FINAL

IMPLICATIONS OF DOMESTIC WATER WELL DRILLING PRACTICES FOR INADVERTENT INTRUDER SCENARIOS

Prepared for

U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Decommissioning, Uranium Recovery,
and Waste Programs

Contract No. 31310018D0001
Task Order No. 31310018F0077 (Task Area 4)

Prepared by

George Adams and Gordon Wittmeyer

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

December 2020

TABLE OF CONTENTS

FIGURES

TABLES

Page

ABBREVIATIONS/ACRONYMS

10 CFR	Title 10 of the *Code of Federal Regulations*
BLS	below land surface
CNWRA®	Center for Nuclear Waste Regulatory Analyses
DOE	U.S. Department of Energy
DTH	Down-The-Hole
ESRP	Eastern Snake River Plain
FTF	F-Area Tank Farm
GMP	Groundwater Management Plan
GSA	General Separations Area
HLW	high-level radioactive waste
HTF	H-Area Tank Farm
IDWR	Idaho Department of Water Resources
IGWA	Idaho Ground Water Association
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LLW	low-level radioactive waste
NGWA	National Ground Water Association
NRC	U.S. Nuclear Regulatory Commission
PA	performance assessment
PDC	Polycrystalline Diamond Compact
PPE	personal protective equipment
SCDHEC	South Carolina Department of Health and Environmental Control
SCDNR	South Carolina Department of Natural Resources
SCGWA	South Carolina Ground Water Association
SCLLR	South Carolina Department of Labor, Licensing, and Regulation
SDF	Saltstone Disposal Facility
SRPA	Snake River Plain Aquifer
SRS	Savannah River Site
SRR	Savannah River Remediation
TAN	Technical Area North
TFF	Tank Farm Facility
USGS	U.S. Geological Survey
UTR	Upper Three Runs
WCUA	Western Capacity Use Area

ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA®) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. 31310018D0001. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of Decommissioning, Uranium Recovery, and Waste Programs. The report is an independent product of CNWRA and does not necessarily reflect the views or regulatory position of NRC.

The authors thanks James Prikryl for his technical review and David Pickett for his programmatic review. The authors also thank Arturo Ramos for providing word processing support in preparation of this document. Finally, the authors wish to thank Cynthia Barr and Hans Arlt (NRC) for many fruitful discussions on the content and organization of this report. These conversations aided development of the presentation of technical information and the conclusions presented in the report.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: No original data were developed to support this report.

ANALYSES AND CODES: No computer codes were used to perform calculations for this report.

EXECUTIVE SUMMARY

Staff at the Center for Nuclear Waste Regulatory Analyses (CNWRA®) conducted a study of domestic water well drilling practices near Idaho National Laboratory (INL) and the Savannah River Site (SRS) to support U.S. Nuclear Regulatory Commission (NRC) reviews of waste-incidental-to-reprocessing determinations by the U.S. Department of Energy (DOE). NRC reviews focus on evaluating near-surface waste disposal performance assessment (PA) models used by DOE to estimate expected radiation doses for comparison with performance objectives in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 61. A hypothetical intruder scenario is considered in PAs conducted in accordance with NRC low-level radioactive waste (LLW) performance objectives at 10 CFR 61.42 that are applicable to NRC waste-incidental-to-reprocessing reviews. NRC requested that CNWRA examine existing water well drilling technologies to determine whether any of these have the potential to penetrate the thick reinforced concrete covers and steel tank liners that function as intruder barriers for LLW and residual waste disposed at INL and SRS. NRC further directed the CNWRA to survey domestic water well drillers who operate in the vicinities of INL and SRS to determine the type of drilling methods they use, the actions they take if they drill into unexpected hard rock and metallic material, and their experience, if any, encountering metal objects, such as rebar in reinforced concrete. In addition, the CNWRA was directed to ask the drillers whether and what type of personal protective equipment (PPE) (e.g., dust masks) their drill crews wear, for acute exposures, how many total hours the drill crew operates the drill rig, and how drill cuttings are managed during and after drilling. CNWRA staff surveyed six water well drillers from the INL area and seven from the SRS area. Seven of the 13 drillers have experienced drilling into reinforced concrete and plate steel. Of these seven drillers, four continued to drill and penetrate the rebar or plate steel, while three moved their drill rigs and started new boreholes. Near INL, water wells require 60 to 70 hours to drill. Near SRS, water wells are shallower than at INL, the formations are more easily penetrated, and a typical well can be drilled in six to eight hours. None of the surveyed drillers have their crew wear breathing protection while on site. In addition to surveying drillers, this study reviewed the hydrogeology near INL and SRS and water well drilling regulations in Idaho and South Carolina. The information gathered and presented in this report can help in understanding current well drilling practices and evaluating the adequacy of DOE PAs for waste-incidental-to-reprocessing reviews.

1 OBJECTIVE

The objective of this report is to strengthen the technical bases for assumptions made regarding how a domestic water well driller would respond to encountering a subsurface radioactive waste system such as a grouted tank or saltstone disposal facility after the period of institutional control. Another important objective of this report is to review the methods used by actual domestic water well drillers to extract and dispose potentially contaminated drill cuttings. The actions of a hypothetical driller who drills into radioactive waste—known in this instance as an inadvertent intruder—will affect the potential for radiation exposure because (i) continued drilling would transport radioactive cuttings to the surface, resulting in acute exposure to the drilling crew and (ii) future use of the well for water and occupation and use of the land where contaminated drill cuttings have been spread could provide a chronic dose pathway to potential inhabitants.

2 SCOPE OF REPORT

This report includes a literature review of the low-level radioactive waste (LLW) forms, LLW containment systems, and disposal cells at the Savannah River Site (SRS) and the Idaho National Laboratory (INL). In addition, this report provides an overview of current water well drilling technology and the results of a survey of well drillers who work near SRS and INL to determine commonly used well drilling practices and the drillers' experiences contacting very resistant material or reinforced concrete and metal objects. The report also provides a comparison of INL and SRS performance assessment assumptions.

Both disposal areas are examined in this study because each has distinct climatic and hydrogeologic regimes that have affected the design of the disposal cells and local domestic water well drilling practices. SRS has a humid subtropical climate with abundant precipitation, relatively shallow depths to groundwater, and underlying aquifers primarily composed of unconsolidated to semi-consolidated sediments. INL is in a semi-arid intermontane region where the local climate depends on physiographic features. Clawson et al. (2007) identify three local-climate zones at INL: (1) the northwest section affected by down-canyon winds and rain shadow effects; (2) the southwest section [where the Tank Farm Facility (TFF) is located] affected by down-valley winds along the Big Lost River channel and strong pre-frontal and afternoon southwesterly winds; and (3) the southeastern section that is shielded from channeled winds, but affected by the higher elevations along the southern INL boundary. The depths to groundwater at INL are generally deeper than at SRS and the underlying aquifer at INL is the Eastern Snake River Plain aquifer composed of fractured and faulted basaltic and andesitic flows that are interspersed with beds of alluvium.

3 BACKGROUND INFORMATION ON WASTE CONTAINMENT SYSTEMS, HYDROGEOLOGY, DRILLING TECHNOLOGY, WELL DRILLING REGULATIONS, AND WELL DRILLING RECORDS

3.1 Waste Containment Systems

This section describes the tanks and vaults used at Idaho National Laboratory (INL) and Savannah River Site (SRS). Particular attention is paid to the mechanical properties and dimensions of the waste containment systems, especially the reinforced concrete roofs, which can be a barrier to inadvertent water well drilling. Reinforced concrete contains one or more layers of steel reinforcing bars, known as rebar, that are added to increase the strength of the composite material where tensile forces arise. For a thick reinforced concrete slab or a thick concrete roof covering a vault, most of the rebar is placed 5 to 10 cm [2 to 4 in] from the base of the concrete to protect it from moisture. The diameter and spacing of standard rebar are selected so that the stresses developed within a bar when the concrete slab is under load do not exceed about 150 MPa [22,000 psi]. Typical low carbon, high strength steel rebar used in concrete slabs range in diameter from 12.5 to 37.5 mm [0.5 to 1.5 in] set in a rectilinear grid on 20- to 45-cm [8- to 18-in] centers. Where a concrete roof is supported by a column or a load-bearing wall, rebar is also placed near the upper surface of the roof.

3.1.1 INL

As described in U.S. Department of Energy (DOE) (2003), the Idaho Nuclear Technology and Engineering Center (INTEC) Tank Farm Facility (TFF) has eleven 1.1 million-liter (L) [300,000-gallon (gal)] tanks and four 110,000-L [30,000-gal] tanks used to store liquid high-level waste (HLW). Four fuel types were reprocessed at INTEC, including Al-clad, Zr-clad, stainless steel-clad, and graphite matrix fuel using various acids. The tanks will be cleaned, filled with grout to stabilize residual waste, and operationally closed. The residual waste material is assumed to be located in the bottom 30 cm [11.8 in.] of the tanks in the PA.

The INL tanks are made of stainless steel and are below ground tanks. The 1.1 million-L [300,000-gal] tanks were constructed over a period of about 14 years starting in 1951. The two oldest tanks (WM-180 and WM-181) are made of Type 347 stainless steel, while the remaining ones are made of Type 304L stainless steel. The thickness of the steel ranges from 0.79 centimeters (cm) [0.3125 inches (in)] in the lower portion of the tanks to 0.64 cm [0.25 in] in the upper portion. These tanks are encased in unlined reinforced concrete vaults. The vault floors are approximately 13.7 meters (m) [45 feet (ft)] belowground (Appendix C of DOE, 2003). This would place the bottom of the tanks at about 13.0 m [42.7 ft] belowground [see Figure 3-7 of DOE (2003)].

There are three configurations for the vaults surrounding the 1.1 million-L [300,000-gal] tanks—monolithic (i.e., cast-in-place) octagonal, monolithic square, and pillar and panel octagonal. The two oldest tanks are surrounded by monolithic octagonal vaults having an inside wall height of 8.33 m [27.33 ft] with roof thickness of at least 38 cm [15 in]. Five of the tanks are surrounded by pillar and panel octagonal vaults having an inside wall height of 9.8 m [32 ft] and a minimum roof thickness of 15 cm [6 in]. The four remaining tanks are encased in monolithic square vaults and have an inside wall height of 9.94 m [32.6 ft] and a minimum roof thickness of 15 cm [6 in]. Table 3-1 summarizes the vault designs and Figures 3-1 through 3-3 illustrate the three vault configurations.

Table 3-1. INL vault designs

Vault Design	Tanks	Year Built	Minimum Roof Thickness cm [in]	Maximum Roof Thickness cm [in]	Vault Top to Grade* m [ft]	Inside Vault Wall Height m [ft]
Monolithic Octagonal	WM-180, 181	1951	38 [15]	175 [69]	2.06 [6.75]	8.33 [27.33]
Pillar and Panel Octagonal	WM-182, 183, 184	1955	15 [6]	107 to 112 [42 to 44]	2.6 to 2.9 [8.5 to 9.5]	9.75 [32]
	WM-185, 186	1957				
Monolithic Square	WM-187, 188	1959	15 [6]	122 to 137 [48 to 54]	2.74 [9]	9.94 [32.6]
	WM-189, 190	1964				

*Before placement of a final cover

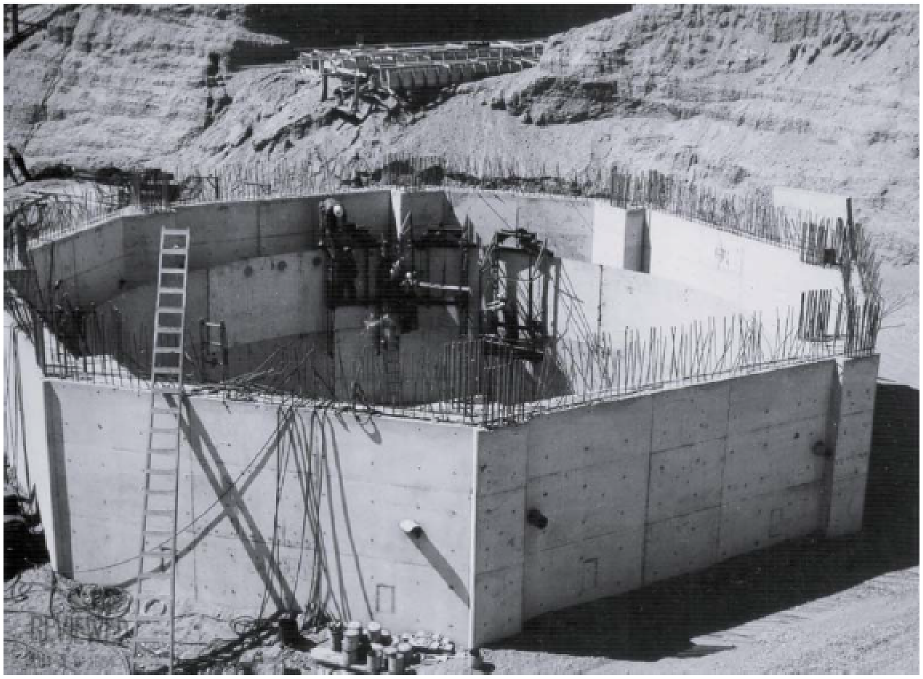


Figure 3-1. Monolithic octagonal vault for tank WM-180 (DOE, 2003)

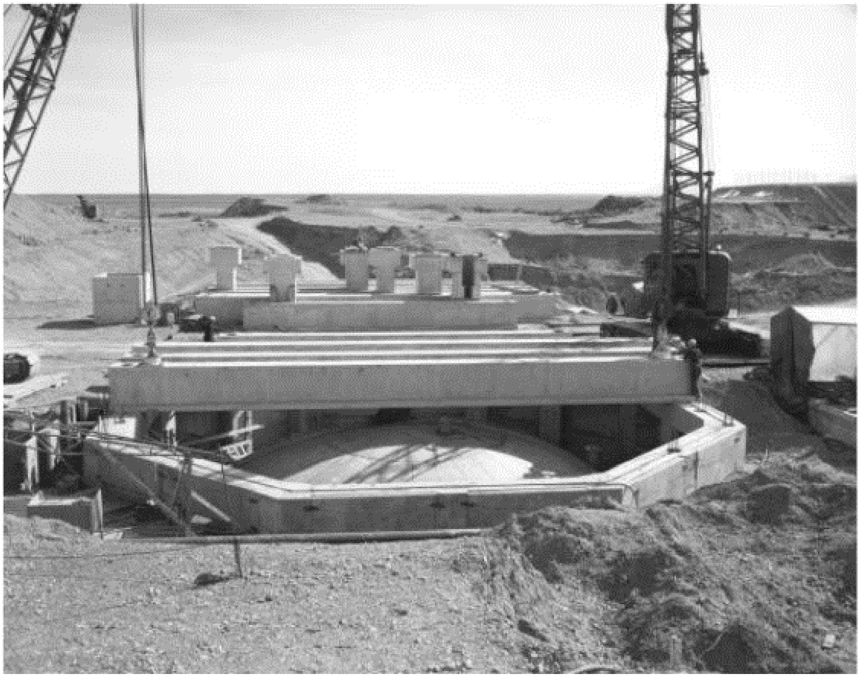


Figure 3-2. Pillar and panel octagonal vault for tank WM-185 showing concrete beams and concrete risers (DOE, 2003)

Figure 3-3. Monolithic square vault for Tank WM-190 (DOE, 2003)

3.1.2 SRS

The F-Area Tank Farm (FTF) Facility, the H-Area Tank Farm (HTF) Facility, and the Saltstone Disposal Facility (SDF) are described in this section.

3.1.2.1 F-area and H-area tank designs

The FTF is in the central region of SRS (SRR, 2010b) in the General Separations Area (GSA). It has 22 tanks that contained liquid radioactive waste generated primarily from the F-Canyon PUREX process. Tanks are cleaned, filled with grout to stabilize residual waste, and operationally closed. The residual waste material is assumed to be a discrete layer at the bottom of the tanks. The FTF has three principal tank designs designated Type I, III/IIIA, and IV. The depth to the bottom of the tanks from the closure cap in the conceptual design is approximately 18.3 to 24.4 m [60 to 80 ft] [See Figure 3.2-72 of SRR (2010b)].

The HTF is in the GSA to the east of the FTF (SRR, 2012). It has 29 tanks that contained waste generated from the H-Canyon chemical separations processes. Type II tanks are in the HTF in addition to the Type I, III/IIIA, and IV designs that are also used at the FTF. Similar to the FTF, the tanks in the HTF are cleaned, filled with grout, and operationally closed. A layer of residual waste material is assumed to remain as a discrete layer at the bottom of the tanks. The PA estimates this layer is about 2.9 cm [1.1 in] thick on average, compared with an approximately 10-m [32.8-ft] thick grout layer above it.

All the tanks are cylindrical in shape and in all cases the primary liner is made of carbon steel. Type I and II tanks have a partial secondary liner (or pan) on the bottom, whereas Type III/IIIA tanks have a full secondary liner. The secondary liners are constructed of carbon steel, and a reinforced concrete vault surrounds the secondary liners. Type IV tanks stored reprocessed liquid HLW but do not have a secondary liner. These tanks have a relatively thin "shotcrete" vault lined with carbon steel. Type IV tanks also differ from other tank types because they have a spherical reinforced concrete domed roof. Table 3-2 summarizes the key features of the various tanks and Figures 3-4 through 3-8 show the different tank designs.

Table 3-2. Key features of F-area and H-area tank designs

Type	Backfill Cover m [ft]	Reinforced Concrete Vault		Tank			
		Roof cm [in]	Walls cm [in]	Primary Liner cm [in]	Diameter m [ft]	Height m [ft]	Capacity ML [Mgal]*
I	2.7 [9]	56 [22]	56 [22]	1.3 [0.5]	22.9 [75]	7.5 [24.5]	2.84 [0.75]
II	0	114 [45]	83.8 [33]	1.6 [0.625]	25.9 [85]	8.2 [27]	3.9 [1.03]
III/IIIA	0	122 [48]	76 [30]	1.3 [0.5]	25.9 [85]	10 [33]	4.9 [1.3]
IV	1.12 [3.67]	17.8 [7] to 25.4 [10]	17.8 [7] at the top, 27.9 [11] at the bottom	0.96 [0.375]	25.9 [85]	10.4 [34] (at the side wall)	4.9 [1.3]

*ML is million-liters and Mgal is million-gallons.

