be determined (drilling or antecedent moisture). Air and water circulation during drilling may have forced small amounts of water to settle out near 55 ft BLS.

Aquifer Test Procedures

During November 16-17, 2009 two single-well aquifer tests were conducted and fluid pressure head, barometric head, fluid temperature, and air temperature were measured continuously. The fluid pressure head, Ψ_w , and temperature were measured with a Solinst Levelogger™, a self contained water level and temperature datalogger suspended on a wireline below the water table (fig. 10). The barometric head, Ψ_{atm} , and temperature were measured with a Solinst Barologger™, a self contained atmospheric pressure and temperature datalogger suspended on a wireline above the water table (fig. 10). Figure 11 shows the measurements through time. The pressure head was compensated for changes in atmospheric pressure (fig. 11) and calculated using the following equation:

$$\Psi = \Psi_w - \Psi_{atm} \quad (1)$$

where

Ψ is compensated pressure head,
 Ψ_w is fluid pressure head, and
 Ψ_{atm} is barometric head.

Recovery data were collected but not analyzed.

Figure 10. Idealized placement of sensor during the aquifer tests, Naval Reactors Facility, Idaho National Laboratory, Idaho. Not to scale.

The flow rate, Q , associated with well discharge was monitored periodically using a Blue-White™ F-2000 paddlewheel flowmeter sensor (fig. 10). Measured flow rates (fig. 12) remained relatively constant throughout the tests at 30 gal/min. Estimates of the average pumping rate during the first and second aquifer tests were 29.9 and 30.0 gal/min, respectively. Discharges ranged from 29.3 to 30.5 gal/min.

NRF-16 AQUIFER TESTS

Figure 11. Changes in compensated pressure head, barometric head, fluid temperature, and air temperature through time during aquifer tests, Naval Reactors Facility, Idaho National Laboratory, Idaho, November 16–17, 2009.

Figure 12. Pumping rates during the aquifer tests, Naval Reactors Facility, Idaho National Laboratory, Idaho, November 16-17, 2009.

Analysis

The single-well aquifer tests were analyzed using the Cooper-Jacob (1946) method. The Cooper-Jacob method is a simplification of the Theis (1935) solution and assumes that the pumping well fully penetrates a confined, homogeneous, and isotropic aquifer. Conditions for the NRF-16 single-well aquifer test depart greatly from the Theis (1935) model because the well partially penetrates an unconfined heterogeneous anisotropic aquifer. The Cooper-Jacob method was used, regardless of the differences between field conditions and theory, due to its simplicity. An analysis of single-well tests by Halford and others (2006) determined that estimating hydraulic properties from a single-well pumping test using anything other than the Cooper-Jacob method is unnecessary and that transmissivity is the only hydraulic property that could be estimated uniquely.

The Cooper-Jacob method estimates transmissivity by fitting a straight line to drawdowns on an arithmetic axis compared with time on a log-arithmetic axis. Transmissivity is determined from the slope of the straight line using the equation:

$$T = \frac{2.3Q}{4\pi} \frac{1}{\Delta s}, \quad (2)$$

where

T is transmissivity,
 Q is the pumping rate,
 Δs is the drawdown across one log cycle.

The drawdown in the well, s , at any given time, t , is determined by subtracting the pressure head at t from the initial pressure head prior to pumping, Ψ_0 . Drawdown as a function of time was calculated using the equation:

$$s(t) = \Psi_0 - \psi(t). \quad (3)$$

Estimates of horizontal hydraulic conductivity were based on the aquifer thickness, b , rather than the screen length. Halford and others (2006) determined that using aquifer thickness as the divisor gave better estimates of transmissivity for unconfined aquifers with partial penetration in most cases.

The horizontal hydraulic conductivity was calculated using the following equation:

$$K = \frac{T}{b}, \quad (4)$$

where

K is the horizontal hydraulic conductivity,
 T is transmissivity,
 b is the thickness of the saturated aquifer.

in equations 5 through 8 are used to designate the first and second aquifer tests, respectively. The Cooper-Jacob transmissivity was estimated for each test by an interpretive approach; all data were not honored and only relevant data were used to fit the semilog slopes. For example, a minimum time of 10 minutes for both aquifer tests was used to avoid early-time complications. The Cooper-Jacob method applied to the first aquifer test is shown in [figure 13](#). The transmissivity and average conductivity for the first test were estimated at $4.5 \times 10^3 \text{ ft}^2/\text{d}$ and 9.2 ft/d , respectively. Calculations of these two parameters are:

$$T_1 = \frac{2.3Q_1}{4\pi} \frac{1}{\Delta s_1} = \frac{2.3 \times 4.00 \text{ ft}^3/\text{min}}{4\pi \times 0.24 \text{ ft}} = 3.1 \text{ ft}^2/\text{min} \text{ or } 4.5 \times 10^3 \text{ ft}^2/\text{d}. \quad (5)$$

Hydraulic Property Estimates

The hydraulic properties of the geohydrologic column, from the water table to the bottom of borehole NRF-16, were defined with transmissivity and horizontal hydraulic conductivity. Estimates of these hydraulic properties were made for each aquifer test. The subscripts $_1$ and $_2$

$$K_1 = \frac{T_1}{b} = \frac{3.1 \text{ ft}^2/\text{min}}{487 \text{ ft}} = 6.3 \times 10^{-3} \text{ ft/min} \text{ or } 9.2 \text{ ft/d}. \quad (6)$$

Figure 13. Analysis of drawdown time series for aquifer test 1 at well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho, November 16, 2009.

In the second aquifer test, all data after 380 minutes were excluded from the analyses due to a pseudo steady-state achieved for later drawdowns (fig. 14). The transmissivity and average conductivity for the second test were estimated at $5.1 \times 10^3 \text{ ft}^2/\text{d}$ and 10.6 ft/d , respectively. Calculations of these two parameters are:

$$T_2 = \frac{2.3Q_2}{4\pi} \frac{1}{\Delta s_2} = \frac{2.3 \times 4.01 \text{ ft}^3/\text{min}}{4\pi \times 0.21 \text{ ft}} = 3.6 \text{ ft}^2/\text{min} \text{ or } 5.1 \times 10^3 \text{ ft}^2/\text{d}. \quad (7)$$

$$K_2 = \frac{T_2}{b} = \frac{3.6 \text{ ft}^2/\text{min}}{487 \text{ ft}} = 7.4 \times 10^{-3} \text{ ft/min} \text{ or } 10.6 \text{ ft/d}. \quad (8)$$

The estimated hydraulic conductivities from the first and second tests are similar with a conductivity difference of 1.4 ft/d . This difference possibly may be attributed to

uncertainty in the Cooper-Jacob method and assumed saturated thickness and (or) a water-level at the start of the second aquifer test that was not fully recovered from the pumpage in the first test.