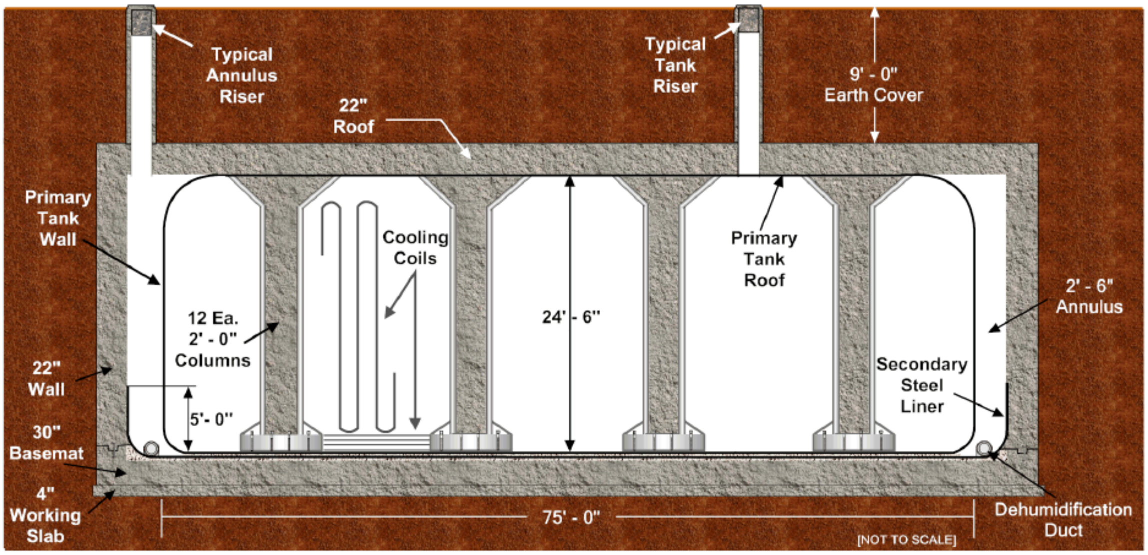


Figure 3-4. Type I tank cross-sectional view (SRR, 2010b)

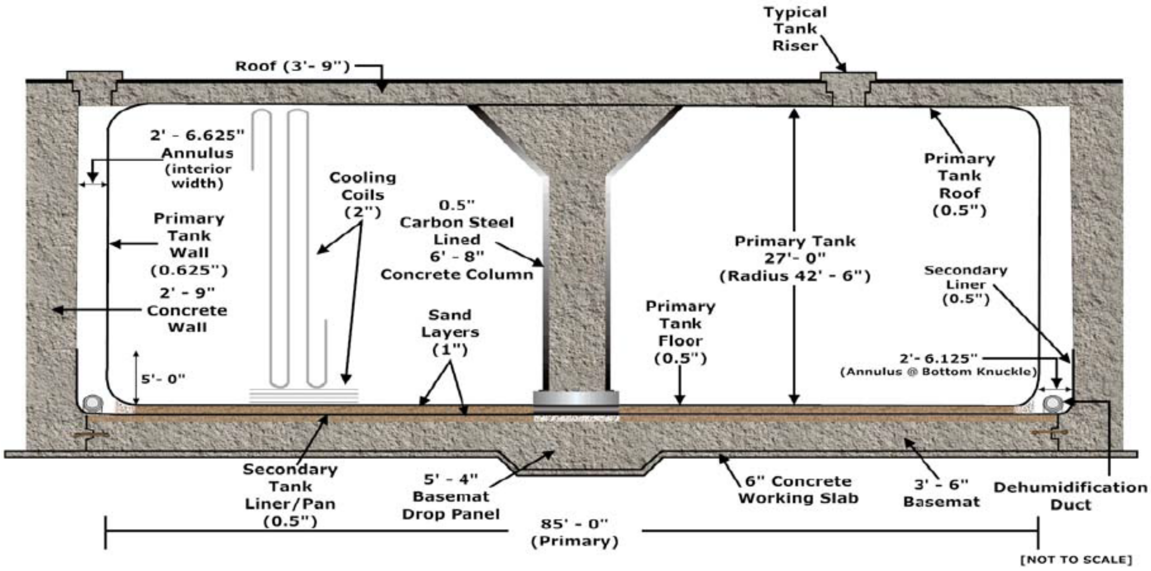


Figure 3-5. Type II tank cross-sectional view (SRR, 2012)

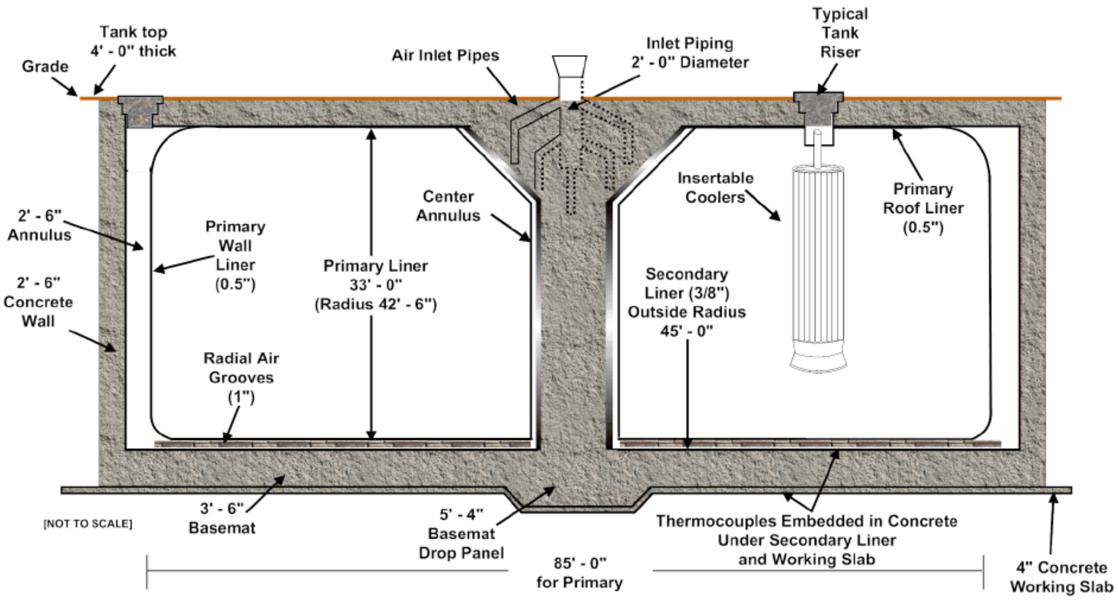


Figure 3-6. Type III tank cross-sectional view (SRR, 2010b)

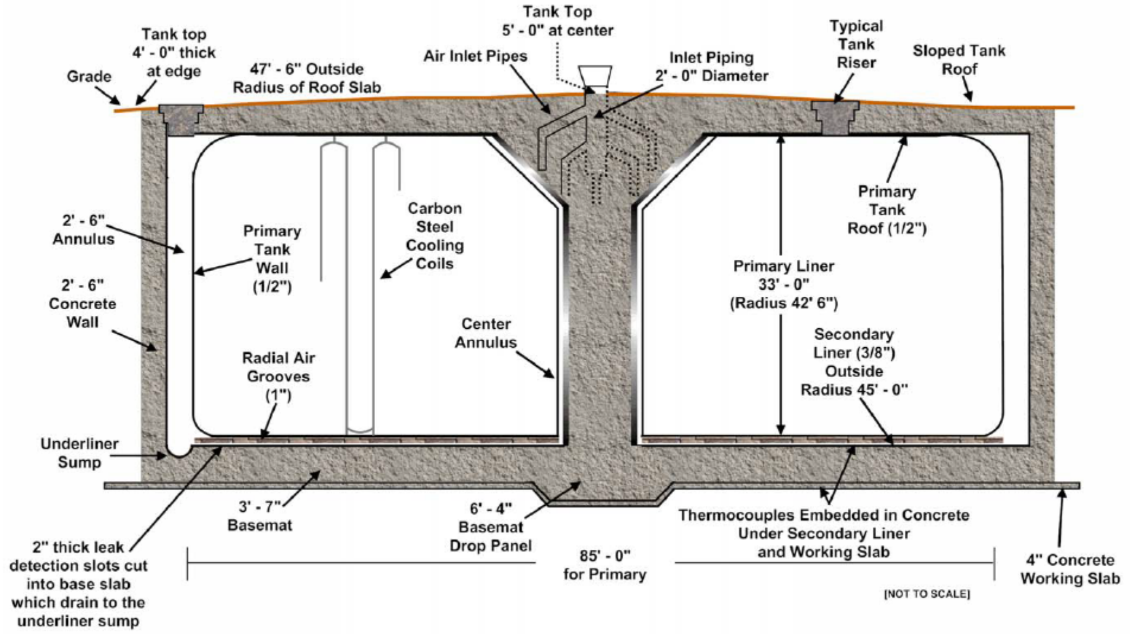


Figure 3-7. Type IIIA tank cross-sectional view (SRR, 2010b)

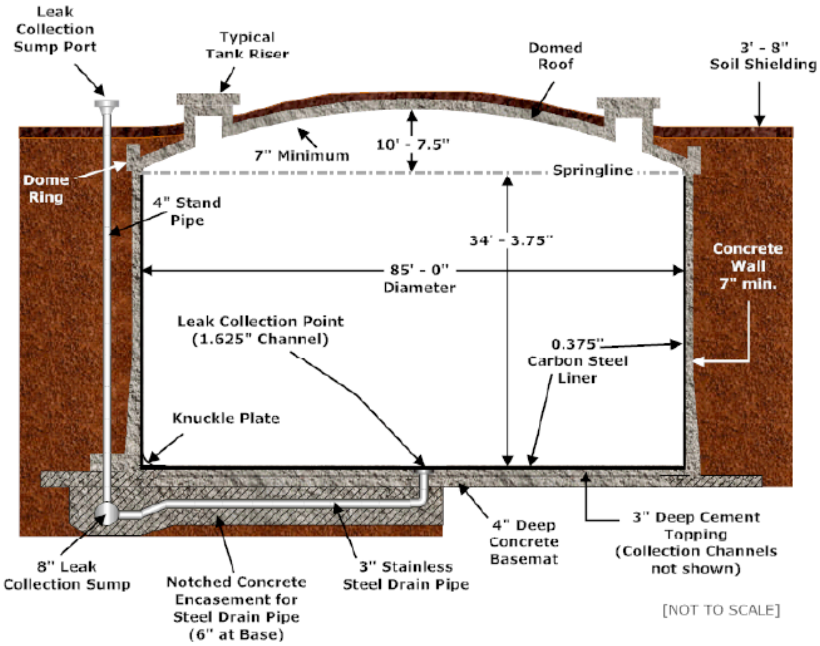


Figure 3-8. Type IV tank cross-sectional view (SRR, 2012)

3.1.2.2 Saltstone facility design

Waste resulting from reprocessing spent nuclear fuel was originally stored in 51 underground carbon steel tanks (see Section 3.1.2.1), 8 of which have been cleaned, stabilized and closed in place (SRR, 2019). Waste removed from the tanks is separated into two streams based on activity. A high activity (i.e., HLW) fraction is vitrified with the glass logs from vitrification planned for ultimate disposal in a geologic repository for HLW. The low activity fraction is treated to reduce the concentrations of key radionuclides and then mixed with dry materials (i.e., cement, blast furnace slag, and fly ash) to form a grout waste form called saltstone. Saltstone is disposed of in specially constructed disposal units in the Saltstone Disposal Facility (SDF) that are later buried under an engineered surface cover. The SDF is located in Z-area, which is in the central region of SRS.

The SDF consists of two rectangular disposal units (i.e., Vaults 1 and 4), six 11.4-million-L [3-million-gal] cylindrical disposal units, and one 121-million-L [32-million-gal] cylindrical disposal unit. At completion, the SDF is expected to include seven 121-million-L [32-million-gal] cylindrical disposal units (SRR 2009; SRR 2017).

Vault 1 is a rectangular reinforced concrete disposal unit that is approximately 183 m [600 ft] long, 30 m [100 ft] wide, and 8 m [27 ft] high (SRR, 2009). It is divided into 6 cells measuring approximately 30 m [100 ft] by 30 m [100 ft]. Three of the cells have been filled and a permanent roof was installed over them. The roof is poured-in-place concrete having a minimum thickness of 15 cm [6 in]. The remaining cells contain no saltstone and have no roof over them.

Vault 4 is a rectangular reinforced concrete disposal unit that is approximately 183 m [600 ft] long, 61 m [200 ft] wide, and 9 m [30 ft] high. It is divided into 12 cells measuring approximately 30 m [100 ft] by 30 m [100 ft]. One cell contains drums of low-activity waste that have been filled with concrete grout. This cell has a poured-in-place 7.6-cm [3-in] thick concrete encased wire mesh roof. The roof on the remaining cells is poured-in-place 15-cm [6-in] thick concrete over steel decking (i.e., 20-gauge corrugated metal, supported by steel joists and 25 cm [10 in] diameter standard pipe columns filled with concrete).

The 11.4-million-L [3-million-gal] cylindrical disposal units are made of reinforced concrete and will be below grade after the closure cap is emplaced (SRR, 2009). They are 45.7 m [150 ft] in diameter with an interior height of 6.7 m [22 ft] {7.2 m [23.5 ft] at the center}. The roof is 20.3 cm [8 in] thick (DOE, 2014). They have a 0.45-cm [0.179-in] thick carbon steel diaphragm, which is used to prevent water seepage out of the concrete disposal cell.

The 121-million-L [32-million-gal] cylindrical disposal units will also be below grade after the closure cap is emplaced and are made of reinforced, Class III sulfate-resistant concrete (DOE, 2014). They are 114 m [375 ft] in diameter with an interior height of 13.1 m [43 ft], a 30.5-cm [12-in] thick (minimum) concrete roof, and approximately 200 interior columns to support the roof.

Figures 3-9 through 3-12 show the design of Vault 4 and the saltstone disposal units.

3.1.3 Summary

The thickness of the top of the tank and vault system affect a driller's ability to penetrate the waste disposal system. At INL, the reinforced concrete vault roof thickness varies from 15 to 175 cm [6 to 69 in] and surrounds a stainless-steel tank. The upper portion of this tank is 0.64 cm [0.25 in] thick. At SRS, the reinforced concrete vault roof thickness varies from 56 to 122 cm [22 to 48 in] for the tanks that have a surrounding vault (i.e., Types I, II, and III/IIIA). These tanks have a carbon steel primary liner that varies in thickness from 1.3 to 1.6 cm [0.5 to 0.625 in]. The Type IV tanks at SRS have a reinforced concrete domed roof 17.8 cm to 25.4 cm [7 to 10 in] thick. Type IV tanks have a 0.96 cm [0.375 in] thick steel liner. At the saltstone facility, vault roofs vary in thickness from 7.6 to 15 cm [3 to 6 in] and consist of poured-in-place concrete over wire mesh or steel decking. The cylindrical disposal units at the saltstone facility have a 20.3 to 30.5-cm [8 to 12-in] thick reinforced concrete roof.

3.2 Hydrogeology

3.2.1 INL

As shown in Figure 3-13, INL is in southeastern Idaho on the west-central portion of the Eastern Snake River Plain (ESRP). DOE (2003) describes the principal surface materials as basalt, alluvium, lacustrine sediments, slope wash sediments and talus, silicic volcanic rocks, and sedimentary rocks. The soil at the TFF on the INTEC site is previously disturbed sandy gravel. Additionally, DOE (2003) characterizes the INTEC site as an area of mainstream alluvium with bedrock units consisting of basaltic lava flows. Most of the basalt volcanic activity occurred from 4 million to 2,100 years ago.

The Snake River Plain Aquifer (SRPA) underlies INL. Groundwater flows from northeast to southwest with discharge occurring as spring flow between Hagerman and Twin Falls (see Figure 3-13). DOE (2003) states that the water surface elevation of the regional groundwater underlying INL ranges from about 1,400 m [4,600 ft] above mean sea level (msl) in the north to about 1,340 [4,400 ft] above msl near the southwest boundary of the site. Within INL, the depth to the regional water table ranges from 60 m [200 ft] in the northeast to 270 m [900 ft] in the west and southwest. The SRPA receives recharge from infiltration, Big Lost River

Figure 3-9. **Vault 4 (SRR, 2009)**

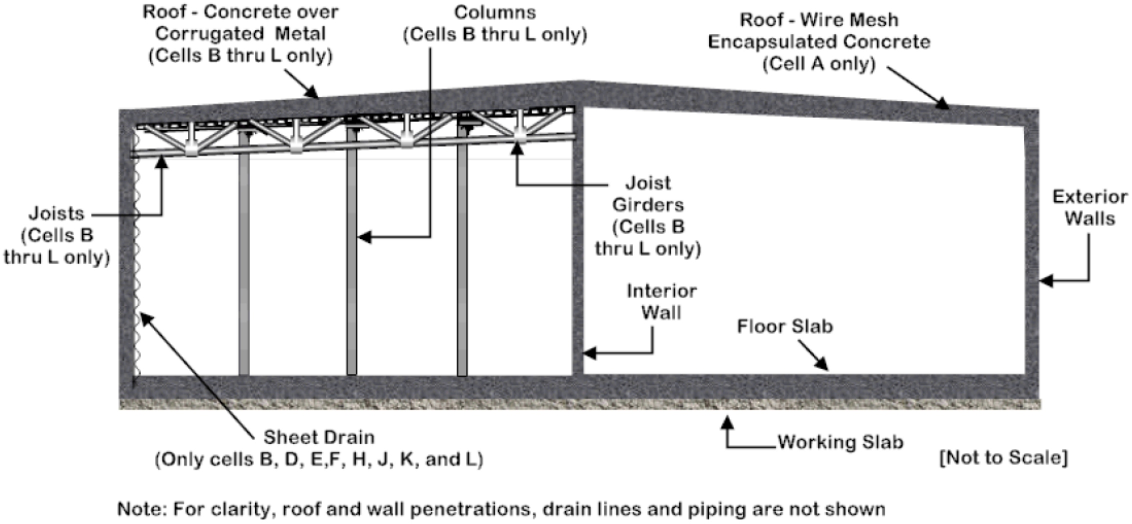
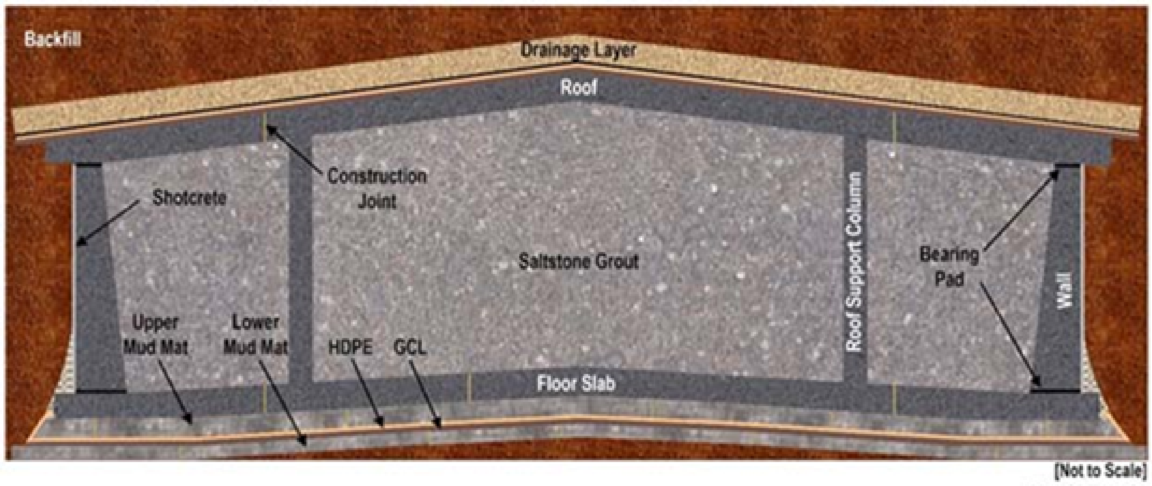


Figure 3-10. **Vault 4 cross section (SRR, 2009)**

Figure 3-11. Saltstone disposal units: Closeup of the 121-million-L [32-million-gal] unit in the bottom image and all the units, including the smaller 11.4-million-L [3-million-gal] units in the top image (SRR, 2017)



[Not to Scale]
2018-SDF-031-R0

Figure 3-12. **121-million-L [32-million-gal] Saltstone disposal unit cross section (SRR, 2020)**

underflow through fluvial deposits directly below the river channel, and surface discharge from the Big Lost River to engineered spreading basins, the Big Lost River sinks, and three playas near Howe (NRC, 2006; Ackerman et al., 2010).

The eastern Snake River Plain is underlain by hundreds to thousands of densely fractured to massive basalt flows interspersed with sediments. This assemblage of stratigraphic units transmits large volumes of groundwater and forms a major aquifer system that along with significant surface water diversions from the Snake River supports large areas of irrigated farmland (Garabedian, 1986). Individual basalt flows have variable lateral extent with average thicknesses of 6 to 8 m [20 to 25 ft]. The total thickness of the basalt flows may exceed a thousand meters (several thousand feet). Groundwater moves laterally through the basalt interflow zones, which consist of rubble zones between lava flows, and vertically through joints, fractures, and the edges of the rubbly interflow zones (Garabedian, 1986). The Quaternary basalt aquifer produces large volumes of water to wells, while the less transmissive older and deeper aquifers produce smaller volumes of water. Where it is saturated or contains perched water bodies, the overlying alluvium produces modest volumes of water in smaller, domestic wells.

Domestic water wells completed in the interfingered unconsolidated alluvial and basalt units in the farming areas and communities immediately adjacent to INL produce water from depths of 1 to 170 m [2 to 570 ft] at rates between 6 and 300 liters per minute (L/min) [1.5 and 80 gallons per minute (gpm)]. Northwest of INL in Butte County, near the farm community of Howe, single residence domestic wells produce potable water from sand, gravel, and fractured basalt units at depths around 30 m [100 ft] at approximately 80 L/min [20 gpm]. Northeast of INL in Jefferson County, near the farm communities of Mud Lake, Terreton, and Hamer, domestic wells produce water from fractured basalt units at depths between 30 and 110 m [100 to 350 ft] at rates between 80 to 190 L/min [20 to 50 gpm].

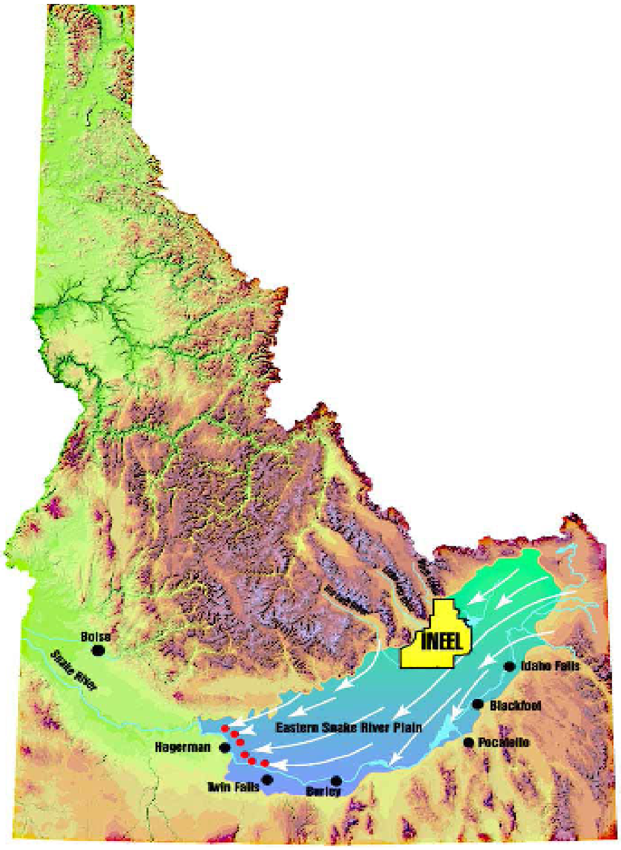


Figure 3-13. **Location of INL on the West Central portion of the ESRP (DOE, 2003)**

South of INL in Bingham County, in the area from Atomic City southeast along Highway 26 toward Tidden Flat and the northwestern outskirts of Moreland, single residence domestic wells produce water from basalt, fractured basalt, and cinders at depths between 30 to 150 m [100 to 500 ft] at rates between 40 to 170 L/min [10 to 45 gpm]. West of INL in Butte County, in the areas near Butte City and south of Arco along the INL boundary, domestic wells produce water from sands and gravels at depths between 1 and 45 m [2 to 140 ft] and fractured basalt and cinders at depths between 20 to 170 m [60 to 570 ft]. Well yield rates in this region range from 60 to 300 L/min [15 to 80 gpm] in the sand and gravel units to 10 to 190 L/min [3 to 50 gpm] in the fractured basalt and “cinder” units. Reported pumping rates were obtained from short, one- to two-hour air lift well yield tests conducted by the driller after drilling has stopped and represent the maximum pumping rates that the water-bearing formations penetrated by borehole can sustain.

In the absence of information about the controlled area formerly occupied by INL, including the detailed geology and hydrogeology within the INL site boundary, a domestic water well driller may rely on information from the water wells that were drilled near this area. Although the depths to water and the sequence and thicknesses of the hydrostratigraphic units encountered in the wells along the INL boundary wells vary greatly, an informed future well driller would anticipate hitting water at depths of between 30 to 170 m [100 to 570 ft] and to drill through unconsolidated surficial deposits, basalt units that are variably fractured, basalt flow rubbly zones, unconsolidated clay, sandy clay sediments, and cinders.

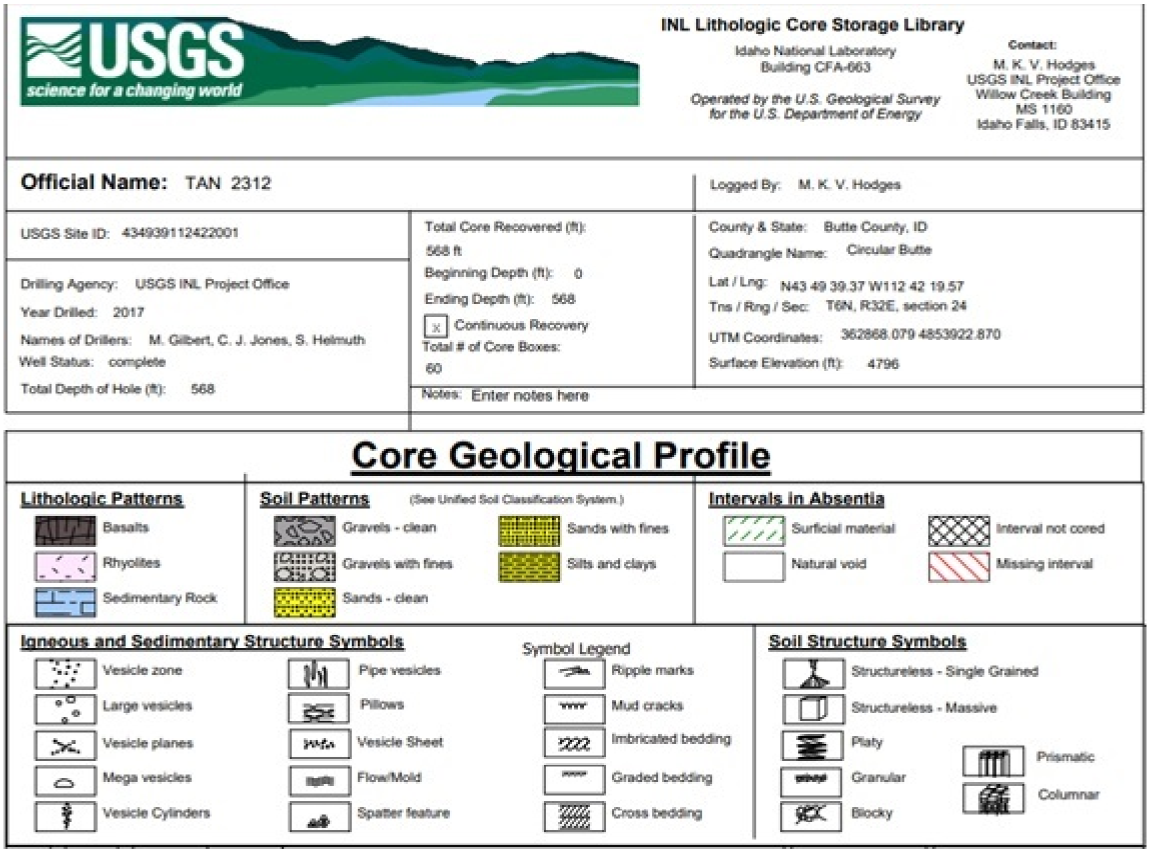
Technical Area North (TAN)-2312 borehole, which was continuously cored starting at the first basalt contact, was constructed by the United States Geological Survey (USGS) and the U.S. Department of Energy (DOE) to refine the stratigraphic framework for the eastern SRPA and to monitor the aquifer's long-term groundwater levels (Twining et al., 2018). Figure 3-14 shows a 3-m [10-ft] section of rock core from TAN-2312 borehole between 84.9- to 88.1-m [278.5- and 289-ft] below land surface (BLS). TAN-2312 is located 2.5 km [1.6 mi] south of the TAN facility main building complex, and approximately 21 km [13 mi] west of the farming community of Terreton. Figure 3-14 illustrates how the fracture frequency (blue, cyan, green bars) of the basalt flows at INL changes rapidly over a very short vertical distance and underscores how difficult it is to predict the depth at which a new water well will intersect a fracture zone that may be capable of transmitting water. The short section of rock core shown in Figure 3-14 is typical of the lithology between 11.3- and 173.1-m [37- and 568-ft] BLS, except for 0.3-m [1-ft] of sand at 51.7-m [169.5-ft] BLS and 0.6-m [2-ft] of calcareous siltstone at 146.4-m [480.3-ft] BLS; however, the fracture frequency varies greatly along the borehole.

3.2.2 SRS

The SRS is on the Atlantic Coastal Plain about 161 km [100 mi] from the Atlantic Coast and 40 km [25 mi] southeast of the Fall Line separating the Atlantic Coastal Plain from the Piedmont (see Figure 3-15). At the Fall Line, hard crystalline rock of the Piedmont meets the softer sedimentary formations of the Atlantic Coastal Plain. Sediments range in thickness from essentially zero at the Fall Line to more than 1.2 km [4,000 ft] at the Atlantic Coast (SRR, 2009). The SRS encompasses portions of Aiken, Barnwell, and Allendale Counties in South Carolina. It is located about 19 km [12 mi] south of Aiken, South Carolina and 24 km [15 mi] southeast of Augusta, Georgia. SRS is in a region of unconsolidated and semi consolidated sediments varying in thickness from about 213 m [700 ft] at the northwestern boundary to 430 m [1,410 ft] at the southeastern boundary (NRC, 2011). Sediments include clays, sands, gravels, and limestones.

The lithostratigraphic and hydrostratigraphic nomenclature used to describe the geology and hydrogeology for SRS and their relationship are shown in Figure 3-16. Because the focus is on an intruder drilling a domestic water well in the GSA at SRS, the description of the hydrostratigraphic units, which comes from Harris et al. (2000), includes the Tertiary and younger units that extend only down to approximately 75 to 100 m [250 to 330 ft] BLS. The Gordon aquifer, which ranges in thickness from 18 to 49 m [60 to 160 ft] at SRS, consists of loose and clayey sand from the Congaree formation and, in some places, sand from the Fourmile Branch and Snapp formations. South of SRS the Gordon aquifer grades to a sandy limestone and then the platform limestone of the lower Floridan aquifer. The Gordon aquifer very occasionally includes clay beds up to 1 m [3 ft] thick and towards its base, thin clay lenses. The overlying low-permeability Gordon confining unit, which consists of the Warley Hill formation, is known as the "green clay" due to its glauconite content. Its thickness ranges from 1.5 m [5 ft] near the northwest of SRS to 26 m [85 ft] downdip to the southeast and is described by Harris et al. (2000) as "…stiff to hard and…commonly fissile."

The Upper Three Runs (UTR) aquifer is 45 to 55 m [150 to 180 ft] thick, lies above the Gordon confining unit, and consists of (i) the lower aquifer comprised of the Santee formation, (ii) a tan clay confining unit consisting of the Twiggs Clay and Irwinton Sand members of the Dry Branch formation, and (iii) the upper aquifer consisting of the upper Dry Branch and Tobacco Road formations. The lower UTR aquifer comprises unconsolidated fine to medium sand and unconsolidated to consolidated carbonate sediments, such as wackestones and packstones.



INL Lithologic Core Storage Library

Idaho National Laboratory
Building CFA-663

Operated by the U.S. Geological Survey
for the U.S. Department of Energy

Contact:
M. K. V. Hodges
USGS INL Project Office
Willow Creek Building
MS 1160
Idaho Falls, ID 83415

Official Name: TAN 2312

Logged By: M. K. V. Hodges

USGS Site ID: 434939112422001

Drilling Agency: USGS INL Project Office
Year Drilled: 2017
Names of Drillers: M. Gilbert, C. J. Jones, S. Helmuth
Well Status: complete
Total Depth of Hole (ft): 568

Total Core Recovered (ft): 568 ft
Beginning Depth (ft): 0
Ending Depth (ft): 568
☒ Continuous Recovery
Total # of Core Boxes: 60

County & State: Butte County, ID
Quadrangle Name: Circular Butte
Lat / Lng: N43 49 39.37 W112 42 19.57
Tns / Rng / Sec: T6N, R32E, section 24
UTM Coordinates: 362868.079 4853922.870
Surface Elevation (ft): 4796

Notes: Enter notes here

Core Geological Profile

Lithologic Patterns
Basalts
Rhyolites
Sedimentary Rock

Soil Patterns (See Unified Soil Classification System.)
Gravels - clean
Gravels with fines
Sands - clean
Sands with fines
Silts and clays

Intervals in Absentia
Surficial material
Natural void
Interval not cored
Missing interval

Igneous and Sedimentary Structure Symbols
Vesicle zone
Large vesicles
Vesicle planes
Mega vesicles
Vesicle Cylinders
Pipe vesicles
Pillows
Vesicle Sheet
Flow/Mold
Spatter feature

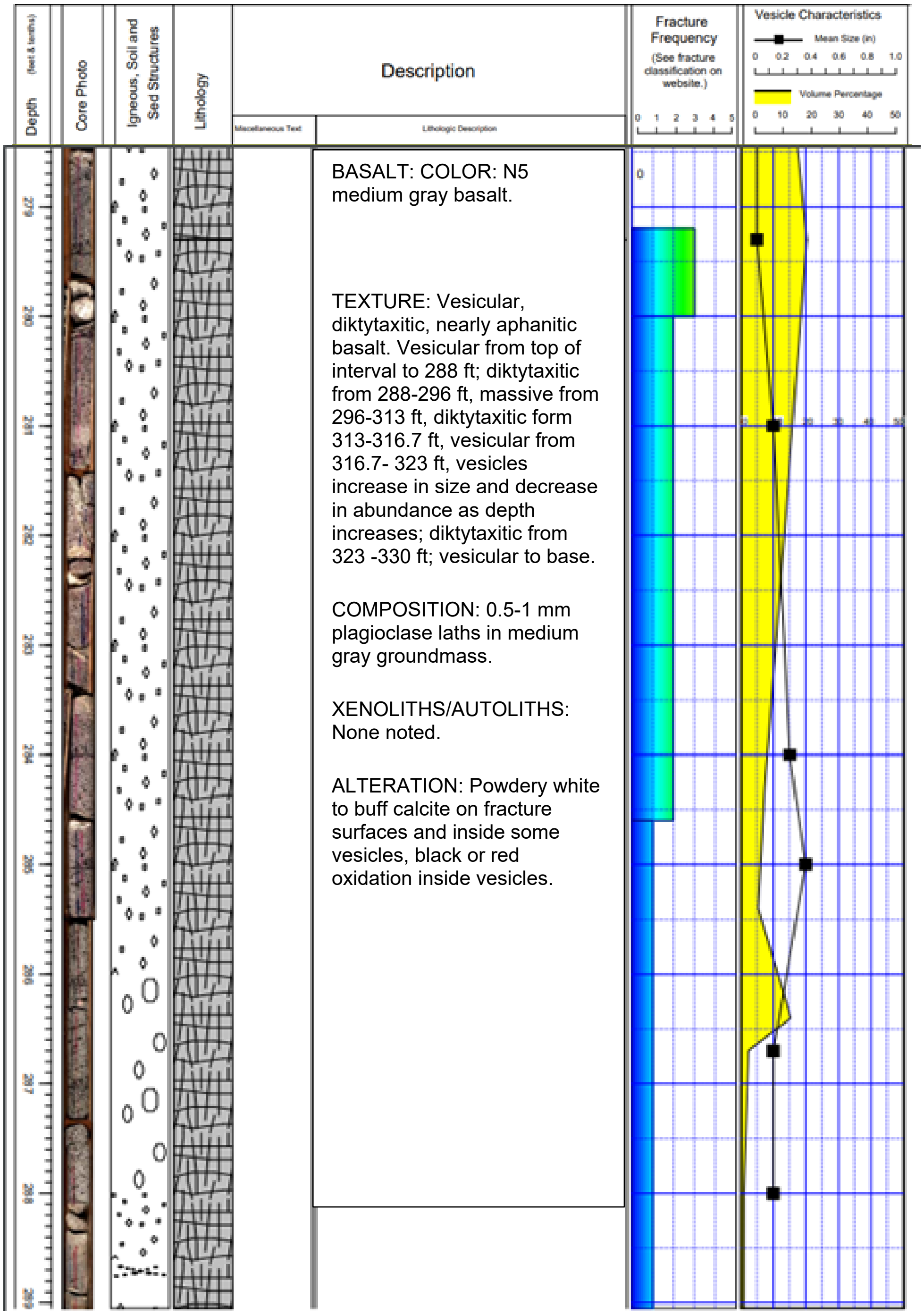
Symbol Legend
Ripple marks
Mud cracks
Imbricated bedding
Graded bedding
Cross bedding

Soil Structure Symbols
Structureless - Single Grained
Structureless - Massive
Platy
Granular
Blocky
Prismatic
Columnar

Figure 3-14(a). Rock core geological profile for TAN-2312 between 85- and 88.1-m [279- and 289-ft] BLS. (a) legend and description of lithology, soil, igneous rock texture, fracture frequency, and vesicle characteristics. (b) core log from left to right: (1) depth BLS in feet; (2) photograph of rock core; (3) vesicle structure; (4) lithology; (5) and (6) description; (7) fracture frequency (0 = unfractured, 5 = highly fractured); (8) vesicle percent volume and mean vesicle diameter (in) (Twining et al., 2018, Appendix 3).

The tan clay confining unit contains clay and sandy clay that is interbedded with clayey sand and sand. The upper UTR aquifer consists of massive beds of sand and clayey sand.

Figure 3-17 shows a northwest-southeast, lithologic cross-section through SRS extending from Aiken County in the northwest to Hampton County in the southeast. Figure 3-17 shows that from northwest to southeast across SRS the lithology of the Congaree formation and Gordon aquifer change from a predominantly sand, silty clay, and conglomeratic sand facies to mixed facies consisting of sand and limestone. Domestic water well drillers familiar with wells drilled north of SRS will anticipate drilling through clays and sands in the GSA, while those drillers more familiar with the area south of SRS may also anticipate drilling into limestone.



BASALT: COLOR: N5 medium gray basalt.

TEXTURE: Vesicular, diktytaxitic, nearly aphanitic basalt. Vesicular from top of interval to 288 ft; diktytaxitic from 288-296 ft, massive from 296-313 ft, diktytaxitic form 313-316.7 ft, vesicular from 316.7- 323 ft, vesicles increase in size and decrease in abundance as depth increases; diktytaxitic from 323 -330 ft; vesicular to base.

COMPOSITION: 0.5-1 mm plagioclase laths in medium gray groundmass.

XENOLITHS/AUTOLITHS: None noted.

ALTERATION: Powdery white to buff calcite on fracture surfaces and inside some vesicles, black or red oxidation inside vesicles.

Figure 3-14(b). Rock core geological profile for TAN-2312 between 85- and 88.1-m [279- and 289-ft] BLS. (a) legend and description of lithology, soil, igneous rock texture, fracture frequency, and vesicle characteristics. (b) core log from left to right: (1) depth BLS in feet; (2) photograph of rock core; (3) vesicle structure; (4) lithology; (5) and (6) description; (7) fracture frequency (0 = unfractured, 5 = highly fractured); (8) vesicle percent volume and mean vesicle diameter (in) (Twining et al., 2018, Appendix 3).

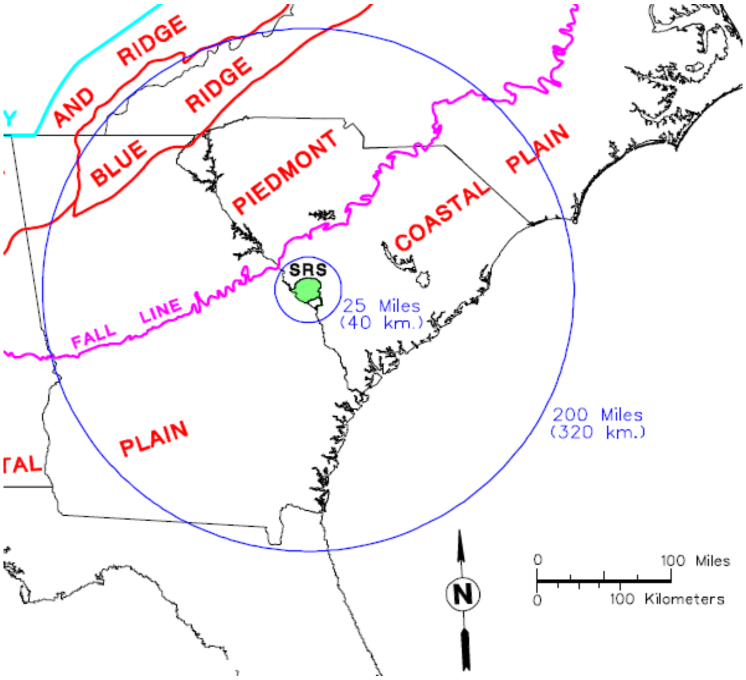


Figure 3-15. **Location of SRS relative to the fall line and Atlantic Coast (SRR, 2010b)**

3.3 Drilling Technologies

An important objective of this report is to determine if an inadvertent intruder drilling a domestic water well can drill through the vault roofs, including reinforced concrete roofs, and waste tanks at the INL INTEC and SRS disposal facilities using drilling practices that are currently used in or near INL or SRS. In addition, a better understanding of drill cuttings management can improve the adequacy of the PA models used to simulate mixing of radioactive waste in the cuttings and mechanical spreading of the contaminated cuttings during and after drilling. The time it takes to drill a well using different methods and the personal protective equipment (PPE) used by the drilling crew members are also important factors that affect estimated potential acute inadvertent intruder doses.

Specialized drilling methods that are designed to penetrate steel reinforced concrete and steel plate, such as diamond coring machines for extracting concrete strength testing samples or drilling holes for routing new conduits, are not frequently used for constructing domestic water wells and are not examined in this section. Some of the general information presented in this section was extracted from the third edition of Johnson's handbook Groundwater and Wells by Sterrett (2007) and the previous edition by Driscoll (1986). Driscoll (1986) features a more in-depth, although less up-to-date, discussion of drilling methods than Sterrett (2007). For more modern drilling methods, such as down-the-hole (DTH) hammers and sonic drilling, additional information was obtained from manufacturers' websites, downloadable technical brochures, and manufacturer's sponsored blogs.