The average transmissivity and hydraulic conductivity for the two aquifer tests are $4.8 \times 10^3 \text{ ft}^2/\text{d}$ and 9.9 ft/d , respectively. The estimated transmissivity was within the range of transmissivity values reported for past aquifer tests conducted at wells near well NRF-16 (fig. 2, table 4); although, the closest aquifer test was conducted more than 1 mi from NRF-16. The estimated transmissivity values from these past aquifer tests (Ackerman, 1991) ranged from 4.4×10^2 to $5.1 \times 10^5 \text{ ft}^2/\text{d}$ with a 7 order of magnitude difference. The hydraulic conductivity of the eastern SRP aquifer at or near the INL ranges from about 1.0×10^{-2} to $3.2 \times 10^4 \text{ ft/d}$ (Anderson and others, 1999).

Figure 14. Analysis of drawdown time series for aquifer test 2 at well NRF-16, Naval Reactors Facility, Idaho National Laboratory, Idaho, November 16, 2009.

Table 4. Comparison of transmissivity values estimated from aquifer tests conducted at wells near well NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.

[Locations of wells shown in [figure 2](#). **Local name** is the local well identifier used in this study. **Site identifier** is the unique numerical identifier used to access well data (<http://waterdata.usgs.gov/nwis>). **Relative uncertainty** in orders of magnitude. **Distance to NRF-16** is the straight line distance within the aerial dimension to well NRF-16. **Abbreviations:** NRF, Naval Reactors Facility; USGS, U.S. Geological Survey; ft²/d, foot squared per day; mi, mile]

Local name	Site identifier	Longitude	Latitude	Transmissivity (ft ² /d)	Relative uncertainty	Distance to NRF-16 (mi)
NRF-16	434018112545101	112°54'51.8"	43°40'18.5"	4.8×10 ³	0.1	0.00
NRF-1	433859112545401	112°54'54"	43°38'59"	5.1×10 ⁵	.4	1.53
NRF-3	433858112545501	112°54'55"	43°38'58"	2.9×10 ⁴	.4	1.55
USGS 12	434126112550701	112°55'07.10"	43°41'26.19"	1.1×10 ⁴	.4	1.32
USGS 17	433937112515401	112°51'54.27"	43°39'36.42"	4.4×10 ²	.1	2.59

Water Sample Collection

Sample Collection Methods

Water sample collection by the USGS INL Project Office at the NRF generally followed guidelines established by the USGS and documented in the USGS National Field Manual (U.S. Geological Survey, variously dated) and Knobel and others (2008). The initial water samples collected prior to well completion were collected using a pre-cleaned stainless-steel thief sampling bottle that was lowered to about 408 ft BLS and filled with formation water. The stainless-steel bottle was then brought to the surface and emptied into a pre-cleaned container; the water was then processed to fill appropriate bottles for analyses. Field measurements also were taken from the pre-cleaned container. Field measurements of pH, specific conductance, water temperature, dissolved oxygen, alkalinity, and turbidity are presented in [table 5](#). Water samples were collected after completing and developing the monitoring well. The well was purged for more than 24 hours at about 30 gal/min. Samples were collected after field measurements were stable from a 0.25-in. stainless steel sample port installed off piping at the wellhead.

Field processing of samples differed depending on the constituents for which analyses were requested. The samples were analyzed by TestAmerica Laboratories and placed in containers and preserved in accordance with laboratory specifications (TestAmerica Laboratories, 2009a, tables 23-1-3). Some additional samples were collected and analyzed by the USGS National Water Quality Laboratory (NWQL) for comparison. The tritium

sample collected for NRF-16 was analyzed at the Brigham Young University Laboratory of Isotope Geochemistry. Analytical methods used by the TestAmerica Laboratories for selected organic and inorganic constituents are described in TestAmerica Laboratories (2009a). Analytical methods used for radionuclide analyses are described in TestAmerica Laboratories (2009b). Analytical methods used by the USGS NWQL for selected organic and inorganic constituents are described by Goerlitz and Brown (1972), Wershaw and others (1987), Fishman and Friedman (1989), Faires (1993), Fishman (1993), and Rose and Schroeder (1995). Samples requiring filtration consisted of filtering the water through a disposable 0.45-μm filter cartridge that had been pre-rinsed with at least 1 L of deionized water.

Guidelines for Interpretation of Analytical Results

Concentrations of radionuclides are reported with an estimated sample standard deviation, *s*, which is obtained by propagating sources of analytical uncertainty in measurements. McCurdy and others, (2008) provide details on interpreting radiological data used by the USGS. The guidelines for interpreting analytical results are based on an extension of a method proposed by Currie (1984) and are given in Davis (2008). In this report, radionuclide concentrations less than 3*s* are considered to be less than a “reporting level.” The reporting level should not be confused with the analytical method detection limit, which is based on laboratory procedures.

Concentrations of inorganic and organic constituents analyzed by TestAmerica Laboratories are reported with reference to laboratory reporting limits (RL). The reporting limit is a threshold value below which results are qualified and is normally the lowest level at which measurements become quantitatively meaningful (TestAmerica Laboratories, 2009a). Some of the analytes were positively identified and the associated numerical value is greater than the method detection level but less than the reporting limit; these values are reported as estimated concentrations. Values reported as less than reporting limits in this report are considered not detected by the laboratory (TestAmerica Laboratories, 2009a).

Concentrations of inorganic and organic constituents analyzed at the NWQL are reported with reference to laboratory reporting levels (LRLs). Details about the approach used by the USGS regarding detection levels and reporting levels are available in Childress and others (1999).

Water Chemistry Results

Water samples were collected from USGS 17, which was used for drill water, from NRF-15 after initial coring, from NRF-16 after initial coring, and again from NRF-16 after developing the monitoring well. Results of analyses are presented in [table 5](#). The initial results from a water sample collected from well NRF-15 on November 20, 2008, indicated that concentrations of chloride and sulfate were much larger than concentrations that normally would be expected of water from the eastern SRP aquifer near the NRF; therefore, additional samples were collected at two different depths on December 10, 2008. Results from that sampling also indicated larger than expected concentrations for chloride and sulfate ([table 5](#)), and a decision was made to drill a new monitoring well in a new location (Kelly Willie, Bechtel Bettis Corporation, written commun., April 6, 2009).