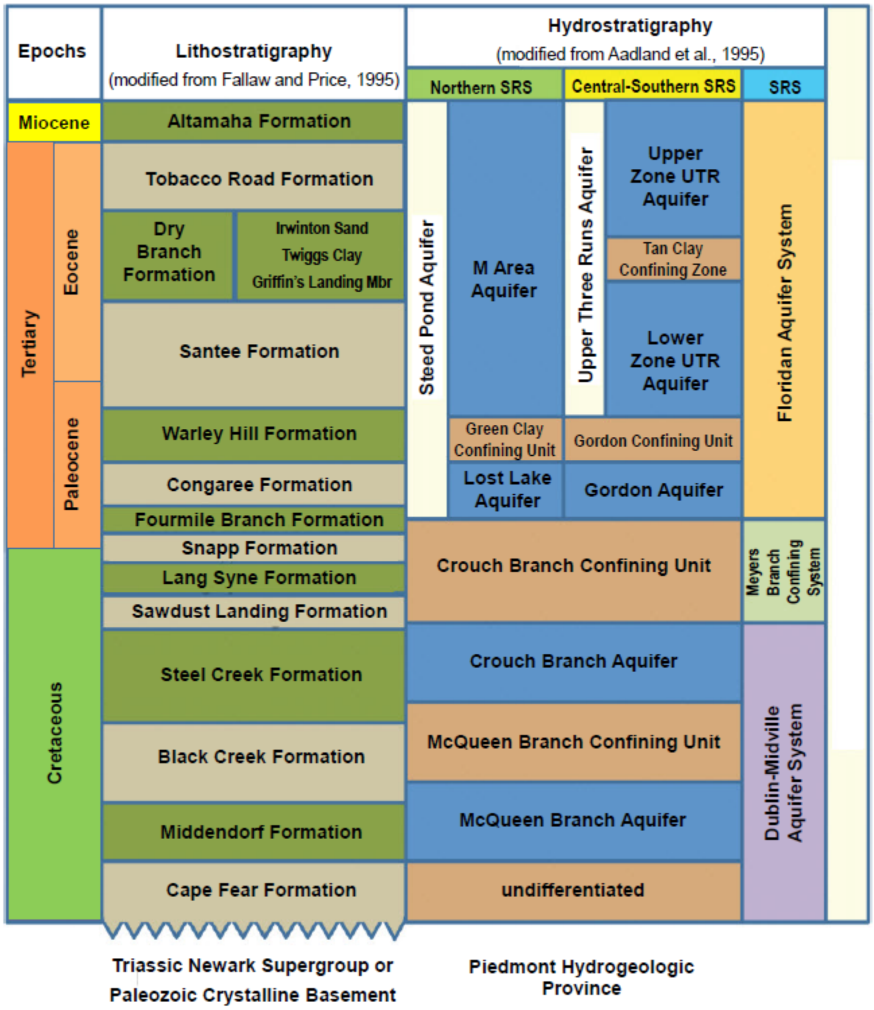


Figure 3-16. Lithostratigraphy and hydrostratigraphy for the Savannah River site [from Page 1, Figure E of Harris et al. (2015)].

A water well drill rig must be able to create an open hole from the ground surface to one or more water bearing formations. The borehole must have a large enough diameter(s) to accommodate conductor or surface casing, well casing and well screens, as well as grout placed for well-head protection, packers and concrete used to isolate formations, gravel packs surrounding well screens or slotted casing, and a submersible pump or the bowls of a shaft-driven pump. The mechanical systems of the rig must be able to penetrate unconsolidated and consolidated geologic formations to reach the desired water-bearing unit or aquifer, remove geologic material as the borehole advances, and raise and lower drilling tools and well components, such as new sections of drill pipe and well casing.

There are four methods commonly used in the water well industry to penetrate geologic materials and advance the borehole: (1) rotary drilling, in which a rotating table fixed to the drilling platform (table drive) or a hydraulic motor that can move up and down the mast (top head drive) rotate the drill string and drill bit; (2) percussion drilling, in which a cable tool rig's low-frequency {0.33 to 0.66 hertz (Hz) [0 to 40 beats per minute (bpm)]} reciprocating walking beam, or a top or down-the-hole (DTH) hammer's high-frequency {13 to 38 Hz [800 to 2,300 bpm]} pneumatic hammer repeatedly raises and lowers a drill bit to fracture and crush

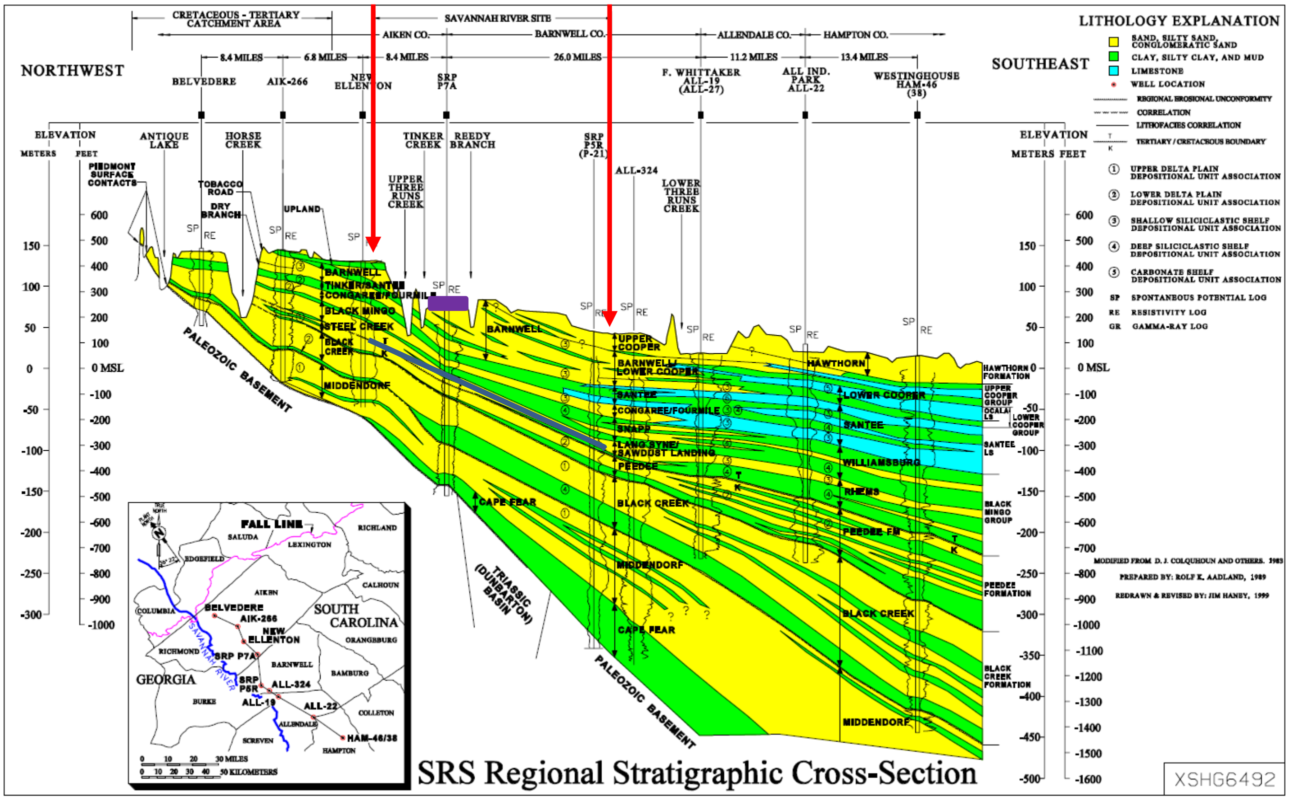


Figure 3-17[1]**. Vertical geologic cross-section depicting formations and their dominant lithology along a northwest-to-southeast transect from Aiken County to Hampton County, South Carolina. The SRS along the transect is indicated by the region between the red arrows. Dipping dark blue bar is the Cretaceous/Tertiary contact. Purple bar is the approximate location of the GSA. Formations predominantly composed of sand facies shown in yellow, clay facies in green, and limestone facies in blue. (Wyatt et al., 2000)**

geologic material at the bottom of the borehole; (3) sonic drilling, in which a mechanical oscillator excites high-frequency {50 to 160 Hz [3,000 to 9,600 bpm]} vertical sympathetic harmonic resonance in the drill string that either induces liquefaction (reduces effective stress to zero) in unconsolidated sediments or delivers high-frequency, fracture-inducing blows to the bottom of a borehole in cohesive soil or consolidated rock; and (4) combined rotary and percussion drilling, in which a DTH or top drive pneumatic hammer applies percussive action at the bottom of the borehole to fracture the material while the drill string is rotated to both advance the bit teeth to fresh rock and to grind rock chips.

---

[1] Reprinted with permission from Wyatt, D.E., R.K. Aadland, and F.H. Syms. "Overview of the Savannah River Site Stratigraphy, Hydrostratigraphy, and Structure." In Carolina Geological Society 2000 Field Trip Guidebook: Savannah River Site: Environmental Remediation Systems in Unconsolidated Upper Coastal Plain Sediments-Stratigraphic and Structural Considerations. M.K. Harris, and D.E. Wyatt, (eds). WSC-MS-2000-00606. Carolina Geological Society. 2000. Copyright 2000 Carolina Geological Society.

There are three primary methods domestic water well drillers use for removing drill cuttings from the borehole: (1) flushing with fluids including air, air with a water spray, air with water and a foaming agent, pure water, and water with various additives, such as bentonite clay, barite, and polymers that change the resulting mud's density and viscosity or modify the mud's rheology to make it shear resistant (thixotropic); (2) bailers, which are long tubes with gravity-actuated, one-way valves at their down-hole ends that entrain and hoist water and cuttings from the bottom of the borehole; and (3) coring bits and core barrels where special drill bits cut ring-shaped holes and then break off and catch the column of geologic material either inside the hollow drill rod or in a separate thin-walled core barrel run-in on wire line through the drill string.

Not all combinations of borehole drilling and cuttings removal methods are used in modern water well drilling practice. Specific combinations are preferred for drilling certain rock types or regularly encountered sequences of rock formations (e.g., a sandstone facies, underlain by a shale facies, underlain by a marine limestones facies). For example, a rotary rig with a DTH hammer will typically be used for competent consolidated formations where the likelihood of borehole formation collapse is minimal. Fine cuttings created by the rotating DTH hammer are removed using air with water spray, and unlike mud, the air-water mixture will not clog the water-bearing fracture zones. For unconsolidated alluvial deposits and soft to hard sedimentary rocks, a rotary rig with drilling mud will be used to lift cuttings, lubricate and cool the drill bit, and prevent borehole collapse. If the likelihood of borehole collapse is high and water is readily available at the site, a driller may use a rotary rig with reverse mud circulation where the drilling fluid is injected into the annulus between the drill string and the borehole and returned up through the center of the hollow drill string to a pit large enough to provide sufficient drilling fluid to accommodate fluid losses to the formation. Cable tool rigs, also known as pounder, churn, or spudder rigs, almost always use bailers to remove cuttings from the borehole. The cable tool rig operator usually pours water into the borehole to make the cuttings flow more rapidly into the bailer. Sonic rigs always retrieve drill cuttings by removing soil and rock cores. Table 3-3 shows most of the typical combinations of drilling and cuttings removal methods used in modern domestic water well drilling. Sterrett (2007) and Driscoll (1986) provide guides for selecting bits for different formations and rock types when drilling with air, foam, or mud rotary rigs. A figure[2] similar to one found in these guides was found on the World Wide Web and reproduced here in as Figure 3-18 [Driscoll (1986) attributes this figure to Ingersoll Rand®].

The geology and hydrogeology of the INL and SRS sites are discussed in Section 3.2. At the INL, the rock types that domestic water well drillers must penetrate are typically alluvial deposits and basalt flows of various composition and texture. Figure 3-18 indicates that for drilling water wells in basalt, a downhole hammer is the preferred bit type. Figure 3-18 does not indicate what drilling fluid is recommended when using a DTH hammer in basalt; however, most rotary rigs with DTH hammers use compressed air to drive the hammer, cool the bit, and lift cuttings. Air rotary methods also make it easy to determine when a water-producing zone has been penetrated as the water is lifted quickly to the surface with the cuttings. At SRS, the rock types that domestic water well drillers must penetrate include fine to coarse-grained alluvium, sand, and clay.

---

[2] https://www.globalsecurity.org/military/library/policy/army/fm/5-484/Ch5.htm (accessed 2/8/2019)

Table 3-3. Common drilling and cuttings removal combinations

Drilling Method and Cuttings Removal Method	Type of Formation	Comments
Rotary Drilling Methods		
Rotary with Water, Direct and Reverse Circulation	Consolidated and unconsolidated alluvial deposits	Use if water is readily available and lower section of well will be screened and the cost of well development to remove mud that has invaded the formation is expensive.
Rotary with Mud, Direct Circulation	Consolidated and unconsolidated deposits and soft to medium hard sedimentary rock	Use where water not readily available and likelihood of borehole formation collapse is minimal
Rotary with Mud, Reverse Circulation	Unconsolidated alluvial deposits and soft to medium sedimentary rock	Water readily available and likelihood of borehole formation collapse is significant
Rotary with Air, Direct Circulation	Consolidated and unconsolidated deposits and soft to medium hard sedimentary rock	Water not readily available and likelihood of borehole formation erosion and collapse is minimal. Not used where large volumes of formation fluid (water) are expected.
Percussion Drilling Methods		
Cable Tool Rig with Sand Bailer	All formations	Cable tool rigs cost significantly less than modern truck-mounted rotary rigs with or without pneumatic hammers and less than sonic rigs, too. Rate of penetration can be very slow, but crews are smaller and require less training than rotary rig crews.
Sonic Drilling Methods		
Sonic Drilling	All formations, but often used when complete cores of soft clay, silt, and sand formations are needed. Capable of coring steel reinforced concrete and thick steel	Drilling rates with sonic rigs can be very rapid. Drilling depth is limited by the increased energy required to vibrate long drill strings at their natural harmonic frequency. Typically used to obtain full core samples for geotechnical and near-surface mineralogical analyses.
Combined Rotary and Percussion Drilling Methods		
DTH Hammer, Rotary with Air, Air with Water Spray, Air-Water-Foam. Direct Circulation	Hard rock, such as granite, basalt, quartzite	Water not readily available. DTH hammer with rotary drilling is typically faster than straight DTH hammer
DTH Hammer, Dual Rotary with Air, Air with Water Spray, Air-Water-Foam. Reverse Circulation Through Annulus of Simultaneously Driven Casing and Drill String	Formations that easily collapse and trap the drill string or could result in lost circulation of drilling fluid. Caving sands and alluvial fans with large boulders.	Dual rotary rigs typically use a top drive system to rotate the drill string and a table drive to rotate and drive the casing, which is affixed with a casing shoe to ream the borehole wall.

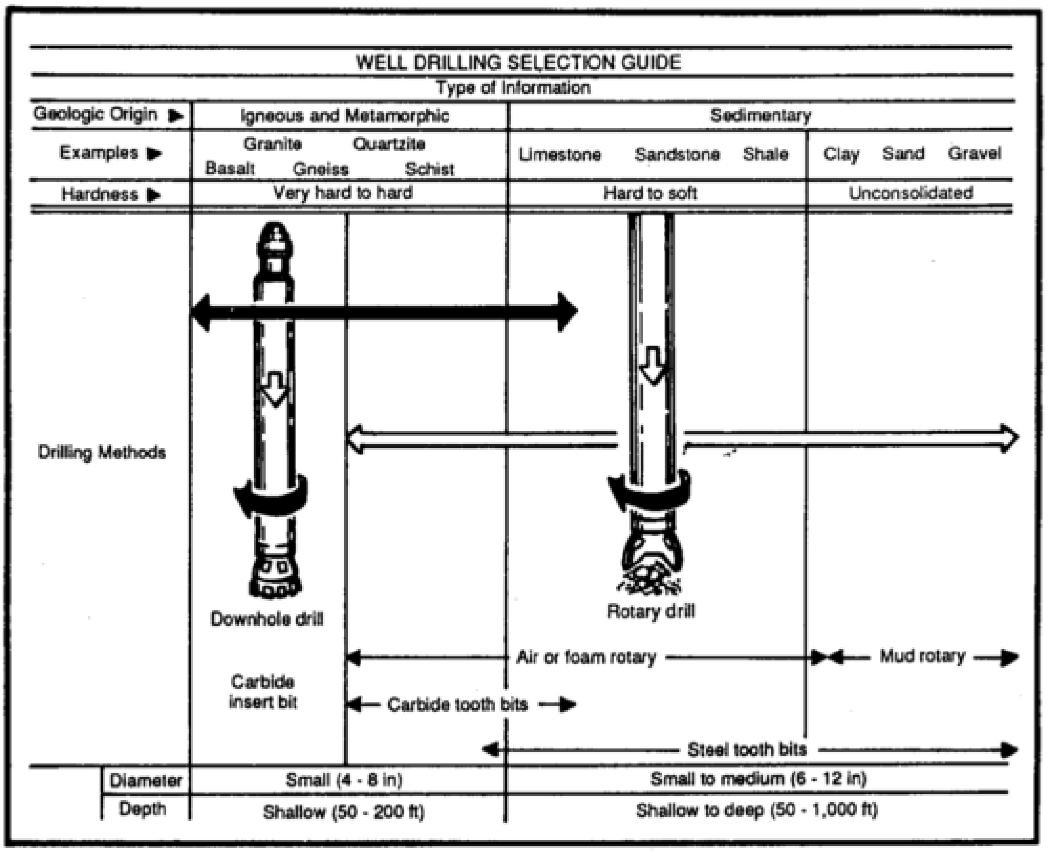


Figure 3-18. **Guide for bit selection for air, foam, and mud rotary drilling methods. The "Downhole drill with Carbide insert bit" shown on the left side of this figure is a rotating DTH pneumatic hammer operated with compressed air, where cuttings are lifted using compressed air with water spray or foam injection. The "Rotary drill with Carbide tooth bits and Steel tooth bits" shown in the center of this figure is a rotating roller cone bit, where cuttings are lifted using compressed air, foam, or mud, depending on the rock being drilled. Foam rotary indicates that water and polymer foaming agents can be added during air rotary drilling to help lift the cuttings. (U.S. Army, 1994)**

3.3.1 Domestic water well drilling methods at INL and SRS

A review of well driller's reports from the four-county area near INL over the past 20 years (1999-2019) shows that of 6,281 domestic water wells, 6,199 were drilled using air rotary methods {which may include the additional cutting action of an air-driven hammer [e.g., using DTH (also known as downhole drilling as shown in Figure 3-18)]}, 80 were drilled with a cable tool rig, and only 2 used a mud rotary rig. Well casing diameters are typically 15.2 cm [6 in],although there are some domestic wells that have 20.3 or 25.4 cm [8 or 10 in] perforated or louvered casing in the lower well production interval. Well drilling information obtained from various sources in the three-county area near SRS indicate that most domestic water wells are drilled with mud rotary rigs, reverse mud rotary rigs, and cable tool rigs.