Inorganic Chemistry Results

Water samples were collected from well NRF-16 and analyzed for total and dissolved concentrations of calcium, potassium, magnesium, and sodium, and dissolved concentrations of bromide, chloride, fluoride, and sulfate ([table 5](#)). Total and dissolved concentrations of selected inorganic constituents including aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc also were determined. Total concentrations of nutrients including ammonia, nitrate plus nitrite, nitrite, orthophosphate, and total Kjeldahl nitrogen were also determined. A comparison of the results between the thief sample collected in

August 2009 and the pumped sample collected in November 2009 indicate good stability of the chemistry in this well. For example dissolved concentrations of calcium were 40 and 43 mg/L, respectively, magnesium, 16 and 15 mg/L, respectively, potassium, estimated at 2.5 mg/L for both samples, sodium, 7.4 and 7.2 mg/L, respectively, chloride, 14 for both samples, and sulfate, 22 and 23 mg/L, respectively ([table 5](#)). Many of the total concentrations were higher in the thief sample than in the pumped sample, which probably was due to particulate matter in the water after drilling. Dissolved concentrations analyzed by the NWQL also were comparable to the dissolved concentrations analyzed by TestAmerica Laboratories ([table 5](#)).

The NRF criteria for a new upgradient well included a well that would produce chemical concentrations that are representative of water that flows under the NRF facility, but that has not been influenced by disposal practices at the NRF. The water table contour map at the NRF indicates that flow near the NRF moves mostly from the north to the south ([fig. 4](#)), so water from the NRF-16 area should flow under the NRF. Concentrations of chloride (14 mg/L), sulfate (23 mg/L), and nitrate (0.6 mg/L) in water from well NRF-16 ([table 5](#)) are well below estimated background levels (20–40 mg/L for chloride, 30–40 mg/L for sulfate, and 0.9 mg/L for nitrate as nitrogen, [Robertson and others, 1974, figs. 24, 27, and 28]) for the eastern SRP aquifer upgradient of the NRF, which indicates that this well is not influenced by disposal practices at the NRF.

Organic Chemistry Results

Water samples from NRF-16 were collected and analyzed for total organic carbon, volatile organic compounds, semi-volatile organic compounds, herbicides, pesticides, and polychlorinated biphenols ([table 5](#)). Water sample results indicate this well had only an estimated concentration of total organic carbon of 0.3 mg/L and an estimated concentration of toluene of 0.48 µg/L. A sample analyzed by the NWQL had a comparable toluene concentration of 0.444 µg/L ([table 5](#)). No other organic compounds were detected.

Radionuclide Results

Water samples from NRF-16 were collected and analyzed for tritium at the Brigham Young University Laboratory of Isotope Geochemistry, and for Strontium-90, Nickel-63, and gross gamma at TestAmerica Laboratories. The tritium concentration was 18.3 ± 0.355 pCi/L and all the other radionuclide concentrations were below the reporting level.

24 Completion Summary for Well NRF-16 near the Naval Reactors Facility, Idaho National Laboratory, Idaho

Table 5. Concentrations of selected radiochemical and chemical constituents in water from wells USGS 17, NRF-15, and NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.

[Locations of wells shown in [figure 2](#). Analytical results in micrograms per liter unless noted otherwise. Sample from well **USGS 17** collected from pumped well. **NRF-15** (11-20-08) sample collected from a thief sample from 394 feet below land surface. **NRF-15** (12-10-08) samples collected from a thief sampler from 423 and 394 feet below land surface, respectively. **NRF-16** (08-26-09) thief sample collected at about 400 feet below land surface. **NRF-16** (11-17-09) samples were collected from a pumped well. **NRF-16** well sampled on 11-17-09; samples analyzed at the National Water Quality Laboratory (NWQL). All other samples analyzed by Test America Laboratories except for NRF-16 (11-17-09) tritium sample analyzed at Brigham Young University Laboratory of Isotope Geochemistry. Pump was set at about 400 feet below land surface. **Abbreviations:** °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; NTU, nephelometric turbidity units; CaCO₃, calcium carbonate; pCi/L, picocurie per liter; N, nitrogen; NC, not collected; NS, not sampled; NA, not analyzed; PCBs, polychlorinated biphenols; USGS, U.S. Geological Survey; NRF, Naval Reactors Facility; E, estimated; <, less than]

Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Time	1212	1416	1212	1345	1145	1025	1025
Water temperature (°C)	14	12.4	11.3	12.1	13.8	13	13
Air Temperature (°C)	10.2	12.3	1.6	2	25.5	1.6	1.6
pH (field)	7.96	7.44	7.62	7.71	7.84	7.52	7.52
pH (lab)	NA	NA	NA	NA	NA	NA	7.67
Specific conductance (µS/cm) (field)	296	570	772	759	358	369	369
Specific conductance (µS/cm) (lab)	300	570	790	770	350	120	380
Dissolved oxygen (mg/L)	9.25	7.63	10.14	9.76	8.24	8.87	8.87
Turbidity (NTU)	84.2	NC	NC	NC	NC	.62	.62
Alkalinity (mg/L as CaCO ₃), Field	132	102	111	106	136	145	145
Alkalinity (mg/L as CaCO ₃), Lab	NS	NA	NA	NA	NA	NA	154
Total dissolved solids (mg/L)	161	310	419	412	194	200	231E
Calcium, total (mg/L)	41	96	120	100	57	44	NS
Calcium, filtered (mg/L)	NS	63	84	93	40	43	46
Magnesium, total (mg/L)	11	35	41	35	24	15	NS
Magnesium, filtered (mg/L)	NS	20	29	32	16	15	16
Potassium, total (mg/L)	E2.8	4.2	7.2	6	5.7	E2.6	NS
Potassium, filtered (mg/L)	NS	E2.8	3.8	4.3	E2.5	E2.5	2.5
Sodium, total (mg/L)	7	23	23	22	8.5	7.3	NS
Sodium, filtered (mg/L)	NS	12	19	19	7.4	7.2	7.3
Bromide (mg/L)	NS	NS	NS	NS	NS	<0.2	NS
Chloride (mg/L)	6.6	64	96	96	14	14	13.7
Fluoride (mg/L)	NS	NS	NS	NS	NS	E0.2	.21
Sulfate (mg/L)	20	84	130	120	22	23	23.3
Ammonia as N (mg/L)	NS	NS	NS	NS	NS	E.054	<.02
Nitrate plus nitrite as N (mg/L)	.34	NS	.88	.89	0.43	.6	.64
Nitrite as N (mg/L)	<.50	<0.5	<.5	<.5	<0.5	<.5	<.002
Orthophosphate (mg/L)	NS	NS	NS	NS	NS	<.5	.027
Total Kjeldahl Nitrogen (mg/L)	NS	NS	NS	NS	NS	<1	NS
Aluminum, total	1,500	49,000	28,000	1,600	18,000	<100	NS
Aluminum, filtered	NS	<100	<100	<100	<100	<100	2.97E
Antimony, total	E.30	E0.37	E.56	E.69	E.56	E.27	NS
Antimony, filtered	NS	E0.29	E.21	E.20	E.28	E.27	.152
Arsenic, total	E2.5	E3.3	5.9	10	6	E1.7	NS
Arsenic, filtered	NS	E.26	E3.7	E.29	<5.0	E1.8	1.94
Barium, total	64	200	390	260	260	78	NS
Barium, filtered	NS	47	92	99	60	75	74
Beryllium, total	<5.0	E.69	E1.5	E.97	E1.2	<5.0	NS
Beryllium, filtered	NS	<5.0	<5.0	<5.0	<5.0	<5.0	<0.2
Boron, filtered	NS	NS	NS	NS	NS	NS	12.6
Cadmium, total	<5.0	<5.0	<5.0	E.57	E.6	<5.0	NS
Cadmium, filtered	NS	E.70	<5.0	<5.0	<5.0	<5.0	.018E
Chromium, total	5.9	80	34	58	34	7.9	NS
Chromium, filtered	NS	<2.0	E.61	<2.0	<2.0	7.8	7.4
Cobalt, filtered	NS	NA	NA	NA	NA	NA	.1