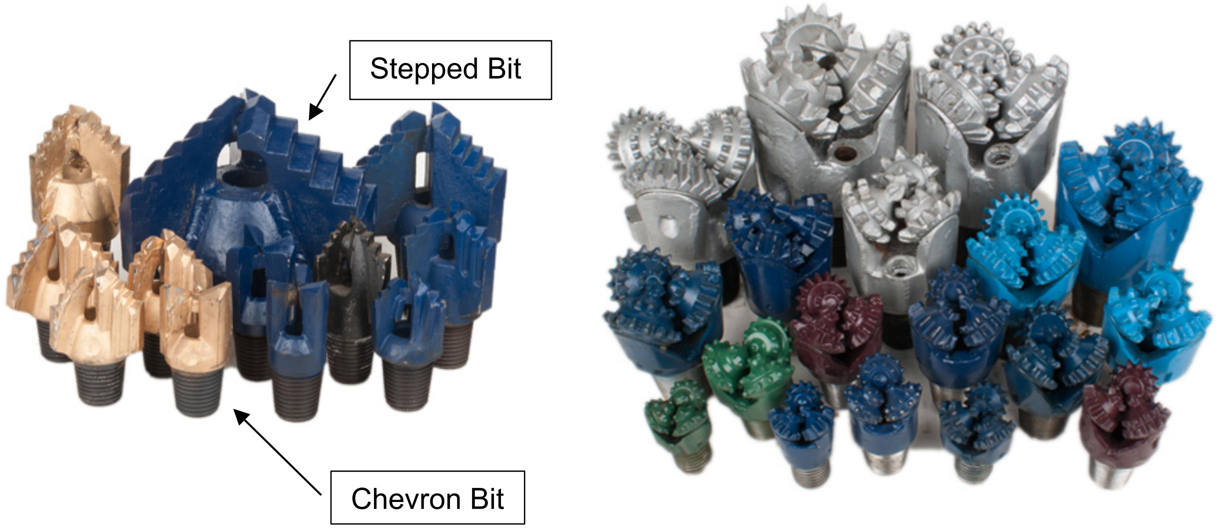
3.3.2 Rotary drilling methods

Depending on the type of drill bit that is used, rotary drill rigs can penetrate consolidated rock with material properties and mechanical characteristics similar to those of concrete vault roofs planned for the INL INTEC site and SRS. An air rotary drill rig uses compressed air to both cool the rotating drill bit and return cuttings and any groundwater or injected water spray to the surface. Note that Figure 3-18 includes foam rotary, and this indicates that water and polymer foaming agents can be added during air rotary drilling to help lift the cuttings. Although air rotary drilling is not as effective as mud rotary or reverse mud rotary for maintaining borehole stability in unconsolidated sediments or other formations prone to caving, some air rotary drill rigs allow casing to be advanced with the drill bit by using a pile hammer, a pneumatic casing hammer, or a second rotary drive for casing fitted with a carbide-studded cutting shoe (dual rotary). These methods for advancing well casing allow air rotary drilling to be used to construct water wells where the overburden consists of loose, unconsolidated materials, such as alluvium. Air rotary rigs deliver energy to the dill bit by a variety of mechanisms, including rotational force (torque) and normal force transferred by the rotating drill string to drag and roller-cone bits (Figure 3-19), percussive force delivered at the top of the drill string (top hammer drill rigs), percussive force delivered by a pneumatically-driven DTH hammer at the bottom of the drill string, and by mechanical oscillators that resonate the drill string and the bit face at frequencies between 50 and 160Hz[3] [3,000 to 9,600 bpm]. Drag and roller-cone bits use the rotation of the drill bit and the downforce [weight on bit] of the rig to cut or crush the formation and sweep cuttings from the work face. Percussive and sonic drilling methods do not use the energy of the rotating drill bit to fracture the rock; however, drilling rates [rate of penetration] using these methods can be increased by carefully adjusting the speed of rotation and weight on bit, the air pressure and air flow rate used to drive the hammer and lift the cuttings, or by adjusting the frequency of the sonic drill head.

The drag bits (also called wing and starter bits) shown in Figure 3-19(a) are typically used by water well drillers for penetrating unconsolidated overburden and rocks that are of soft or medium hardness. Drag bits have sharpened tungsten carbide inserts welded or brazed to notch-shaped benches in the cutting blades. The bit-teeth attached to the roller-cone bit of the mill-tooth tri-cone type as shown in Figure 3-19(b) are composed of built-up tungsten carbide set in cobalt.

---

[3] http://www.sonic-drill.com/HOW_SONIC_WORKS.html (accessed 2/11/2019)



(a)

(b)

Figure 3-19[4]. **(a) Drag bits of the stepped and chevron types and (b) roller-cone bits of the mill-tooth tri-cone type [Archway Engineering (UK) LTD, 2016].**

3.3.2.1 How drag and roller-cone drill bits used in rotary drilling penetrate consolidated rock

The blades on stepped- and chevron-type drag bits apply shearing, cutting, or chipping, as well as grinding forces to the working face of the rock. These forces are primarily a combination of the radial forces from torque applied by the rotary drive and axial forces applied by the weight of the drill string plus the pulldown or minus the pullback from the rig's hoisting equipment (the net downward force is the weight on bit). Gray et al. (1962) studied rock breaking by a single tungsten-carbide tooth from a stepped-type drag bit using a laboratory-scale experimental apparatus that measured the fluctuating vertical and radial forces applied by the tooth and captured images of the chip breaking process using high speed photography. From their study the authors present two theories to explain the failure mechanism. According to the "shear-plane" theory, brittle failure occurs on a fracture plane whose orientation with respect to the force applied by the tooth is a function of the internal friction angle θ [Figure 3-20(a)] as defined by the Mohr-Coulomb failure criterion

$$\tau = \sigma \tan(\theta) + c, \tag{3-1}$$

---

[4] Reprinted with permission from Archway Engineering (UK) LTD. "Full-hole Drill Bits." http://www.archway-engineering.com/product-category/rotary/full_hole_drill_bits/ (accessed 12/8/2020). Copyright 2016 Archway Engineering (UK) LTD.

where τ is the rock shear strength, σ is the applied normal stress, and c is the cohesion. According to the "tensile-arc" theory, the force from the drag-bit tooth produces a semi-circular fracture trajectory that starts perpendicular to the vertical cut face and then arcs up to meet the uncut horizontal rock surface at a 90-degree angle [Figure 3-20(b)]. The shapes of the rock chips produced in the Gray et al. (1962) experiments suggest that the rock breaking action of drag bit teeth may result from a combination of these two failure mechanisms.

Maurer (1965) conducted experiments on how roller-cone tooth penetration and rock cratering are affected by pressure from the drilling fluid, the formation fluids, and overburden. Maurer's conceptual model of rock crater formation under atmospheric pressure is illustrated in Figure 3-21. After tooth penetration [Figure 3-21(a)] the rock immediately below the bit tooth is crushed [Figure 3-21(b)], forming a wedge of finely powdered rock. As the force from the tooth increases further, the crushed rock compresses until the applied shear stress exceeds the shear strength of the rock and a cup-shaped envelope of intersecting fracture planes forms [Figure 3-21(c)]. The rock in the cup-shaped region surrounding the tooth [Figure 3-21(d)] is then broken when the pressure between the tooth and the rock exceeds what Maurer calls the "threshold contact pressure," which exceeds 2,700 MPa [400,000 psi] for very strong rock such as granite. In shallow boreholes with low fluid pressures, the rock fails "explosively" and the crushed rock is ejected from the cup-shaped craters. For very deep boreholes, the pressure exerted by the drilling fluid and overburden increases the shear strength of the rock and greater weight on bit is required to maintain a high rate of penetration. In addition, high fluid pressures prevent the cuttings from being ejected from the craters and lifted to the surface and may slow the rate of penetration.

3.3.3 Percussion drilling methods

Percussion drilling, which includes traditional cable tool rigs and modern pneumatically driven hammers, is the preferred method for penetrating hard rock (Figure 3-18). Although 80 water wells were drilled near the INL site during the past 20 years using cable tool rigs, this technology is used less frequently than air rotary for drilling water wells because the large diameter boreholes require heavier, more expensive casing, and because rates of penetration are slow.

Figure 3-22 shows a truck-mounted Bucyrus-Erie 22W cable tool drill rig used to drill large-diameter deep water wells. A cable tool rig drills by repeatedly lifting and dropping a heavy cutting bit attached to the bottom end of a cable. After the heavy cutting bit [Figure 3-23(a)] has fractured and crushed rock in the bottom of the borehole, a bailer [Figure 3-23(b)] is run downhole on a separate cable to retrieve cuttings and clean the hole. A bailer is simply a pipe with a bail at the top for attaching the cable and a flap valve, or similar device, at the bottom to retain the cuttings when the bailer is pulled to the surface. Water is often poured into the borehole to help cuttings flow into the bailer. Figure 3-24 shows button-type percussion bits for pneumatic-powered top and DTH hammers that are used on air rotary rigs.

Percussion drilling methods penetrate rock by a sequence of impacts (Tandanand, 1973). Each impact: (i) elastically deforms the rock and crushes surface irregularities; (ii) generates fractures that emanate radially from the point of impact; (iii) forms a wedge of crushed rock beneath the cutting edge of the tool; (iv) generates fractures along shear stress trajectories that emerge at the rock surface; and (v) ejects rock chips and crushed rock from the crater. Between impacts, the face of the drill bit is rotated (indexed) to facilitate removal of cuttings and

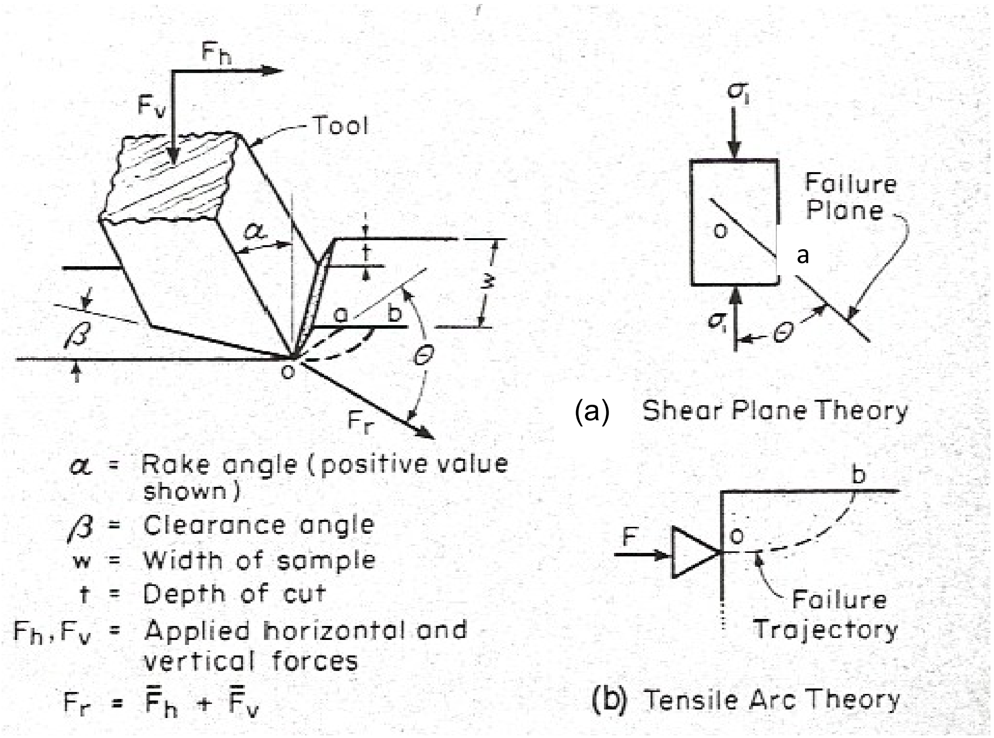


Figure 3-20[5]. **Theories for rock breakage mechanisms for drag bits. F_v is the vertical force, F_h is the horizontal force, and F_r is the sum of the vertical and horizontal forces applied by the tip of the drag bit blade. (a) Shear plane theory for rock breakage: σ_1 is the normal stress, shear failure occurs along the plane a that lies at an angle of θ with respect to the normal stress applied by F_r. (b) Tensile arc theory: F is the normal force applied to a vertical edge of the rock face by the drag bit blade and failure is assumed to occur along the arc o$-b$. [Gray et al. (1962), Figure 4]**

---

[5] Reprinted with permission from Gray, K.E., F. Armstrong, and C. Gatlin. “Two-Dimensional Study of Rock Breakage in Drag-Bit Drilling at Atmospheric Pressure.” Journal of Petroleum Technology. pp. 93–98. January 1962. Copyright 1962 Society of Petroleum Engineers.

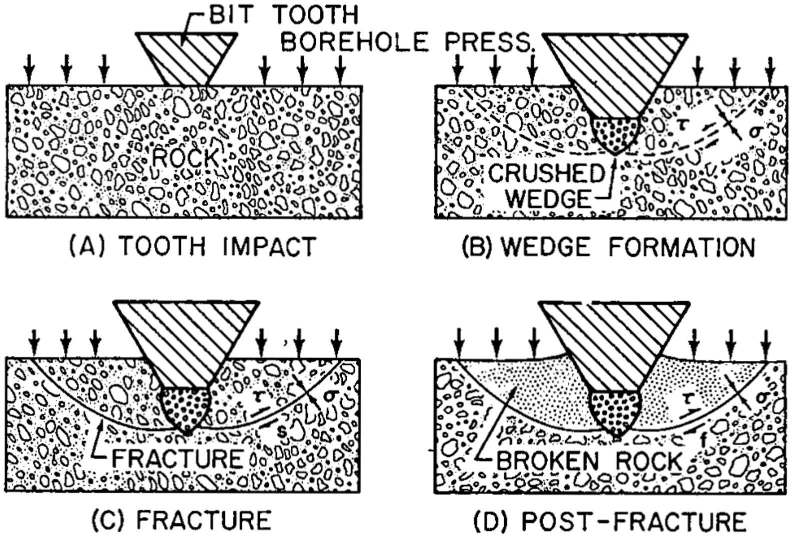


Figure 3-21[6]. **Rock crater formation mechanism for roller-cone bits. [Maurer (1965), Figure 2]**

Figure 3-22[7]. **Truck-mounted Bucyrus-Erie 22W cable tool rig. (Holt Services Inc., 2020).**

---

[6] Reprinted with permission from Maurer, W.C. “Bit-Tooth Penetration Under Simulated Borehole Conditions.” Petroleum Transactions. pp. 1,433–1,442. December 1965. Copyright 1965 Society of Petroleum Engineers.

[7] Reprinted with permission from Holt Services Inc. “Cable Tool Drill Rigs.” 2020. <http://www.holtservicesinc.com/cable-tool-drill-rigs.htm> (December 8, 2020). Copyright 2020 Holt Services Inc.

(a) (b)

Figure 3-23. (a)[8] Carbide button bit manufactured by RAMPP; (b)[9] flat bottom (top) and dart bailers (middle) and valve for flat bottom bailer (bottom). (Rampp Company, 2020).

advance the cutting face to fresh rock. Video clips show how Wendell J. Lee Well Services[10] of Spartanburg, South Carolina and Lee & Sims Drilling Services[11] of Denton, South Carolina, use a sequence of the previously described bits to drill water wells in the Piedmont region of South Carolina (See Figure 3-15). The drill rig shown in the first video clip is an air rotary rig. The Epiroc T3W rotary drill rig shown in the second video clip can drill with air or mud. In both videos, a drag bit is used to start the hole and penetrate the upper 6 to 6.6 m [20 to 25 ft] of overburden. According to Lucon (2013), proper use of a sonic drilling system requires an understanding of the frequency range and power that can be delivered by the sonic drill head, the length of the steel drill string, which serves as the resonator, and the mechanical properties of the formation being drilled. The sonic drill head develops vertical or axially-oriented elastic pressure waves in the steel drill string that deliver forces at the drill bit ranging from 22,680 to 127,005 kgf [50,000 to 280,000 lbs] at frequencies up to 160 Hz [9,600 bpm]. According to Lucon (2013) the key to effective drilling with a sonic rig is "…efficient transfer of massive vibrational wave energy put into the top of the steel drill pipe to the bottom bit, with very little power loss in the process." When a length of drill string is driven at its resonant frequency

---

[8] Reprinted with permission from Rampp Company. "Carbide Button Bits." <http://www.ramppco.com/products-drilling-tools/product/16-carbide-button-bits.html> (December 9, 2020). Copyright 2020 Rampp Company.

[9] Reprinted with permission from Rampp Company. "Bailers & Sand Pumps." <http://www.ramppco.com/bailers-sand-pumps.html> (December 9, 2020). Copyright 2020 Rampp Company.

[10] https://www.youtube.com/watch?v=JT4Ouba7PFs (accessed 3/6/2020)

[11] https://www.youtube.com/watch?v=eUlhtw9cisU (accessed 3/6/2020)

(a) (b)

Figure 3-24. **(a)[12]Top Hammer Drill Bits (a) and (b)[13] Pneumatic DTH Hammers with Full-Face Drill Bits (b). (Sandvik, 2020).**

$$\gamma = \frac{c}{2l} \qquad \text{3-2}$$

where C is the celerity of steel {5,000 m/s, [16,500 ft/s]} and l is the length of the drill string, the antinodes located at the top and bottom of the string are driven at their maximum vertical amplitude. If a drill string is 61 m [200 ft] long, the resonant frequency is only 41.25 Hz [2,475 bpm]. Since sonic drill heads have a limited frequency range {50 to 160 Hz [3,000 to 9,600 bpm]}, this 61 m [200 ft] long drill string would actually be driven at the first overtone of the resonant frequency, or 82.5 Hz [4,950 bmp]. As drilling deepens, the sonic head is operated at higher overtones to deliver higher forces at the cutting face.

Since the sonic head resonates the drill string in the vertical or axial direction, the cutting action of the drill bit in hard rock is similar to the percussive action of a DTH hammer (Section 3.3.3). However, when the drill string resonates in unconsolidated material, such as sands and gravels, the cutting action of the drill bit is different. In unconsolidated media, the vibrating drill bit fluidizes the grains and then displaces the granular media as it advances because the media has no compressive strength when fluidized.

---

[12] Reprinted with permission from Sandvik. “Top Hammer Drilling Tools.” <https://www.rocktechnology.sandvik/en/products/rock-tools/top-hammer-drilling-tools/> (December 9, 2020). Copyright 2020 Sandvik

[13] Reprinted with permission from Sandvik. “Down-The-Hole Drilling Tools.” <https://www.rocktechnology.sandvik/en/products/rock-tools/down-the-hole-drilling-tools/> (December 9, 2020). Copyright 2020 Sandvik.

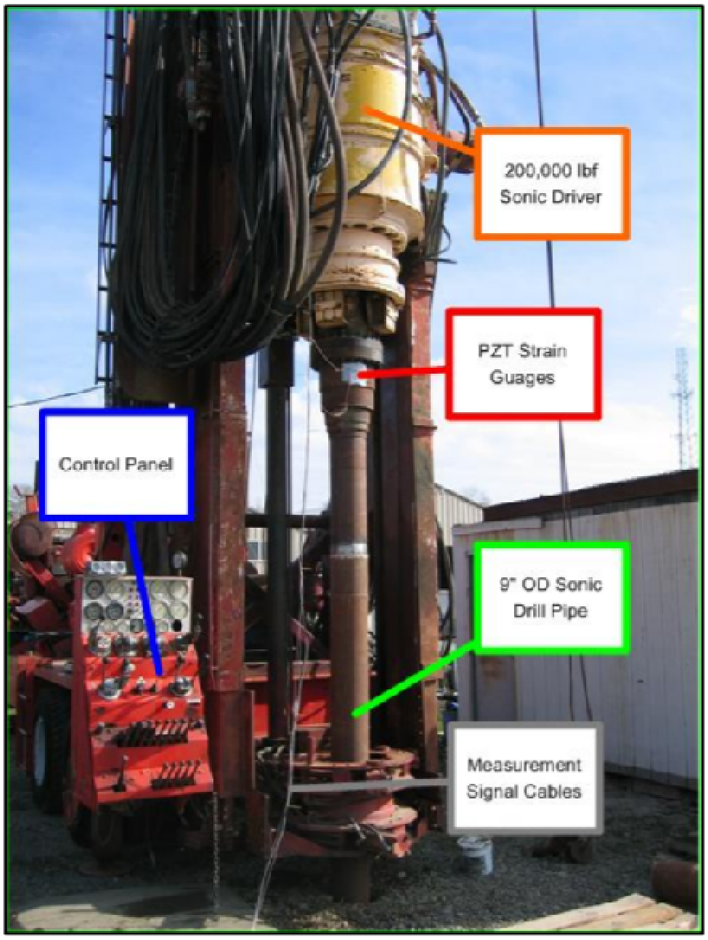


Figure 3-25[14]**. Sonic drill system. (Lucon, 2013).**

3.3.4 Combined rotary and percussion drilling methods

The materials reviewed in preparing this section on water well drilling methods suggest that combining rotary and percussion drilling is the rule rather than an exception. As noted previously, the rotating action of pneumatic percussion methods, such as top hammer and DTH hammer tools, as well as the slight rotation of the heavy cutting bit with every stroke of a cable tool rig serve to (i) advance the cutting face to a fresh section of rock (indexing) and (ii) in the case of pneumatic percussion drilling, help to grind the rock fractured by the percussive action to facilitate its removal by the air, air-water, or air-water-foam drilling fluid. Where a top hammer or DTH hammer is being used to penetrate alluvium and colluvium composed of unconsolidated or uncemented sands, gravels, cobbles, and boulders, the dual rotary methods described previously prevent formation collapse by advancing casing fitted with a cutting shoe just behind the rotating drill string with a pneumatic hammer.

---

[14] Reprinted with permission from Lucon, Peter Andrew. "Resonance: the science behind the art of sonic drilling." Diss. Montana State University-Bozeman, College of Engineering, 2013. <https://scholarworks.montana.edu/xmlui/bitstream/handle/1/3483/LuconP0513.pdf?isAllowed=y&sequence=1> (October 19, 2020). Copyright 2013 Peter Andrew Lucon.

3.3.5 Summary of well drilling methods

Table 3-4 summarizes well drilling and cuttings removal methods and their use near INL and SRS. As discussed in Section 4.2, well drillers near INL and SRS can drill through reinforced concrete. Although some would move their drill rig if they could, it is not always possible.

3.4 Regulations for Drilling Water Wells

This section focuses on the definition of a "well driller" in the Idaho and South Carolina regulations.