Table 5. Concentrations of selected radiochemical and chemical constituents in water from wells USGS 17, NRF-15, and NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.—Continued

[Locations of wells shown in [figure 2](#). Analytical results in micrograms per liter unless noted otherwise. Sample from well **USGS 17** collected from pumped well. **NRF-15** (11-20-08) sample collected from a thief sample from 394 feet below land surface. **NRF-15** (12-10-08) samples collected from a thief sampler from 423 and 394 feet below land surface, respectively. **NRF-16** (08-26-09) thief sample collected at about 400 feet below land surface. **NRF-16** (11-17-09) samples were collected from a pumped well. **NRF-16** well sampled on 11-17-09; samples analyzed at the National Water Quality Laboratory (NWQL). All other samples analyzed by Test America Laboratories except for NRF-16 (11-17-09) tritium sample analyzed at Brigham Young University Laboratory of Isotope Geochemistry. Pump was set at about 400 feet below land surface. **Abbreviations:** °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; NTU, nephelometric turbidity units; CaCO₃, calcium carbonate; pCi/L, picocurie per liter; N, nitrogen; NC, not collected; NS, not sampled; NA, not analyzed; PCBs, polychlorinated biphenols; USGS, U.S. Geological Survey; NRF, Naval Reactors Facility; E, estimated; <, less than]

Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Copper, total	E1.5	88	56	35	40	<20	NS
Copper, filtered	NS	<10	10	<10	<10	<20	<1
Iron, total	3,100	86,000	39,000	22,000	31,000	<100	NS
Iron, filtered	NS	E30	<100	<100	<100	<100	E5.6
Lead, total	E4.6	E5.3	16	E8.1	14	<9.0	NS
Lead, filtered	NS	<3.0	<3.0	<3.0	<3.0	<3.0	E.023
Lithium, filtered	NS	NS	NS	NS	NS	NS	1.99
Manganese, total	45	1,300	860	550	380	E.51	NS
Manganese, filtered	NS	410	160	150	160	E.31	E.257
Mercury, total	<.20	E.054	E.1	E.096	<.2	<.2	NS
Mercury, filtered	NS	<.20	E.077	E.079	<.2	<0.2	NS
Molybdenum, filtered	NS	NS	NS	NS	NS	NS	2.84
Nickel, total	E3.5	120	60	E38	46	<40	NS
Nickel, filtered	NS	E16	E7.3	E6.2	E7.8	<40	.591
Selenium, total	<15	E9.8	E6.5	<15	E6.2	<15	NS
Selenium, filtered	NS	<15	E8.2	E6.4	<15	<15	1.45
Silver, total	E1.0	<10	E1.2	E1.3	<10	<10	NS
Silver, filtered	NS	<10	E.98	E1.7	<10	<10	<.01
Strontium, filtered	NS	NA	NA	NA	NA	NA	233
Thallium, total	E.034	E0.031	E.22	E.34	E.27	E.02	NA
Thallium, filtered	NS	<1.0	E.041	<1.0	<1.0	E.023	<.02
Tungsten, filtered	NS	NS	NS	NS	NS	NS	.567
Uranium, filtered	NS	NS	NS	NS	NS	NS	2.12
Vanadium, filtered	NS	NS	NS	NS	NS	NS	5.34
Zinc, total	E13	240	140	260	120	<20	NS
Zinc, filtered	NS	22	30	E6.6	E7.5	<20	<2.8
Total organic carbon (mg/L)	NS	NS	NS	NS	NS	E.30	NS
Tritium (pCi/L)	27.39±1.4	NS	NS	NS	NS	18.3±0.356	NS
Strontium-90 (pCi/L)	0.22±0.195	NS	NS	NS	NS	0.15±0.17	NS
Cesium-137 (pCi/L)	-0.8±4.1	NS	NS	NS	NS	0.008±4.0	NS
Cobalt-60 (pCi/L)	0.0±1.05	NS	NS	NS	NS	0.0±7.5	NS
Nickel-63 (pCi/L)	-0.5±0.65	NS	NS	NS	NS	1.7±0.85	NS
Deuterium (per mil)	NS	NS	NS	NS	NS	NS	-136.7
Oxygen-18 (per mil)	NS	NS	NS	NS	NS	NS	-17.54
Volatile organic compounds							
Acetone	E2.6	NS	NS	NS	NS	<10	NS
Acetonitrile	<30	NS	NS	NS	NS	<30	NS
Acrolein	<20	NS	NS	NS	NS	<20	NS
Acrylonitrile	<20	NS	NS	NS	NS	<20	<2.5
Allyl chloride	<2.0	NS	NS	NS	NS	<2.0	NS
Benzene	<1.0	NS	NS	NS	NS	<1.0	<.1
Bromobenzene	NS	NS	NS	NS	NS	NS	<.2
Bromochloromethane	NS	NS	NS	NS	NS	NS	<.2
Bromodichloromethane	<1.0	NS	NS	NS	NS	<1.0	<.1
Bromoform	<1.0	NS	NS	NS	NS	<1.0	<.2

Table 5. Concentrations of selected radiochemical and chemical constituents in water from wells USGS 17, NRF-15, and NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.—Continued