3.4.1 Idaho rules

The Idaho Department of Water Resources (IDWR) has statutory authority for statewide administration of the rules for well construction and licensing of drillers. Rule 10 of the Idaho Well Construction Standards (IDAPA 37.03.09) defines a well driller as "Any person who operates drilling equipment, or who controls or supervises the construction of a well, and is licensed under Section 42-238, Idaho Code." Rule 20.01 of the Well Driller Licensing Rules (IDAPA 37.03.10) under Licensing Requirements states, "A well shall only be drilled by or under the responsible charge of a licensed driller except that a property owner, who is not licensed, can construct a well on his property for his own use without the aid of power-driven mechanical equipment."

3.4.2 South Carolina rules

South Carolina Code of Regulations, Chapter 61-71 (Regulation 61-71) establishes minimum standards for the construction, maintenance, and operation of individual residential and irrigation wells among others. Section D.1 of Regulation 61-71 specifies, "All wells shall be drilled, constructed, and abandoned by a South Carolina certified well driller per S.C. Code Section 40-23-10 et seq." Regulation 61-44 specifies permit requirements for individual residential wells and irrigation wells. Section B.9 of Regulation 61-44 defines a well driller as someone licensed with the South Carolina Department of Labor, Licensing, and Regulation (SCLLR) for constructing wells. However, this section also states, "This term shall include owners constructing or abandoning wells on their own property for their own personal use only, except that such owners are not required to be licensed by the Department of Labor, Licensing, and Regulation for constructing wells…."

3.5 Well Drilling Records

Staff compiled well drilling records for counties surrounding INL and SRS and the results of this work are described in the following two sections. The reason for compiling these records was to identify well drillers who are actively drilling wells near INL and SRS and to identify those having the most experience. The identified well drillers could then be surveyed to determine current well-drilling practices and to determine how a driller would respond after encountering unexpected material such as concrete and rebar.

3.5.1 Areas near INL

Well drilling information was compiled for the counties of Butte, Jefferson, Bingham, and Bonneville. The 10 companies listed in Table 3-5 drilled 99 percent of the domestic-single

Table 3-4. Summary of well drilling methods and use in areas near INL and SRS

Drilling Method	Drilling Method Applied	Typically Applied to	Able to Drill through Reinforced Concrete	Level of Effort/Difficulty
Sonic with coring	Neither area	Core samples	Yes	Minimal.
Air, air-water, air-foam rotary with DTH Hammer	INL	Granite, Basalt, hard metamorphic rocks, such as quartizite	Yes	Damage to bit, loss of carbide buttons
Air, air-water rotary with drag and roller cone bits	INL	Limestone, Sandstone	Yes	Damage to bit and extra drilling time needed
Cable Tool Rig	INL	All Formations	Yes	Minimal
Mud Rotary with drag and roller cone bits	SRS	Clay, Sand, and Gravel	Yes	Time needed to obtain or build a coring bit

Table 3-5. Companies drilling the greatest number of domestic single-residence wells in four counties near INL (Starting from January 1, 2009)

Driller **Contact Information from:** **https://research.idwr.idaho.gov/apps/wellconstruction/licwelldrillers/**	Butte	Jefferson	Bingham	Bonneville	Total	Surveyed*
Jody Denning Well Drilling, Inc. Jody Duane Denning P.O. Box 460 Ucon, ID 83454 (208) 523-4600	3	432	100	206	741	No
Daniel Denning Drilling, Inc. Daniel Coey Denning P.O. Box 460 Ucon, ID. 83454 (208) 523-4600	1	153	150	95	399	Yes
Teton Water Works, LLC Kelly J. Bond P.O. Box 502 Shelley, ID 83274-0502 (208) 357-1850	4	114	137	52	307	Yes
High Plains Drilling, Inc. Marcus L. Frandsen P.O. Box 756 Rexburg, ID 83440 (208) 356-5582	2	258	18	11	289	Yes

Table 3-5. Companies drilling the greatest number of domestic single-residence wells in four counties near INL (Starting from January 1, 2009)

Driller **Contact Information from:** **https://research.idwr.idaho.gov/apps/wellconstruction/licwelldrillers/**	**Butte**	**Jefferson**	**Bingham**	**Bonneville**	**Total**	**Surveyed***
Independent Drilling Rodney J. Hendricks 692A W HWY 39 Blackfoot, ID 83221-5511 (208) 684-3788	10	11	181	9	211	Yes
Vollmer Well Drilling Kenneth L. Vollmer, Jr. 4068 North Haroldsen Idaho Falls, ID 83401 (208) 552-0236	2	15	56	16	89	No
H & H Well Service Doug Hendricks 3255 W 3000 N Moore, ID 83255 (208) 554-2702	51	0	0	0	51	No
Andrew Well Drilling Services, Inc. Roger P. Buchanan P.O. Box 3176 Idaho Falls, ID 83403 (208) 522-2794	0	17	3	22	42	Yes
Couch Well Drilling, Inc. Scott S. Couch 609 N 500 W Paul, ID 83347 (208) 532-4244	2	0	9	0	11	No
Barrus Drilling & Pump Guy L. Barrus P.O. Box 59 Basalt, ID 83218 (208) 346-6129	1	3	3	1	8	Yes

*Attempted to contact many of the drillers in this table. Some drillers were not surveyed because phone messages were not returned after more than one attempt.

residence wells in these counties. Well drilling records were obtained from IDWR on their Well Construction Search website (IDWR, 2018) on August 21, 2018. Well records go back to the 1940s. Therefore, the data was filtered to include wells constructed on or after January 1, 2009 to identify well drillers to survey who are more likely to be in business currently. The construction date of January 1, 2009 was arbitrarily chosen. On or after January 1, 2009, there were 2,167 domestic-single residence wells drilled with the 10 companies shown in Table 3-5 drilling 2,148 (99%) of them. The two-line entries for Jody Denning Well Drilling, Inc. and Daniel Denning Drilling, Inc. account for 1,140 wells or 53% of all domestic-single residence wells drilled in these four counties.

Figure 3-26 shows the distribution of domestic single-residence wells drilled within a 40 kilometer (km) [25-mile (mi)] region around INL. The data in this figure are from the same source as Table 3-5. It includes wells for the four counties around INL but is further limited to only include wells within 40 km [25 mi] of INL. The wells are categorized by drilling company. This figure shows that the well drillers listed in Table 3-5 were also the predominant drillers in the 40 km [25-mi] region around INL.

3.5.2 Areas near SRS

Obtaining well drilling records for the area around SRS was more difficult than finding them for INL. Well drilling records can be obtained from the South Carolina Department of Natural Resources (SCDNR) website (SCDNR, 2018). However, only 8 records were found from 2009, and records only go to 2014. Tables showing these records are included in Attachment 2. Also, because well drilling records were sparse from 2009 and afterwards on the SCDNR website (SCDNR, 2018), additional resources were evaluated. Attachment 2 contains data compiled from Appendix A of "Evaluation of Well Drilling Records in the Vicinity of SRS from CY2005 Through CY2009", SRR-CWDA-2010-00054 (SRR, 2010a). Twelve well drillers were identified; however, only three have active Class A licenses[15]. Section 40-23-320(A) of the South Carolina Code of Laws describes well-drilling classes as follows:

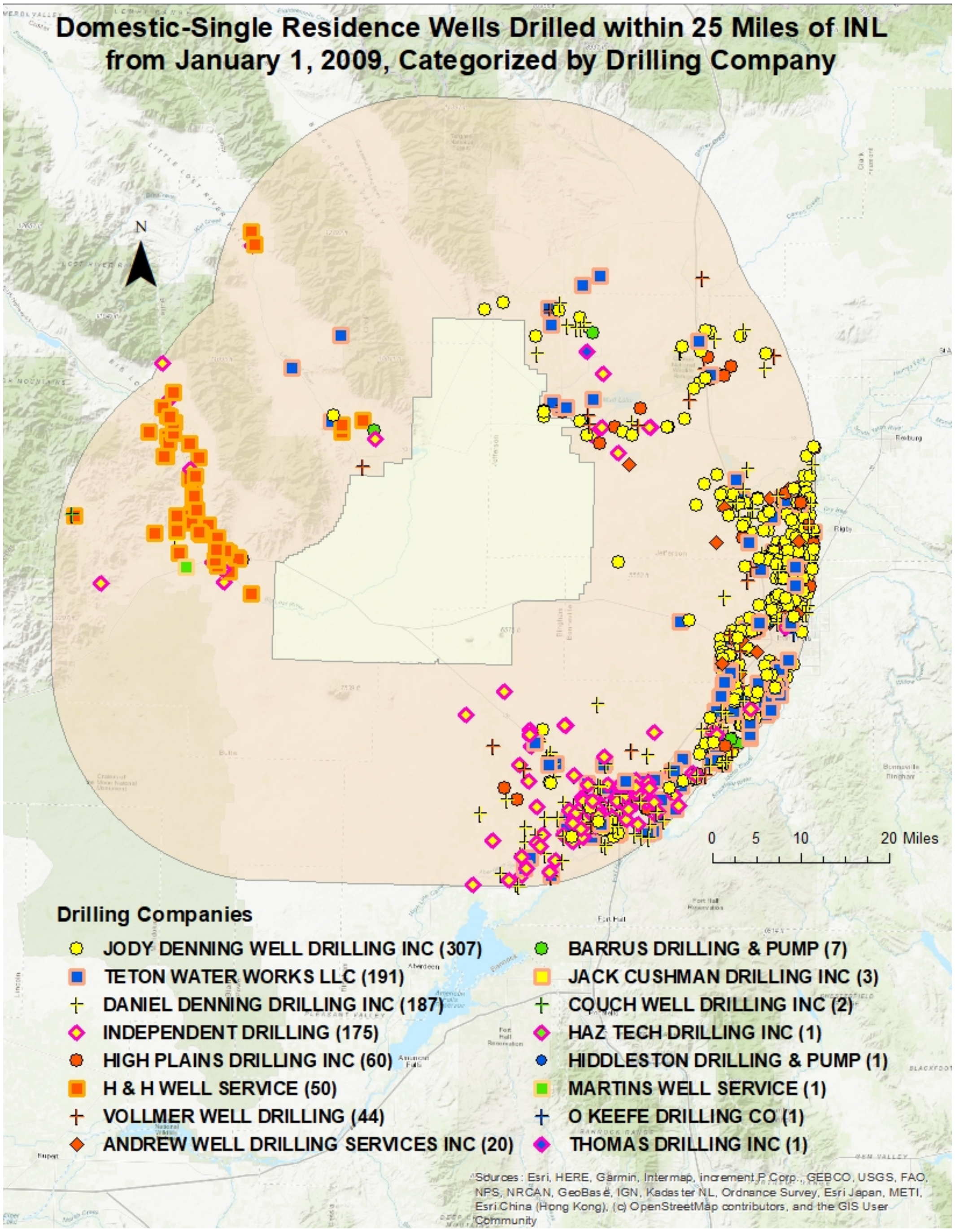
> Well drilling licenses must be issued in one of three well drilling categories-environmental wells, coastal wells, and rock wells-and in one of four classes-Class "D", Class "C", Class "B", and Class "A". However, a Class "A" licensee is authorized to practice in all three well drilling categories. No person may engage, or offer to engage, in the drilling of wells for which he does not possess a license of the proper well drilling category and class.

Because the previously discussed data sources produced limited results for surveying well drillers, additional review was conducted. The South Carolina Department of Health and Environmental Control, Bureau of Water provided their listing of well drillers who have drilled private wells in Aiken, Allendale, and Barnwell counties. The SRS is located within these three counties as shown in Figure 3-27 Twenty-three of these drillers have a Class A license with the South Carolina Department of Labor, Licensing & Regulation. These drillers are listed in Table 3-6 ordered alphabetically and grouped by the number of counties where they drilled private wells. Anthony Bouknight and James Hallman are listed in Table 3-6. Among other drillers, they were previously interviewed in Birk (2007) about local well-drilling practices in the vicinity of SRS.

A summary of these interviews is included in Appendix B of Birk (2007), who examined well-drilling records and interviewed five local drillers to understand current well-drilling practices. Birk (2007) concluded that a professional driller would likely drill into the Gordon Aquifer or deeper [i.e., at least 51.8-m (170-ft) deep]. Well drillers in the Aiken area expect to drill 73 to 91-m [240 to 300-ft] deep for a quality well. For residential wells, drillers look for a yield of 0.08 to 0.11 m^3/min [20 to 30 gallons per minute]. Also, a property owner may drill a shallow well for their own use, but Birk (2007) considers this probability reasonably small (about 0.13).

---

[15] For discussion on licenses see Section 40-23-320 of https://www.scstatehouse.gov/code/t40c023.php



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 3-26. Wells within a 40 km [25-mi] region surrounding INL categorized by drilling company also showing the number of wells drilled in parentheses

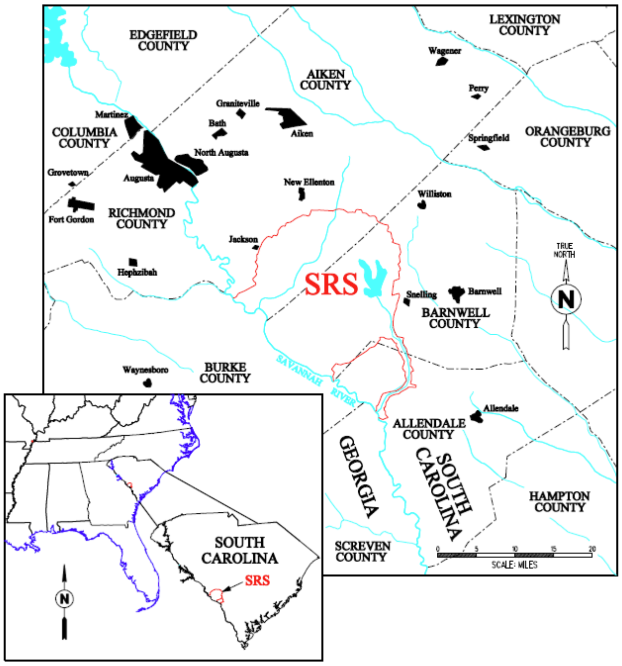


Figure 3-27. SRS showing its location in Aiken, Barnwell, and Allendale counties

Table 3-6. Class A Well Drillers from South Carolina Department of Health and Environmental Control, Bureau of Water and the counties in which they are active

Driller	Aiken	Allendale	Barnwell	Surveyed*
Bouknight, James A 1020 AC Bouknight Road, Gilbert, SC 29054 803-657-5848	Yes	Yes	Yes	No
Shumpert, Randall A Randy Shumperts Well Drilling 4605 Capital Way, Neeses, SC 29107 803-247-5991	Yes	Yes	Yes	Yes
Swearingen, Mike AAA Well Drilling 3071 Highway 6, Lexington, SC 29073 803-755-1203	Yes	Yes	Yes	Yes
Allen, Hagood J 1664 Carver Road, Bamberg, SC 29003 803-793-7727		Yes	Yes	Yes
Hallman, James Abes Drilling Services 105 Jasmine Lane, Windsor, SC 29856 803-649-5861	Yes		Yes	No
Martin Jr, John D 3457 Rum Gully Road, Islandton, SC 29929 843-866-2030		Yes	Yes	No

Table 3-6. Class A Well Drillers from South Carolina Department of Health and Environmental Control, Bureau of Water and the counties in which they are active

Driller	Aiken	Allendale	Barnwell	Surveyed*
Rivers, Carnell P.O. Box 293, Hampton, SC 29924 803-943-4904		Yes	Yes	Yes
Sowers, Buck L Dixie Well & Pump Service 119 Bristol Drive, Graniteville, SC 29829 706-829-3005	Yes		Yes	Yes
Still, Larry M 223 Hunt Club Road, Barnwell, SC 29812 803-259-1235		Yes	Yes	No
Waymyer, Wilbur Waymyer's Well Drilling 494 Todd Creek Road, Neeses, SC 29107 803-536-9557	Yes		Yes	No
Austin, Donald Shay Austin Drilling, Inc. 2584 Fish Hatchery Road, West Columbia, SC 29172 803-926-7080			Yes	No
Breland, Clyde Breland Well Drilling 1948 Browning Gate Road, Estill, SC 29918 803-625-3992		Yes		No
Beck, Duane Beck Well Drilling, Inc. 486 Croft Mill Road, Aiken, SC 29801 803-648-1989	Yes			Yes
Coleman, Herndon H Abes Drilling Services 105 Jasmine Lane, Windsor, SC 29856 803-649-5861	Yes			No
Colwell, Jerry Kevin Middle Georgia Water Systems, Inc. P.O. Box 949, Zebulon, GA 30295 770-567-3400	Yes			No
Heanue Sr, Geoffrey R Heanue Well Drilling, Inc. 104 Heanues Hollow, Prosperity, SC 29127 803-405-1290	Yes			No
Horry, Aaron P Horrys Water Well 255 Glover Road, Ridgeland, SC 29936 843-726-8560		Yes		No
Lane, Timothy J 6794 Bells Highway, Ruffin, SC 29475 843-538-3909		Yes		No

Table 3-6. Class A Well Drillers from South Carolina Department of Health and Environmental Control, Bureau of Water and the counties in which they are active

Driller	Aiken	Allendale	Barnwell	Surveyed*
Langford, Billy Billy Langford Well Drilling 610 Richland Creek Road, Ward, SC 29165 864-445-2889	Yes			No
Miller III, Wilbur C 3352 Pond Branch, Leesville, SC 29070 803-532-5014	Yes			No
Rodgers Jr, James E Rodgers Well Drilling P.O. Box 2358, Greenwood, SC 29646 864-223-5489	Yes			No
Starnes, Johnny R 7502 Wagener Road, Salley, SC 29137 803-564-5432	Yes			Yes
Swearingen, Bobby M 3071 Highway 6, Lexington, SC 29073 803-755-1203			Yes	No

*Attempted to contact many of the drillers in this table. Some drillers were not surveyed because phone messages were not returned after more than one attempt.

4 SURVEY RESULTS

Attachment 1 includes the scoping and survey questionnaire. Scoping questions were intended for organizations such as the National Ground Water Association (NGWA) or their state counterparts, the Idaho Department of Water Resources (IDWR), and the South Carolina Department of Health and Environmental Control (SCDHEC). The survey questions were for well drillers. Although survey participants are listed in Tables 3-5 and 3-6, comments are not attributed to specific participants.

4.1 Scoping Surveys

4.1.1 Areas near Idaho National Laboratory

Staff contacted the IDWR and the Idaho Ground Water Association (IGWA) and the conversations are summarized as follows:

1. Professional well-drilling companies who obtain a permit from the IDWR drill residential water wells. Property owners could drill their own shallow well {i.e., a well less than 5.5-m [18-ft]} deep because the IDWR does not regulate water well drilling until the well is at least 5.5-m [18-ft] deep. IGWA staff are aware that farmers may re-drill a well if they had their own equipment; however, this equipment may be 30 to 40 years old. In addition, if a new well were needed, then the farmer would hire a professional well driller.

2. Well drilling records over the past 20 years show that the air rotary method was used to drill 99% of the domestic water wells in the area around Idaho National Laboratory (INL). However, mud rotary and percussion drilling are used as well. In addition, “drill and drive” was mentioned. In this method, the casing is advanced while drilling.

3. With respect to reinforced concrete, well drillers may be able to drill through it; however, on encountering steel, IDWR staff would expect the driller to stop and investigate. Typically, if drillers encountered steel, they would contact a well inspector at the regional IDWR office.

4. There are some cases where a well driller will move the drill rig. If the driller encounters a geothermal area {water that is 29 °C [85 °F] or more}, they would need to notify IDWR, plug the well, and move the rig over. Drillers cannot comingle hot and cold water. Also, drillers would move the rig if they encountered uranium. In addition, a surface seal is required to 12.2 m [40 ft]. If a driller encounters boulders and cannot get the casing in the well, they would move the rig and drill again. Typically, they would move the rig 6.1 m [20 ft] or more.

5. Drillers typically review drill logs before going out to start drilling a new well. In addition, drillers would be prevented from drilling close to an area of known contamination or close to a hazardous site. Near such locations, drillers may be required to use special equipment to seal the well as it is drilled.

4.1.2 Areas near Savannah River Site

Staff contacted the South Carolina Ground Water Association (SCGWA) and the SCDHEC. The conversations are summarized as follows:

1. The SCDHEC has been developing a Western Capacity Use Area (WCUA) Groundwater Management Plan (GMP) (SCDHEC, 2019). The draft GMP was reviewed by SCGWA. The GMP evaluates current groundwater use and provides guidance for future groundwater management using information such as hydrologic and environmental data. The area of this study encompasses Aiken, Allendale, and Barnwell Counties.

2. The vast majority of well drillers near Savannah River Site (SRS) would move the drill rig if they hit something hard such as reinforced concrete. However, drillers would not always be able to move a drill rig, so sometimes drillers would try to drill through the hard material. They would not need to get another permit to move the rig a few feet.

3. Some drillers who have experience drilling through harder formations in the northern part of Aiken County and drillers who have experience drilling monitoring wells would have equipment (e.g., air rotary equipment) capable of drilling through reinforced concrete.

4. Some people drill their own wells and they are allowed to do so on their own property for their own use. They need to file a notice of intent with SCDHEC. SCDHEC expects very few (in the single percentages) wells are drilled by private landowners. Mostly, allowing property owners to drill their own wells applies to people living in coastal areas drilling shallow wells {6.1 to 9.1 m [20 to 30 ft]}. To drill deeper wells, you need knowledge and experience and most property owners would not have this knowledge and experience.

5. Some drillers may look at drill logs posted online before drilling if they’re not familiar with an area, but many will rely on their own experience instead of looking at logs online ahead of time. Drillers will try to understand the site ahead of time by talking to the construction contractor or property owner. They’ll look at the site plan to understand where they’re drilling in relation to setbacks. Also, on occasion a driller will call SCDHEC to try and understand what depth they need to drill a well. However, drillers typically stay in a particular area that they are familiar with. They avoid drilling in areas where they are unfamiliar because they can hit something unexpected, which would cause them additional time and cost.

6. Sonic drilling is used for coring mostly. It is a technology available primarily to larger companies from out of state.

4.2 Well-Driller Surveys

4.2.1 Areas near Idaho National Laboratory

Staff contacted water well drillers near INL. The conversations are summarized as follows:

1. As shown in Table 3-4, air rotary technology is used in regions containing basalt. Consistent with this, five out of the six drillers surveyed (or 83%) use air rotary technology. One of these five also uses cable rigs. For air rotary, drillers typically use an additive such as Baroid Quik-Foam. The additive keeps the dust down, lifts the cuttings, and provides lubrication. The drill crews do not typically wear masks for drilling residential water wells.

2. Two of the six drillers surveyed run cable rigs. One of them exclusively runs cable rigs; the other one runs both air rotary and cable rigs. Cable rigs drill at a slower pace than air rotary rigs, and one driller emphasized that by going slower, he can develop accurate logs of the underground. He can drill about 6.1 m [20 ft] per day on average in the area around INL.

3. For air rotary, one driller estimated he drills about 30.5 m [100 ft] per day in the area near INL. He said shallow wells are 152 m [500 ft] deep but typically wells are 183 to 213 m [600 to 700 ft] deep. Another driller said it takes him 5 to 6 days to drill a 244 m [800 ft] well. He recently completed one near INL that took 6 days and was 250 m [820 ft] deep.

4. Overburden is generally less than 15 m [50 ft] thick in the vicinity of INL. Overburden is drilled with a tricone bit and once basalt, lava, or rhyolite are encountered, the driller switches to down-the-hole (DTH) hammer.

5. Drillers use a tricone drill bit with carbide button teeth. Drilling through rebar damages the bit because it knocks the buttons off. Some drillers said they could drill through rebar, but the bit would have to be replaced afterwards.

6. Three out of the six drillers surveyed had experience drilling through reinforced concrete and steel:

    a. One driller had experience unexpectedly drilling through an old foundation and hitting one small piece of rebar.

    b. Another driller had experience drilling through steel well casing. When the casing shifted or a weld broke, he ended up drilling through 0.64-cm [0.25 in] thick casing {a total of 1.27 cm [0.5 in] of steel}.

    c. Another driller hit reinforced concrete when drilling near an old bridge. He could not move the rig and used a hammer to drill through two, 20-cm [8-in] layers

7. Someone could drill their own well if they met state regulations, and one driller knew of people who had shallow wells to water the yard. In addition, one driller said that someone could use an old cable tool rig (i.e., a “pounder rig”) and that it would push through reinforced concrete. He doubted that any private individual would have access to a modern drill rig because of the cost. One driller interviewed who used a cable rig stated that he could go through reinforced concrete.

8. Cuttings are left in the vicinity of the well near the drill rig. The landscaper will level out the property, including the cuttings, afterwards. Sometimes the cuttings are used on roadways. One driller who uses air rotary said that he will create a mound about 3-m [10-ft] square and 0.3 m [1 ft] high around the drill head. He typically drills residential wells at 1- to 5-acre sites, and the owner will move the cuttings afterwards.

9. Some drillers said they would move the drill rig if they hit something unexpected such as an old foundation or cistern. They would move the rig over 3 m [10 ft] or less. In addition, one driller mentioned that he may only have to move the rig a few inches to get past the rebar.

Drilling of Irrigation Wells

10. One driller who uses a cable rig to drill irrigation wells 152 to 183 m [500 to 600 ft] deep and 51 to 61 cm [20 to 24 in] in diameter will leave a mound of cuttings on the surface that is about 9 m [30 ft] across and 1 to 1.2 m [3 to 4 ft] deep at the highest point.

4.2.2 Areas near Savannah River Site

Staff contacted well drillers near SRS. The conversations are summarized as follows:

1. All seven well drillers surveyed in the vicinity of SRS use mud rotary; however, one driller also has access to air rotary rigs. He uses air rotary to drill wells in the northern portions of the state where he can hit granite. For mud rotary, drillers use a drag bit to start when drilling through clay and sand. They switch to a roller cone when drilling through harder formations such as limestone.

2. Four out of seven drillers surveyed mentioned losing circulation while drilling. One driller said there were times he needed to move the rig two to four times while drilling a well. He said most drillers would move the rig on loss of circulation. Loss of circulation occurs when the drilling fluid (or mud) flows into geologic formations such as voids instead of returning to the surface.

3. Drillers use a mud pan or mud pit. The mud pans are 1.2 m by 2.4 m [4 ft by 8 ft] to 1.5 m by 3.0 m [5 ft by 10 ft]. One driller said he uses a mud pan he designed that holds a few hundred gallons. They shovel the cuttings out of the mud pan to the area around the well head {6.1 to 7.6 m [20 to 25 ft] from the well head} as the well is being drilled. The property owner or landscape contractor will further spread the cuttings afterwards. One driller who digs a mud pit said the pit is 1.8 m by 2.4 m by 1.8 m deep [6 ft by 8 ft by 6 ft deep]. He may use the cuttings to backfill around the well. This driller would also leave the cuttings within an area of about 7.6 m [25 ft] from the well head.

4. Drillers do not typically use breathing protection unless they are mixing dry materials like Portland cement.

5. Four out of the seven well drillers surveyed have experience hitting hard materials such as reinforced concrete and steel.

    a. One driller built a special coring-type bit when he encountered reinforced concrete and could not move the rig.

    b. One driller has experience hitting old septic tanks. He said he would move the rig at least 7.6 to 9 m [25 to 30 ft] if he encountered an old septic tank.

    c. Another driller said that he hit concrete from an old building that was buried at the site. He would expect to move the rig 3 to 6.1 m [10 to 20 ft]) if he encountered buried concrete.

    d. Another driller hit an old building foundation and moved the rig 1.5 m [5 ft]. In addition, he said that once he hit a 1.9-cm [0.75-in] thick steel plate buried underground. He had nowhere to move the rig, so he drilled through it.

6. Some drillers would try to drill through reinforced concrete. To do so, they may change bits. One driller surveyed has access to an air rotary rig and could use a hammer and drill through the reinforced concrete. He also mentioned that he could use a polycrystalline diamond compact (PDC) bit.

7. One driller said if he hit something hard and had to move the rig, he would not charge the residential customer more. Other drillers would charge more, and some explained that they charge more to cover the extra cost of materials.

8. Some drillers said they drill a 20-cm [8-in] hole for a 10-cm [4-in] residential water well. One driller said he drills a 23 cm [9 in] hole for residential wells. They place casing all the way down with a well screen at the bottom. Near SRS, drillers would expect to drill 30.5 to 122 m [100 to 400 ft] deep.

9. Drillers would expect to be able to drill a residential water well in one day. Some drillers estimated it would take 4 to 6 hours to drill a 61 m [200 ft] well. Others said it would take 6 to 8 hours. One would expect to drill 61 to 91 m [200 to 300 ft] deep and take about a day (10 to 18 hours). The longer estimate may include setup and tear down time in addition to actual drilling time.

10. Drillers mentioned that property owners could drill their own well if they had the equipment to do so. One driller mentioned that he would expect such wells to be shallow. Another one mentioned that he has seen trailer-mounted mud rotary rigs for sale on eBay, so he thinks a property owner could have access to the equipment to drill their own well.

Drilling of Irrigation Wells

11. One driller was drilling a 41-cm [16-in] irrigation well while we were talking to him during the survey. He expected it to take him a month to drill the well.

5 SUMMARY

This section summarizes the information obtained from well driller surveys, with comparisons between drillers near Idaho National Laboratory (INL) and Savannah River Site (SRS).

In terms of drilling time and depth, drillers near INL would drill a well in 6 to 7 days to a depth of 183 to 244 m [600 to 800 ft]. Assuming 10-hour workdays, drillers near INL would be working near their rig approximately 60 to 70 hours. Near SRS, drillers would drill a well in one day to a depth of 30 to 91 m [100 to 300 ft]. Although time estimates differ significantly among the drillers near SRS, they would likely be in the vicinity of their drill rig for 6 to 8 hours and possibly for as long as 18 hours.

Well drillers near INL typically use air rotary, whereas drillers near SRS use mud rotary. None of the well drillers near INL or SRS wear breathing protection while drilling. Although air rotary has the potential to create more dust, drillers use an additive while drilling that keeps the dust down. One air rotary driller also said if dust is a problem, he can inject some water.

Drillers near both INL and SRS have experience drilling through reinforced concrete and steel. In both areas, a driller would stop drilling and try to understand what they hit by talking to the property owner, the contractor for the site, or a well inspector. Depending on how much room was available or the requirements for the well, some drillers said they would try to move the rig. Estimates for how much they would move the rig ranged from 1 to 1.2 m [3 to 4 ft] up to 9 m [30 ft]. Some drillers would try to drill through the reinforced concrete or steel, especially if they were restricted from moving the rig, and one driller mentioned that he may have to move the rig just a few inches to get past the rebar if he needed to drill through the reinforced concrete. In addition, one driller near INL who uses air rotary was able to use a hammer to drill through the reinforced concrete. A driller near SRS built a special coring-type bit to go through the concrete.

From reviewing the regulations near INL and SRS and surveying drillers and state agencies, a property owner could drill their own well for their own use in both areas. Near INL, any well drilled by a property owner would likely be shallow because Idaho Department of Water Resources (IDWR) does not regulate wells less than 5.5 m [18 ft] deep. One driller in the area near INL further clarified that if a property owner met state regulations, they could use an old cable tool rig (or “pounder rig”), which would push through reinforced concrete. However, he doubted that any private individual would have access to a modern rig capable of drilling through the consolidated material near INL because of the rig’s cost. South Carolina state regulations allow a property owner to drill a well on their own property for their own use. Furthermore, one driller in South Carolina said that mud rotary equipment would be available to a property owner. For example, he has seen trailer-mounted mud rotary rigs for sale on eBay.

In some cases, drillers would charge more if they hit something unexpected such as reinforced concrete, but this is not always the case. One driller near INL hit an old cistern but did not charge the customer more for his time or for damage to the rig. However, one driller near INL said that if he hit reinforced concrete and had to change to a coring bit, he would charge the customer more. Another driller near INL said he would charge the customer more if he started drilling and then needed to move the rig. In South Carolina, one driller said that if he damaged the bit while drilling, he would not charge the customer more. Note, however, in South Carolina a significant issue is losing circulation (drilling fluid (or mud) flows into geologic formations such as voids instead of returning to the surface.), and this sometimes requires the driller to move the rig. In addition, some drillers said they would charge the customer more for the extra drilling materials required after losing circulation.

6 COMPARISON TO PERFORMANCE ASSESSMENT ASSUMPTIONS

Tables 6-1 through 6-4 compare the U.S. Department of Energy (DOE) performance assessment (PA) assumptions and their relationship to the well driller responses in this study. The focus in this comparison is on the PAs for the tank farms, where high-level waste (HLW) was stored and residual waste may be present in the tanks. Highlighted text in Tables 6-1 through 6-4 indicate assumptions that differ from the well-drilling surveys. The results from the comparison are discussed in this section.

For both the Idaho National Laboratory (INL) and Savannah River Site (SRS) tank farm PAs, the inadvertent intruder is assumed to drill into an underground structure following an assumed 100-year institutional control period following tank farm closure. For INL, the intruder drills into a tank; for SRS, the intruder drills into a 7.6-cm [3-in] transfer line in the base case scenarios[1]. For SRS, credit is taken for a system of engineered barriers, which are assumed to preclude intrusion into the tanks until 500 years post-closure, at which time the PA evaluates an acute exposure involving intrusion into a cleaned, closed, and decommissioned HLW tank in a sensitivity analysis case. The potential to drill into an underground tank and vault system is supported by well-driller surveys at both INL and SRS. At both sites, drillers have experience drilling into reinforced concrete and steel. One driller near INL drilled through 0.64-cm [0.25-in] thick steel casing {a total of 1.3-cm [0.5-in] of steel}; a driller near SRS drilled through 1.9 cm [0.75 in] of steel plate buried underground. Some drillers would try to drill through the reinforced concrete and steel, and some have equipment that can do so. For example, some drillers have access to air rotary rigs equipped with a hammer. These rigs could drill through reinforced concrete. In addition, one driller near SRS was able to build a special coring-type bit to drill through reinforced concrete. For SRS, drillers typically use mud rotary and drill into soft material such as sand and clay. However, there are granite formations to the north of SRS and some of the larger companies have the equipment and experience to drill into the harder rock formations and would also have the capability to drill into a tank and vault system.

Well drillers near INL and SRS typically drill wells deeper than what is assumed in the PAs. The INL PA assumes a well is drilled to a depth of 122 m [400 ft]; however, drillers surveyed near INL would expect to drill a well 183 to 244 m [600 to 800 ft] deep. The SRS PA assumes wells are drilled to a depth of 30.5 m [100 ft]; however, well drillers surveyed near SRS would expect to drill a well 30 to 91 m [100 to 300 ft] deep. As described in SRR (2010a), wells are drilled deeper to the northwest in Aiken County, where domestic wells are drilled to a mean depth of 53.9 m [177 ft], and shallower to the southeast in Barnwell County, where domestic wells are drilled to a mean depth of 39 m [128 ft]. Therefore, the PA assumptions regarding depth of drilling appear to be conservative (i.e., drilling deeper would lead to dilution of contaminated drill cuttings in additional clean material). Nonetheless, it is expected that the evaluation would consider the scenario leading to the greatest dose, that is, assuming a well is drilled into the shallowest aquifer if that led to higher doses compared to a scenario where a driller completed a drinking water well in a deeper aquifer.

For the acute intruder drilling scenario, both INL and SRS PAs include direct exposure, inhalation of resuspended drill cuttings, and inadvertent soil ingestion pathways. None of the well drillers surveyed use breathing protection while drilling. In the INL PA, a 56-cm [22-in]

---

[1] For INL, DOE also evaluates a home construction scenario that involves intrusion into HLW transfer piping located within 3 m (10 ft) of ground surface.

irrigation well is drilled for the acute exposure scenario or a 15-cm [6-in] residential drinking water well for the chronic exposure scenario, whereas in the SRS PAs, a 20-cm [8-in] residential well is drilled. In PAs for both sites, direct exposure to drill cuttings accounts for most of the acute dose (INL: 86%, SRS H-Area Tank Farm (HTF): 95%). For INL, the PA assumes cuttings are spread over an area equal to about half an acre {2,200 m^2 [23,681 ft^2]}, resulting in a peak dose to the intruder of 2.32 mSv/yr [232 mrem/yr] for the conservative inventory case (or 1.52 mSv/yr [152 mrem/yr] for the inventory reported in the waste determination). However, from discussions with well drillers, drill cuttings remain in the vicinity of the well head during drilling and are spread out to some unknown area by the owner or landscape contractor after the driller leaves the site. The INL PA accounts for the possibility that cuttings remain closer to the driller in its sensitivity analysis, in which cuttings are placed in a 3-m by 3-m [10-ft by 10-ft] pit instead of being spread out. In this sensitivity analysis, the peak dose could be a factor of two to three higher for the pit scenario. The higher end of the range considers a bounding inventory case. Note that the actual use of a pit is not considered likely based on survey information, but cuttings are expected to remain in the vicinity of the driller during drilling operations.

Table 6-1. Assumptions at INL related to pathways and exposure and their relationship to well-drilling surveys

Highlighted text shows assumptions that differ from surveys.

	Description	Timing of Intrusion	Pathways	Well Drilling Technique	Distribution of Drill Cuttings	Key Radionuclides/Pathway Contributors
INL PA Assumption: Acute Intruder-Drilling Scenario {Page numbers from DOE (2003) unless otherwise indicated}	The intruder is located directly over a tank on the Tank Farm Facility (TFF) {p. 5-6} The intruder drills through the reinforced concrete vault, tank, and grout. In addition, the intruder drills directly through residual material in the tank and through the sandpad. {p. 5-4}	100 years post-closure Timing is not delayed due to the robustness of engineered barriers. {p. 5-5}	• Inhalation of resuspended drill cuttings • External exposure to the ground source • Inadvertent soil ingestion. {p. 5-5}	Irrigation Well: • Technique: Not stated • Diameter: 56 cm [22 in] Irrigation well for the acute exposure scenario {p. 5-5} • Depth: 122 m [400 ft] {p. 5-6} • Time: 160 hours (irrigation well) {p. 5-5}	Area: 2,200 m^2 [23,681 ft^2] {p. 5-4} Contaminated Zone Thickness: 1.4 cm [0.54 in] thick (on the surface). {p. 5-6, 5-40}	Maximum dose of 2.32 mSv/yr [232 mrem/yr] at 100 years {p, 5-27} Major radionuclide contributors: • ^{137}Cs/^{137m}Ba: 1.88 mSv/yr [188 mrem/yr] • ^{238}Pu: 0.15 mSv/yr [15 mrem/yr] • ^{90}Sr/^{90}Y: 0.0864 MSv/yr [8.64 mrem/yr] • ^{239}Pu: 0.053 mSv/yr [5.3 mrem/yr] • ^{241}Am: 0.051 mSv/yr [5.1 mrem/yr] • ^{240}Pu: 0.028 mSv/yr [2.8 mrem/yr] {p. 5-27} Pathway contributors: • External: ~2 mSv/yr [~200 mrem/yr] (86%) • Inhalation: ~0.3 mSv/yr [~30 mrem/yr] (13%) • Ingestion: ~0.04 mSv/yr [~4 mrem/yr] (1.7%) {p. 5-34}
INL PA Assumption: Chronic Intruder-Drilling Scenario {Page numbers from DOE (2003) unless otherwise indicated}	The intruder is located directly over a tank on the TFF {p. 5-6} The intruder drills through the reinforced concrete vault, tank, and grout. In addition, the intruder drills directly through residual material in the tank and through the sandpad. {p. 5-4, The chronic post-drilling scenario is an extension of the acute drilling scenario.}	100 years post-closure Timing is not delayed due to the robustness of engineered barriers. {p. 5-35}	• Inhalation of resuspended contaminated soil • Inhalation of gaseous radionuclides released from the waste • External radiation • Ingestion of contaminated soil • Ingestion of contaminated beef and milk • Ingestion of contaminated vegetables {p. 5-3, 5-38} Groundwater pathway is not considered in the inadvertent intruder analysis {p. 5-5; p. 91, (DOE 2006)}	Residential Well: • Technique: Not stated • Diameter: 15 cm [6 in] {p. 5-19} • Depth: Not stated	Area: 2,200 m^2 [23,681 ft^2] {p. 5-19} Thickness: 61 cm [24 in] thick (tilling depth) {p. 5-19}	Maximum dose of 0.911 mSv/yr [91.1 mrem/yr] at 100 years {p. 5-35} Major radionuclide contributors: • ^{90}Sr/^{90}Y: 0.515 mSv/yr [51.5 mrem/yr] • ^{137}Cs/^{137m}Ba: 0.365 mSv/yr [36.5 mrem/yr] {p. 5-35} Pathway Contributors: • Ingestion of vegetables: ~0.45 mSv/yr [~45 mrem/yr] (49%) • External: ~0.35 mSv/yr [~35 mrem/yr] (38%) • Ingestion of beef: ~0.065 mSv/yr [~6.5 mrem/yr] (7.1%) • Ingestion of milk: ~0.03 mSv/yr [~3 mrem/yr] (3.3%) • Inhalation: ~0.013 mSv/yr [~1.3 mrem/yr] (1.4%) • Ingestion of soil: ~0.00025 mSv/yr [~0.025 mrem/yr] (0.03%) {p. 5-38}
Idaho Well-Drilling Surveys	Some of the drillers surveyed have experience drilling into steel and reinforced concrete and have equipment capable of drilling through this material. Some would move the rig rather than try to drill through because the steel damages the bit and the drilling rate would be slow. One driller said that if he were to move the rig, he would shift it 1 to 1.2 m [3 to 4 ft]. One driller mentioned that drillers may hammer through the reinforced concrete using a down-the-hole hammer or that a diamond coring bit could be used. Also, one driller surveyed said that he would not charge the customer more if he ruined a bit hitting rebar.	One of the well drillers said that a property owner could drill their own well if they met state regulations. He said someone could use an old cable tool rig and that it would push through reinforced concrete. He doubted that any private individual would have access to a modern drill rig because of the cost.	None of the well drillers surveyed uses breathing protection while drilling; however, those drillers using air rotary include a foaming additive while drilling. The additive keeps the dust down, lifts the cuttings, and provides lubrication.	Technique: Drillers typically use air rotary; one driller surveyed uses a cable rig; no one surveyed uses mud rotary Residential Well: • Technique: air rotary • Diameter: 25 cm [10 in] for first 12 m [38 ft], then 20 cm [8 in] down to about 152 m [500 ft], then 15 cm [6 in] for the remainder • Depth: 183 to 244 m [600 to 800 ft] • Time: 6 to 7 days (60 to 70 hours assuming a 10-hour workday) Irrigation Well: • Technique: cable rig • Diameter: 51 to 61 cm [20 to 24 in] • Depth: 152 to 183 m [500 to 600 ft]. • Time: A month or more (approximately 160 to 200 hours assuming 8 to 10-hour workdays)	Drill cuttings remain in the vicinity of the well during drilling, but the actual spreading area is unknown. After the well is drilled, cuttings are spread out by the landscape contractor. One driller surveyed uses a cable rig and drills irrigation wells 51 to 61 cm [20 to 24 in] in diameter. He said that a 152-m [500-ft] well will generate a mound about 9 m [30 ft] across and 1 to 1.2 m [3 to 4 ft] deep at the highest point. One driller who uses air rotary said that he will create a mound about 3-meter [10-foot] square and 0.3 m [1 ft] high around the drill head. He typically drills residential wells at 4,047 to 20,234-m^2 [1 to 5-acre] sites.	N/A

References:

U.S. Department of Energy (DOE). (2006). “Basis for Section 3116 Determination for the Idaho Nuclear Technology and Engineering Center Tank Farm Facility.” DOE/NE-ID-11226, Revision 0.