[Locations of wells shown in [figure 2](#). Analytical results in micrograms per liter unless noted otherwise. Sample from well **USGS 17** collected from pumped well. **NRF-15** (11-20-08) sample collected from a thief sample from 394 feet below land surface. **NRF-15** (12-10-08) samples collected from a thief sampler from 423 and 394 feet below land surface, respectively. **NRF-16** (08-26-09) thief sample collected at about 400 feet below land surface. **NRF-16** (11-17-09) samples were collected from a pumped well. **NRF-16** well sampled on 11-17-09; samples analyzed at the National Water Quality Laboratory (NWQL). All other samples analyzed by Test America Laboratories except for NRF-16 (11-17-09) tritium sample analyzed at Brigham Young University Laboratory of Isotope Geochemistry. Pump was set at about 400 feet below land surface. **Abbreviations:** °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; NTU, nephelometric turbidity units; CaCO₃, calcium carbonate; pCi/L, picocurie per liter; N, nitrogen; NC, not collected; NS, not sampled; NA, not analyzed; PCBs, polychlorinated biphenols; USGS, U.S. Geological Survey; NRF, Naval Reactors Facility; E, estimated; <, less than]

Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Volatile organic compounds—Continued							
Bromomethane	<2.0	NS	NS	NS	NS	<2.0	<0.4
Carbon disulfide	<2.0	NS	NS	NS	NS	<2.0	NS
Carbon tetrachloride	<1.0	NS	NS	NS	NS	<1.0	<2
CFC-113	NS	NS	NS	NS	NS	NS	<1
Chlorobenzene	<1.0	NS	NS	NS	NS	<1.0	<1
Chloroethane	<2.0	NS	NS	NS	NS	<2.0	<2
Chloroform	<1.0	NS	NS	NS	NS	<1.0	<1
Chloromethane	<2.0	NS	NS	NS	NS	<2.0	<2
Chloroprene	<1.0	NS	NS	NS	NS	<1.0	NS
<i>cis</i> -1,2-dichloroethene	NS	NS	NS	NS	NS	NS	<1
<i>cis</i> -1,3-dichloropropene	<1.0	NS	NS	NS	NS	<1.0	<2
Dibromochloromethane	<1.0	NS	NS	NS	NS	<1.0	<2
Dibromomethane	<1.0	NS	NS	NS	NS	<1.0	<2
Dichloromethane	6.6	NS	NS	NS	NS	NA	<2
Dichlorodifluoromethane	<2.0	NS	NS	NS	NS	<2.0	<2
Ethyl methacrylate	<3.0	NS	NS	NS	NS	<3.0	NS
Ethylbenzene	<1.0	NS	NS	NS	NS	<1.0	<1
Iodomethane	<1.0	NS	NS	NS	NS	<1.0	NS
Isobutyl alcohol	<110	NS	NS	NS	NS	<110	NS
Isopropylbenzene	NS	NS	NS	NS	NS	NS	<2
Methacrylonitrile	<10	NS	NS	NS	NS	<10	NS
Methyl methacrylate	<4	NS	NS	NS	NS	<4	NS
Methyl tertiary butyl ether (MTBE)	NS	NS	NS	NS	NS	NS	<2
<i>n</i> -butylbenzene	NS	NS	NS	NS	NS	NS	<2
<i>n</i> -propylbenzene	NS	NS	NS	NS	NS	NS	<2
Propionitrile	<20	NS	NS	NS	NS	<20	NS
<i>sec</i> -butylbenzene	NS	NS	NS	NS	NS	NS	<2
Styrene	<1.0	NS	NS	NS	NS	<1.0	<1
<i>tert</i> -butylbenzene	NS	NS	NS	NS	NS	NS	<2
Tetrachloroethene	<1.0	NS	NS	NS	NS	<1.0	<1
Toluene	<1.0	NS	NS	NS	NS	E.48	.444
<i>trans</i> -1,2-dichloroethene	<1.0	NS	NS	NS	NS	<1.0	<1
<i>trans</i> -1,3-dichloropropene	<3.0	NS	NS	NS	NS	<3.0	<2
<i>trans</i> -1,4-dichloro-2-butene	<3.0	NS	NS	NS	NS	<3.0	NS
Trichloroethene	<1.0	NS	NS	NS	NS	<1.0	<1
Trichlorofluoromethane	<2.0	NS	NS	NS	NS	<2.0	<2
Vinyl acetate	<3.0	NS	NS	NS	NS	<3.0	NS
Vinyl chloride	<1.0	NS	NS	NS	NS	<1.0	<2
Xylene	<2.0	NS	NS	NS	NS	<2.0	<2
1,1,1,2-tetrachloroethane	<1.0	NS	NS	NS	NS	<1.0	<2
1,1,1-trichloroethane	<1.0	NS	NS	NS	NS	<1.0	<1
1,1,2,2-tetrachloroethane	<1.0	NS	NS	NS	NS	<1.0	<2
1,1,2-trichloroethane	<1.0	NS	NS	NS	NS	<1.0	<2
1,1-dichloroethane	<1.0	NS	NS	NS	NS	<1.0	<1

Table 5. Concentrations of selected radiochemical and chemical constituents in water from wells USGS 17, NRF-15, and NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.—Continued

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Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Volatile organic compounds—Continued							
1,1-dichloroethene	<1.0	NS	NS	NS	NS	<1.0	<0.1
1,1-dichloropropene	NS	NS	NS	NS	NS	NS	<.2
1,2,3-trichloropropane	<2.5	NS	NS	NS	NS	<2.5	<.2
1,2,3-trichlorobenzene	NS	NS	NS	NS	NS	NS	<.2
1,2,4-trimethylbenzene	NS	NS	NS	NS	NS	NS	<.2
1,2-Dibromo-3-chloropropane (DBCP)	<5.0	NS	NS	NS	NS	<5.0	<.5
1,2-dibromoethane	<1.0	NS	NS	NS	NS	<1.0	<.2
1,2-dichloroethane	<1.0	NS	NS	NS	NS	<1.0	<.2
1,2-dichloropropane	<1.0	NS	NS	NS	NS	<1.0	<.1
1,3-dichloropropane	NS	NS	NS	NS	NS	NS	<.2
1,3,5-trimethylbenzene	NS	NS	NS	NS	NS	NS	<.2
1,4-dichlorobenzene	NS	NS	NS	NS	NS	NS	<.1
1,4-dioxane	<200	NS	NS	NS	NS	<200	NS
2-butanone (MEK)	<6.0	NS	NS	NS	NS	<6.0	NS
2-chlorotoluene	NS	NS	NS	NS	NS	NS	<.2
2-hexanone	<5.0	NS	NS	NS	NS	<5.0	NS
2,2-dichloropropane	NS	NS	NS	NS	NS	NS	<.2
4-chlorotoluene	NS	NS	NS	NS	NS	NS	<.2
4-isopropyltoluene	NS	NS	NS	NS	NS	NS	<.2
4-methyl-2-pentanone	<5.0	NS	NS	NS	NS	<5.0	NS
Semi-volatile organic compounds							
a,a-dimethylphenethylamine	<50	NS	NS	NS	NS	<50	NS
Acenaphthene	<4.0	NS	NS	NS	NS	<4.0	NS
Acenaphthylene	<4.0	NS	NS	NS	NS	<4.0	NS
Acetophenone	<10	NS	NS	NS	NS	<10	NS
Aniline	<10	NS	NS	NS	NS	<10	NS
Anthracene	<4.0	NS	NS	NS	NS	<4.0	NS
Aramite	<40	NS	NS	NS	NS	<40	NS
Benzo-[a]-anthracene	<4.0	NS	NS	NS	NS	<4.0	NS
Benzo-[a]-pyrene	<4.0	NS	NS	NS	NS	<4.0	NS
Benzo-[b]-fluoranthene	<4.0	NS	NS	NS	NS	<4.0	NS
Benzo-[ghi]-perylene	<4.0	NS	NS	NS	NS	<4.0	NS
Benzo-[k]-fluoranthene	<4.0	NS	NS	NS	NS	<4.0	NS
Benzyl alcohol	<10	NS	NS	NS	NS	<10	NS
Bis (2-chloroethyl) ether	<10	NS	NS	NS	NS	<10	NS
Bis (2-chloroethoxy) methane	<10	NS	NS	NS	NS	<10	NS
Bis (2-chloroisopropyl) ether	<10	NS	NS	NS	NS	<10	NS
Bis (2-ethylhexyl) phthalate	E2.3	NS	NS	NS	NS	<10	NS
Benzyl <i>n</i> -butylphthalate	<4.0	NS	NS	NS	NS	<4.0	NS
Chlorobenzilate	<10	NS	NS	NS	NS	<10	NS
Chrysene	<4.0	NS	NS	NS	NS	<4.0	NS
Diallylate	<20	NS	NS	NS	NS	<20	NS

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Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Semi-volatile organic compounds—Continued							
Di-benzo-[a,h]-anthracene	<4.0	NS	NS	NS	NS	<4.0	NS
dibenzofuran	<4.0	NS	NS	NS	NS	<4.0	NS
Diethyl phthalate	<4.0	NS	NS	NS	NS	<4.0	NS
Dimethiote	NA	NS	NS	NS	NS	<20	NS
Dimethyl phthalate	<4.0	NS	NS	NS	NS	<4.0	NS
Di-n-butylphthalate	<4.0	NS	NS	NS	NS	<4.0	NS
Di-n-octylphthalate	<4.0	NS	NS	NS	NS	<4.0	NS
Diphenylamine	<10	NS	NS	NS	NS	<10	NS
Disulfoton	<50	NS	NS	NS	NS	<50	NS
Ethyl methanesulfonate	<10	NS	NS	NS	NS	<10	NS
Famphur	NA	NS	NS	NS	NS	<100	NS
Fluoranthene	<4.0	NS	NS	NS	NS	<4.0	NS
9H-fluorene	<4.0	NS	NS	NS	NS	<4.0	NS
Hexachlorobenzene	<10	NS	NS	NS	NS	<10	NS
Hexachlorobutadiene	<10	NS	NS	NS	NS	<10	<0.2
Hexachlorocyclopentadiene	<50	NS	NS	NS	NS	<50	NS
Hexachloroethane	<10	NS	NS	NS	NS	<10	NS
Hexachlorophene	NA	NS	NS	NS	NS	<1,000	NS
Hexachloropropene	<100	NS	NS	NS	NS	<100	NS
Indeno-[1,2,3-cd]-pyrene	<4.0	NS	NS	NS	NS	<4.0	NS
Isodrin	NA	NS	NS	NS	NS	<10	NS
Isophorone	<10	NS	NS	NS	NS	<10	NS
Isosafrole	<20	NS	NS	NS	NS	<20	NS
Methapyrilene	<50	NS	NS	NS	NS	<50	NS
Methyl methanesulfonate	<10	NS	NS	NS	NS	<10	NS
Methyl parathion	NA	NS	NS	NS	NS	<50	NS
Naphthalene	<4.0	NS	NS	NS	NS	<4.0	<.5
Nitrobenzene	<10	NS	NS	NS	NS	<10	NS
N-nitrosodiethylamine	<10	NS	NS	NS	NS	<10	NS
N-nitrosodimethylamine	<10	NS	NS	NS	NS	<10	NS
N-nitrosodi-n-butylamine	<10	NS	NS	NS	NS	<10	NS
N-nitrosodi-n-phenylamine	<10	NS	NS	NS	NS	NA	NS
N-nitrosodi-n-propylamine	NA	NS	NS	NS	NS	<10	NS
N-nitrosodiphenylamine	<10	NS	NS	NS	NS	<10	NS
N-nitrosomethylethylamine	<10	NS	NS	NS	NS	<10	NS
N-nitrosomorpholine	<10	NS	NS	NS	NS	<10	NS
N-nitrosopiperidine	<10	NS	NS	NS	NS	<10	NS
N-nitrosopyrrolidine	<10	NS	NS	NS	NS	<10	NS
OOO-triethyl phosphorothioate	<50	NS	NS	NS	NS	<50	NS
o-toluidine	<10	NS	NS	NS	NS	<10	NS
Parathion	NA	NS	NS	NS	NS	<50	NS
Pentachlorobenzene	<10	NS	NS	NS	NS	<10	NS
Pentachloroethane	<50	NS	NS	NS	NS	<50	NS
Pentachloronitrobenzene	<50	NS	NS	NS	NS	<50	NS

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Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Semi-volatile organic compounds—Continued							
Pentachlorophenol	<50	NS	NS	NS	NS	<50	NS
Phenacetin	<20	NS	NS	NS	NS	<20	NS
Phenanthrene	<4.0	NS	NS	NS	NS	<4.0	NS
Phenol	<10	NS	NS	NS	NS	<10	NS
Phorate	NA	NS	NS	NS	NS	<50	NS
Pronamide	NA	NS	NS	NS	NS	<20	NS
Pyrene	<10	NS	NS	NS	NS	<10	NS
Pyridine	<20	NS	NS	NS	NS	<20	NS
Safrole	<20	NS	NS	NS	NS	<20	NS
Sulfotepp	NA	NS	NS	NS	NS	<50	NS
Thionazin	NA	NS	NS	NS	NS	<50	NS
1,2,4,5-tetrachlorobenzene	<10	NS	NS	NS	NS	<10	NS
1,2,4-trichlorobenzene	<4.0	NS	NS	NS	NS	<4.0	<0.2
1,2-dichlorobenzene	<4.0	NS	NS	NS	NS	<4.0	<.1
1,3,5-trinitrobenzene	<50	NS	NS	NS	NS	<50	NS
1,3-dichlorobenzene	<4.0	NS	NS	NS	NS	<4.0	<.1
1,3-dinitrobenzene	<10	NS	NS	NS	NS	<10	NS
1,4-dichlorobenzene	<4.0	NS	NS	NS	NS	<4.0	NS
1,4-naphthoquinone	<50	NS	NS	NS	NS	<50	NS
1-naphthylamine	<10	NS	NS	NS	NS	<10	NS
2,3,4,6-tetrachlorophenol	<50	NS	NS	NS	NS	<50	NS
2,4,5-trichlorophenol	<10	NS	NS	NS	NS	<10	NS
2,4,6-trichlorophenol	<10	NS	NS	NS	NS	<10	NS
2,4-dichlorophenol	<10	NS	NS	NS	NS	<10	NS
2,4-dimethylphenol	<10	NS	NS	NS	NS	<10	NS
2,4-dinitrophenol	<30	NS	NS	NS	NS	<30	NS
2,4-dinitrotoluene	<10	NS	NS	NS	NS	<10	NS
2,6-dichlorophenol	<10	NS	NS	NS	NS	<10	NS
2,6-dinitrotoluene	<10	NS	NS	NS	NS	<10	NS
2-acetylaminofluorene	<100	NS	NS	NS	NS	<100	NS
2-chloronaphthalene	<4.0	NS	NS	NS	NS	<4.0	NS
2-chlorophenol	<10	NS	NS	NS	NS	<10	NS
2-methylnaphthalene	<4.0	NS	NS	NS	NS	<4.0	NS
2-methylphenol	<10	NS	NS	NS	NS	<10	NS
2-naphthylamine	<10	NS	NS	NS	NS	<10	NS
2-nitroaniline	<10	NS	NS	NS	NS	<10	NS
2-nitrophenol	<10	NS	NS	NS	NS	<10	NS
2-picoline	<20	NS	NS	NS	NS	<20	NS
3,3'-dichlorobenzidine	<50	NS	NS	NS	NS	<50	NS
3,3'-dimethylbenzidine	<20	NS	NS	NS	NS	<20	NS
3-methylcholanthrene	<20	NS	NS	NS	NS	<20	NS
3-methylphenol	<10	NS	NS	NS	NS	<10	NS
3-nitroaniline	<10	NS	NS	NS	NS	<10	NS
2-methyl-4,6-dinitrophenol	<50	NS	NS	NS	NS	<50	NS

Table 5. Concentrations of selected radiochemical and chemical constituents in water from wells USGS 17, NRF-15, and NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.—Continued

[Locations of wells shown in [figure 2](#). Analytical results in micrograms per liter unless noted otherwise. Sample from well **USGS 17** collected from pumped well. **NRF-15** (11-20-08) sample collected from a thief sample from 394 feet below land surface. **NRF-15** (12-10-08) samples collected from a thief sampler from 423 and 394 feet below land surface, respectively. **NRF-16** (08-26-09) thief sample collected at about 400 feet below land surface. **NRF-16** (11-17-09) samples were collected from a pumped well. **NRF-16** well sampled on 11-17-09; samples analyzed at the National Water Quality Laboratory (NWQL). All other samples analyzed by Test America Laboratories except for NRF-16 (11-17-09) tritium sample analyzed at Brigham Young University Laboratory of Isotope Geochemistry. Pump was set at about 400 feet below land surface. **Abbreviations:** °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; NTU, nephelometric turbidity units; CaCO₃, calcium carbonate; pCi/L, picocurie per liter; N, nitrogen; NC, not collected; NS, not sampled; NA, not analyzed; PCBs, polychlorinated biphenols; USGS, U.S. Geological Survey; NRF, Naval Reactors Facility; E, estimated; <, less than]

Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
Semi-volatile organic compounds—Continued							
4-aminobiphenyl	<50	NS	NS	NS	NS	<50	NS
4-bromophenyl phenyl ether	<10	NS	NS	NS	NS	<10	NS
4-chloro-3-methylphenol	<10	NS	NS	NS	NS	<10	NS
4-chloroaniline	<10	NS	NS	NS	NS	<10	NS
4-chlorophenyl phenyl ether	<10	NS	NS	NS	NS	<10	NS
4-dimethylaminoazobenzene	<20	NS	NS	NS	NS	<20	NS
4-methylphenol	<10	NS	NS	NS	NS	<10	NS
4-nitroaniline	<10	NS	NS	NS	NS	<10	NS
4-nitrophenol	<10	NS	NS	NS	NS	<10	NS
4-nitroquinoline-1-oxide	NA	NS	NS	NS	NS	<100	NS
4-phenylenediamine	NA	NS	NS	NS	NS	<100	NS
5-nitro o-toluidine	<20	NS	NS	NS	NS	<20	NS
7,12-dimethylbenzo-[a] anthracene	<20	NS	NS	NS	NS	<20	NS
Herbicides							
2,4-D	NS	NS	NS	NS	NS	<4.0	NS
Dinoseb	NS	NS	NS	NS	NS	<1.0	NS
2,4,5-TP	NS	NS	NS	NS	NS	<1.0	NS
2,4,5-T	NS	NS	NS	NS	NS	<1.0	NS
Propyzamide	<20	NS	NS	NS	NS	NA	NS
Pesticides							
Aldrin	NS	NS	NS	NS	NS	<.05	NS
alpha-BHC	NS	NS	NS	NS	NS	<.05	NS
beta-BHC	NS	NS	NS	NS	NS	<.05	NS
delta-BHC	NS	NS	NS	NS	NS	<.05	NS
gamma-BHC (Lindane)	NS	NS	NS	NS	NS	<.05	NS
Chlordane (technical)	NS	NS	NS	NS	NS	<.5	NS
Chlorobenzilate	NS	NS	NS	NS	NS	<.1	NS
4,4'-DDD	NS	NS	NS	NS	NS	<.05	NS
4,4'-DDE	NS	NS	NS	NS	NS	<.05	NS
4,4'-DDT	NS	NS	NS	NS	NS	<.05	NS
Diallate	NS	NS	NS	NS	NS	<1.0	NS
Dieldrin	NS	NS	NS	NS	NS	<.05	NS
Endosulfan I	NS	NS	NS	NS	NS	<.05	NS
Endosulfan II	NS	NS	NS	NS	NS	<.05	NS
Endosulfan sulfate	NS	NS	NS	NS	NS	<.05	NS
Endrin	NS	NS	NS	NS	NS	<.05	NS
Endrin aldehyde	NS	NS	NS	NS	NS	<.05	NS
Heptachlor	NS	NS	NS	NS	NS	<.05	NS
Heptachlor epoxide	NS	NS	NS	NS	NS	<.05	NS
Isodrin	NS	NS	NS	NS	NS	<.1	NS
Kepone	NS	NS	NS	NS	NS	<1.0	NS
Methoxychlor	NS	NS	NS	NS	NS	<.1	NS
Toxaphene	NS	NS	NS	NS	NS	<2.5	NS

Table 5. Concentrations of selected radiochemical and chemical constituents in water from wells USGS 17, NRF-15, and NRF-16, near the Naval Reactors Facility, Idaho National Laboratory, Idaho.—Continued

[Locations of wells shown in [figure 2](#). Analytical results in micrograms per liter unless noted otherwise. Sample from well **USGS 17** collected from pumped well. **NRF-15** (11-20-08) sample collected from a thief sample from 394 feet below land surface. **NRF-15** (12-10-08) samples collected from a thief sampler from 423 and 394 feet below land surface, respectively. **NRF-16** (08-26-09) thief sample collected at about 400 feet below land surface. **NRF-16** (11-17-09) samples were collected from a pumped well. **NRF-16** well sampled on 11-17-09; samples analyzed at the National Water Quality Laboratory (NWQL). All other samples analyzed by Test America Laboratories except for NRF-16 (11-17-09) tritium sample analyzed at Brigham Young University Laboratory of Isotope Geochemistry. Pump was set at about 400 feet below land surface. **Abbreviations:** °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; NTU, nephelometric turbidity units; CaCO₃, calcium carbonate; pCi/L, picocurie per liter; N, nitrogen; NC, not collected; NS, not sampled; NA, not analyzed; PCBs, polychlorinated biphenols; USGS, U.S. Geological Survey; NRF, Naval Reactors Facility; E, estimated; <, less than]

Constituent or measurement	USGS 17 (11-03-08)	NRF-15 (11-20-08)	NRF-15 (12-10-08)	NRF-15 (12-10-08)	NRF-16 (08-26-09)	NRF-16 (11-17-09)	NRF-16 (NWQL)
PCBs							
Aroclor 1016	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1221	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1232	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1242	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1248	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1254	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1260	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1262	NS	NS	NS	NS	NS	<1.0	NS
Aroclor 1268	NS	NS	NS	NS	NS	<1.0	NS

Summary

Well NRF-16 was cored and completed during August 3, 2009, through November 24, 2009, as a Comprehensive Environmental Response Compensation and Liability Act monitoring well in cooperation with the U.S. Department of Energy's Naval Reactors Laboratory Field Office, Idaho Branch Office, (NRLFO/IBO). The core from the borehole was used to interpret lithologic units, geophysical logs were collected to describe geologic and hydrologic features, two consecutive hydraulic pump tests were completed to determine hydraulic properties of the aquifer, and water samples were collected and analyzed to determine the water chemistry of the aquifer. All data collected indicate that well NRF-16 meets guidelines established for a new upgradient monitoring well for the Naval Reactors Facility (NRF) groundwater monitoring program.

Lithologic core data indicate olivine tholeiite basalt comprised 96 percent of the unsaturated zone and 100 percent of saturated zone at NRF-16. Five sediment layers, not including surficial sediment, were described as primarily fine-to-coarse alluvial sand ranging from 0.2 to 6 feet thick. Sediment layers are near 15, 65, 122, 209, and 336 ft below land surface (BLS) with no sediment intersecting the screened section of borehole between 362 to 422 ft BLS.

Geophysical and borehole video logs were collected after coring, reaming, and completing NRF-16. Geophysical logs indicate a complex fractured basalt stratigraphy with interbedded sediment layers. Neutron and borehole video logs collected during drilling show no evidence of perched water.

Neutron, caliper, and gamma-gamma dual density logs for the section of aquifer extending from 360 to 424 ft BLS show water producing zones extending from 362 to 365 ft BLS, 375 to 388 ft BLS, 392 to 398 ft BLS, and 403 to 406 ft BLS. Gamma-gamma dual density logs analyzed for pre- and post-cement grouting show consistent readings, which indicate that an annular seal is present from land surface to 339 ft BLS.

Two consecutive single-well aquifer tests were conducted in the eastern Snake River Plain (SRP) aquifer to define hydraulic characteristics for NRF-16. The top of the aquifer (depth to water) is near 360 ft BLS. This monitoring well was designed with wire wrap screen extending from 362 to 422 ft BLS. Average transmissivity and hydraulic conductivity determined from the two aquifer tests are 4.8×10^3 ft²/d and 9.9 ft/d, respectively. Aquifer tests were analyzed using the Cooper-Jacob method. Estimated NRF-16 average transmissivity and hydraulic conductivity are within the range of values determined from past aquifer and tracer tests in the NRF area.

Water samples were collected from well NRF-16 following hydraulic pump testing and laboratory results for listed constituents met NRF requirements for an upgradient monitoring well. Water samples were analyzed for metals, nutrients, total organic carbon, volatile organic compounds, semi-volatile organic compounds, herbicides, pesticides, polychlorinated biphenols, and radionuclides. Water samples were analyzed for total and dissolved concentrations of calcium, magnesium, potassium, sodium, aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel,

selenium, silver, thallium, and zinc. The dissolved constituent concentrations collected from thief samples prior to well completion were comparable with constituent concentrations collected after completion from the purged well; however, the total concentrations differed for many constituents due to particulate material in the samples collected by the thief sampler. Water samples were analyzed for total concentrations of nutrients including ammonia, nitrate plus nitrite, nitrite, orthophosphate, and total Kjeldahl nitrogen and dissolved concentrations of bromide, chloride, fluoride, and sulfate. Chloride, nitrate, and sulfate concentrations were all less than background concentrations for the eastern SRP aquifer north of the NRF. Water samples for most of the organic compounds and radionuclides had concentrations below the reporting limits and reporting levels.

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Appendixes

The appendixes can be accessed and downloaded at URL <http://pubs.usgs.gov/sir/2010/5101/>.

Appendix A. Chemical Material Safety Data Sheets
(Published on DVD – In pocket at back of printed report)

INTRO – Material Safety Data Sheets for chemicals used during coring and drilling NRF-16

Appendix B. Video Files
(Published on DVD – In pocket at back of printed report)

INTRO – Three Flash video files for well NRF-16 (see [table 2](#) for depths)

[NRF16_PerchedWater](#)

[NRF16_OpenHole](#)

[NRF16_Screen](#)

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