DOE, Idaho Operations Office. (2003). “Performance Assessment for the Tank Farm Facility at the Idaho National Engineering and Environmental Laboratory.” DOE/ID-10966, Revision 1.

Table 6-2. Sensitivity/uncertainty analyses at INL and their relationship to well-drilling surveys

	Sensitivity or Uncertainty Analyses
INL PA Assumption: Acute Intruder-Drilling Scenario {Page numbers from DOE (2006) unless otherwise indicated}	Cuttings are placed in a 3-m by 3-m [10-ft by 10-ft] pit during drilling operations instead of being spread over the surface. The acute intruder dose reaches a maximum of 3.07 mSv/yr [307 mrem/yr] with the highest predicted sandpad inventory. {p. 92; p. RAI-16-2, CH2M (2006)}
INL PA Assumption: Chronic Intruder-Drilling Scenario {Page numbers from DOE (2006) unless otherwise indicated}	Varied the following parameters: • Well diameter: [25, 20, and 15 cm (10, 8, and 6 in)]: Dose increases by about a factor of three when increasing well diameter from 15 to 25 cm [6 to 10 in] • Contaminant spreading area [1,100; 1,600; and 2,200 m^2 (0.3, 0.4, and 0.5 acres)]: Dose increases by a factor of two when decreasing spreading area from 2,200 to 1,100 m^2 [0.5 to 0.3 acres]. • Tilling depth [30, 46, and 61 cm (12, 18, and 24 in)]: Dose increases by a factor of two when decreasing the tilling depth from 61 to 30 cm [24 to 12 in]. {p. 94; pp. RAI-16-3 to RAI-16-4, CH2M (2006)}
Idaho Well-Drilling Surveys	DOE's sensitivity analysis (DOE, 2006) refers to a "pit" but not specifically to a "mud pit." However, drillers that use a pit (or pan) typically drill wells using mud rotary. None of the drillers surveyed near INL use mud rotary, so a pan or pit would not typically be used in this area. However, from the surveys, cuttings are expected to remain in the vicinity of the driller during drilling operations, so a sensitivity analysis where cuttings remain within a 3-m by 3-m [10-ft by 10-ft] area is consistent with the surveys. One driller said that he would expect to drill a residential well at 4,047 to 20,234-m^2 [1 to 5-acres] sites. So, varying the spreading area over the range used in the sensitivity analysis is reasonable because the contaminant spreading area could account for up to half of the site area. The well diameters used in the sensitivity analysis correspond to the diameters for residential wells from the surveys. For a residential well, the diameters are: 25 cm [10 in] for the first 12 m [38 ft], then 20 cm [8 in] down to about 152 m [500 ft], then 15 cm [6 in] for the remainder.

References:

CH2M WG Idaho. "Response to Request for Additional Information on the Draft Section 3116 Determination Idaho Nuclear Technology and Engineering Center Tank Farm Facility." ICP/EXT-06-01204. 2006.
DOE. "Basis for Section 3116 Determination for the Idaho Nuclear Technology and Engineering Center Tank Farm Facility." DOE/NE-ID-11226, Revision 0. U.S. Department of Energy. 2006.

Table 6-3. Assumptions at SRS related to pathways and exposure and their relationship to well-drilling surveys

Highlighted text shows assumptions that differ from surveys.

	Description	Timing of Intrusion	Pathways	Well Drilling Technique	Distribution of Drill Cuttings	Key Radionuclides/Pathway Contributors
SRS PA Assumption: Acute Intruder-Drilling Scenario {Page numbers from SRR (2012) unless otherwise indicated}	The inadvertent intruder is located on the tank farm directly over a 7.6-cm [3-in] transfer line. The intruder drills a well into a 7.6 cm [3-in] transfer line, but not into the reinforced concrete vault, tank, and grout. The transfer line is penetrated during the installation of a drinking water well. {p. 343}	100 years post-closure Timing is not delayed due to the robustness of engineered barriers for the inadvertent intruder drilling into a 7.6 cm [3-in] transfer line. DOE assumed as a bounding case that a well driller could drill through an intact transfer line immediately after the end of institutional control. {p. 798} For the sensitivity analysis in which an inadvertent intruder drills into a waste tank, timing is delayed to 500 years post-closure. {p. 773}	• Inhalation of re-suspended drill cuttings • External exposure to the drill cuttings • Inadvertent ingestion of drill cuttings {p. 343}	• Technique: Not stated • Diameter: 20 cm [8 in] {p. 487} • Depth: 30.5 m [100 ft] {p. 487} • Time: 20 hours {p. 488} or • Pipe diameter 7.5 cm [3 in] Note that local well drillers expect to reach good drinking water aquifers at 46 to 61 m [150 to 200 ft] {p. 349}	Area: Not stated Depth: Not stated	HTF: The peak dose to the acute intruder in the 10,000-year performance period is 0.013 mSv/yr [1.3 mrem/yr] at 100 years Major Radionuclide Contributors: • ^{137}Cs/^{137m}Ba: 0.0119 mSv/yr [1.19 mrem/yr] (91.2%) • ^{90}Sr/^{90}Y: 0.000429 mSv/yr [0.0429 mrem/yr] (3.3%) • ^{238}Pu: 0.000429 mSv/yr [0.0429 mrem/yr] (3.3%) • ^{241}Am: 0.000078 mSv/yr [0.0078 mrem/yr] (0.6%) Pathway Contributors: • Drill cuttings direct exposure: 0.013 mSv/yr [1.3 mrem/yr] (95%) • Drill cuttings ingestion: 0.00022 mSv/yr [0.022 mrem/yr] (1.6%) • Drill cuttings inhalation: 0.00044 mSv/yr [0.044 mrem/yr] (3.3%) {p. 767} FTF: The peak dose to the acute intruder is 0.016 mSv/yr [1.6 mrem/yr] at 100 years {SRR, 2010, p. 784} primarily from Cs-137/Ba-137m from the direct exposure pathway.
SRS PA Assumption: Chronic Intruder-Agricultural (Post-Drilling Scenario) {Page numbers from SRR (2012) unless otherwise indicated}	The inadvertent intruder drills a well into a 7.6-cm [3-in] transfer line, but not into the reinforced concrete vault, tank, and grout. The transfer line is penetrated during the installation of a drinking water well. {p. 345, The chronic intruder-agriculture scenario is an extension of the acute intruder-drilling scenario.} PORFLOW was used for deterministic modeling for performance results and for single-parameter sensitivity analysis. {p. 39} In PORFLOW calculations, the concentrations used for the chronic intruder dose calculations are taken at a 1-m [3.3-ft] perimeter boundary that surrounds the whole HTF. {p. 454-455} GoldSim was used for probabilistic evaluation and supported uncertainty analyses and sensitivity analyses. {pp. 39-40} In the HTF GoldSim Model, the chronic intruder analysis is performed by choosing one of seven possible well locations adjacent to a tank {p. 454-455}	100 years post-closure Timing is not delayed due to robustness of engineered barriers. DOE assumed as a bounding case that a well driller could drill through an intact transfer line immediately after the end of institutional control. {p. 798}	The primary water source is a well drilled into the groundwater aquifers through a transfer line. Soil used for gardening is contaminated with both drill cuttings and irrigation well water. Livestock and poultry drink well water and eat fodder from a pasture irrigated with well water. The primary mechanism for transport of radionuclides is expected to be leaching to the groundwater, groundwater transport to the well/stream, and subsequent human consumption or exposure. {pp. 346, 352} The intruder exposure pathways from well water follow: • Direct ingestion • Ingestion and inhalation while showering • Ingestion of milk and meat from livestock • Ingestion of meat and eggs from poultry • Ingestion of vegetables grown in garden soil • Inhalation while irrigating • Inhalation of dust from the soil • Ingestion of soil • Direct radiation exposure from radionuclides on the soil {pp. 346, 450} Stream pathways involving recreational use and fish ingestion. The intruder may be exposed to volatile radionuclides from drill cuttings and contaminated well water. • Direct plume shine • Inhalation {p. 346}	• Technique: Not stated • Tank Diameter: 20 cm [8 in] {p. 487} • Depth: 30.5 m [100 ft] {p. 487}, or • Pipe diameter 7.5 cm [3 in] Note that local well drillers expect to reach good drinking water aquifers at 46 to 61 m [150 to 200 ft] {p. 349}	Area of garden: 100 m^2 [1,076 ft^2] {p. 487} Depth: 15 cm [5.9 in] (tilling depth) {p. 487} Fraction of time chronic intruder spends working in the garden: 0.01 (This is about 14 minutes per day.) {p. 488}	HTF: The peak dose at 100 years is approximately 0.4 mSv/yr [40 mrem/yr] and is from contaminated drill cuttings distributed across a garden primarily from Sr-90/Y-90. {p. 768 and 769} FTF: The peak dose at 100 years is 0.727 mSv/yr [72.7 mrem/yr] and is almost entirely from ingestion of vegetables contaminated with drill cuttings. (SRR, 2010, p. 787) The principle radionuclides by dose were Sr-90/Y-90 (56 percent) and Cs-137/Ba-137m (44 percent) for the vegetable ingestion pathway.
South Carolina Well-Drilling Surveys	One of the drillers that was surveyed said that he hit a ¾ inch steel plate buried underground. He had nowhere to move the rig, so he drilled through the plate. Many of the drillers surveyed have experience drilling into hard material such as reinforced concrete and steel, so drilling into a tank could have been the base-case analysis at 100 years after closure.	Some of the well drillers mentioned that a property owner could drill their own well for their own use. Trailer-mounted mud rotary rigs are available and can be purchased by a property owner.	Because the drillers are using mud rotary, they do not expect much dust to be generated and they do not wear breathing protection unless mixing material such as Portland cement.	All of the drillers surveyed use mud rotary to drill wells in the area around SRS although one of them has access to air rotary rigs as well. Residential Well: • Technique: mud rotary • Diameter: 20 cm [8 in] bore for a 10-cm [4-in] well with casing to the bottom {gravel-packed sand well with a perforated pipe at the bottom} • Depth: 30 to 91 m [100 to 300 ft] • Time: Drillers near SRS drill a well in one day. Although time estimates differ significantly among the drillers, they would likely be in the vicinity of their drill rig for at least 6 to 8 hours and possibly for as much as 18 hours.	During mud rotary drilling, the drill cuttings pile up in a mud pan or mud pit while drilling. The drillers shovel the cuttings out of the pan or pit to an area around the well. Some drillers said the mud pan is about 1.2 m by 2.4 m [4 ft by 8 ft]. One driller designed his own mud pan which holds 757 to 1,136 l [200 to 300 gal]. In addition, one driller surveyed uses a mud pit. He said the mud pit is about 1.8 m wide by 2.4 m long by 1.8 m deep [6 ft wide by 8 ft long by 6 ft deep]. When the cuttings are shoveled out of the pan or pit, they are deposited in an area that is within about 7.6 m [25 ft] of the well head.	N/A

References:

SRR, LLC "Performance Assessment for the H-Area Tank Farm at the Savannah River Site." SRR-CWDA-2010-00128, Revision 1. 2012.

Table 6-3. Assumptions at SRS related to pathways and exposure and their relationship to well-drilling surveys

Highlighted text shows assumptions that differ from surveys.

	Description	Timing of Intrusion	Pathways	Well Drilling Technique	Distribution of Drill Cuttings	Key Radionuclides/Pathway Contributors
SRR. “Performance Assessment for the F-Tank Farm at the Savannah River Site.” SRS-REG-2007-00002, Revision 1. 2010.						

Table 6-4. Sensitivity/uncertainty analyses at SRS and their relationship to well-drilling surveys

	Sensitivity or Uncertainty Analyses
SRS PA Assumption: Acute Intruder-Drilling Scenario {Page numbers from SRR (2012) unless otherwise indicated}	Intruder drills into a waste tank instead of a 7.6-cm [3-in] transfer line. Waste tank engineered barriers (e.g., closure cap erosion barrier, waste tank top concrete, and waste tank liner roof, etc.) are expected to prevent drilling directly into the waste tank inventory. Therefore, this scenario is not considered to occur until at least 500 years after closure. HTF: The acute IHI dose at 500 years from drilling through Tank 13 is 0.14 mSv/yr [14 mrem/yr], which is approximately 9 times higher than the 100-year dose associated with drilling into a 7.6-cm [3-in] diameter transfer line. {p. 773} The acute IHI dose from drilling into a 10-cm [4 in] transfer line 0.03 mSv/yr [3 mrem/yr] at 100 years. FTF: The acute IHI dose at 500 years from drilling through Tank 18 is approximately 0.071 mSv/yr [7.1 mrem/yr] which is more than 4 times higher than the 100-year dose associated with drilling into a 7.6-cm [3-in] transfer line. {SRR, 2010, p. 802}
SRS PA Assumption: Chronic Intruder-Agricultural (Post-Drilling Scenario) {Page numbers from SRR (2012) unless otherwise indicated}	HTF: Intruder drills into a waste tank instead of a 7.6-cm [3-in] transfer line. The chronic IHI dose at 500 years from drilling through Tank 13 is 1 mSv/yr [100 mrem/yr], or approximately 2 times higher than the 100-year dose associated with drilling into a 7.6-cm [3-in] diameter transfer line. {p. 773} 773 773773 The chronic IHI dose from drilling into a 10-cm [4-in] transfer line is 0.7 mSv/yr [70 mrem/yr] at 100 years. FTF: The chronic IHI dose at 100 years from drilling into a 10-cm [4-in] transfer line is 1.25 mSv/yr [125 mrem/yr].
South Carolina Well-Drilling Surveys	Many of the drillers surveyed have experience drilling into hard material such as reinforced concrete and steel, so the sensitivity analysis of drilling into a tank could have instead been the base-case analysis at 100 years after closure. Upon hitting reinforced concrete and steel, some drillers said they would stop and talk to the property owner or contractor to try and understand what they hit before continuing. Also, some would move the drill rig if there was room, but others would try and drill through the reinforced concrete and steel. One driller said that he had access to an air rotary rig, and he could use a hammer to drill through reinforced concrete. He also mentioned that he could use a polycrystalline diamond compact bit. Another driller said that he hit reinforced concrete in the past, and when this occurred, he used a special coring type bit to drill through the concrete because he could not move the rig. One driller said that he hit a ¾ inch steel plate buried underground. He had nowhere to move the rig, so he drilled through the plate.

References:
Savannah River Remediation (SRR), LLC (2012). “Performance Assessment for the H-Area Tank Farm at the Savannah River Site.” SRR-CWDA-2010-00128, Revision 1.
SRR (2010). “Performance Assessment for the F-Tank Farm at the Savannah River Site.” SRS-REG-2007-00002, Revision 1.

The distribution of drill cuttings for the acute intruder scenario is not discussed in the SRS PAs. In addition, the peak dose in the SRS PAs is significantly lower than for INL. For SRS, the peak dose at 100 years post-closure from drilling into a 7.6-cm [3-in] transfer line is only 0.013 mSv/yr [1.3 mrem/yr] at the HTF and 0.016 mSv/yr [1.6 mrem/yr] at the F-Area Tank Farm (FTF). In the SRS sensitivity analysis in which an intruder drills into a tank and vault system at 500 years, the acute intruder dose increases to only 0.14 mSv/yr [14 mrem/yr] at the HTF and to around 0.071 mSv/yr [7.1 mrem/yr] at the FTF (at 500 years). If intrusion were assumed to occur following a 100-year institutional control period, it is expected that the doses could be considerably higher from relatively short-lived radionuclides such as Cs-137 and Sr-90 (i.e., about a factor of 10 for every 100 years).

For the chronic intruder drilling scenario, both the INL and SRS PAs account for contaminated drill cuttings spread on the surface and tilled into the soil. In both cases, the chronic intruder is exposed to direct radiation exposure as well as inhalation and ingestion of contaminated soil, as well as ingestion of meat and milk products from animals foraging on the contaminated soil and from vegetables grown in the contaminated soil. Although the INL PA does not include the groundwater pathway, the peak dose at 100 years post-closure is more than twice that of the SRS HTF. For INL, the peak chronic dose at 100 years post-closure is 0.911 mSv/yr [91.1 mrem/yr] from a 15-cm [6-in] residential well. The INL PA found ingestion of vegetables as the greatest contributor (49%), followed by external exposure (38%). For the SRS HTF, the peak chronic dose at 100 years is only 0.4 mSv/yr [40 mrem/yr] and is from contaminated drill cuttings distributed across a garden from drilling into a 7.6-cm [3-in] transfer line. For the SRS FTF, the dose reaches a peak value of 0.727 mSv/yr [72.7 mrem/yr] at 100 years and is almost entirely from ingestion of vegetables from a garden contaminated with drill cuttings . The garden is only 100 m^2 [1,076 ft^2].

The INL PA evaluates the chronic intruder dose to a 1,000-year compliance period, for which the peak dose is 0.911 mSv/yr [91.1 mrem/yr] at 100 years (or 0.25 mSv/yr [25 mrem/yr] using the updated waste determination inventory). The SRS PAs evaluate the chronic intruder dose out to 20,000 years, although most of the dose at later times is associated with drinking water ingestion related to leaching of waste from the tanks and not necessarily from intrusion into the residual waste inventory from well drilling.

As stated before, the potential to drill into a tank and vault system is supported by the well-driller surveys at both INL and SRS. Near both sites, drillers have experience drilling into reinforced concrete and steel, and some drillers would try to drill through the material rather than move the rig. For the SRS sensitivity analysis in which an intruder drills through a tank and vault system at 500 years, the chronic intruder dose increases significantly compared to drilling into a 7.6-cm [3-in] transfer line. For the SRS HTF, the chronic intruder dose increases to 1 mSv/yr [100 mrem/yr] (at 500 years), which is comparable to the chronic peak dose for INL at 100 years {0.911 mSv/yr [91.1 mrem/yr]}.

The area that drill cuttings are spread out and the tilling depth are part of the chronic intruder calculations, but these assumptions also differ significantly between the INL and SRS PAs. The tilling depth is 61 cm [24 in] at INL but only 15 cm [5.9 in] at SRS. The area that drill cuttings are spread out is 2,200 m^2 [23,681ft^2] at INL, which is about half an acre. One driller near INL will typically drill residential wells at 4,047 to 20,234-m^2 [1 to 5 acre] sites. So, a spreading area of 2,200 m^2 [23,681ft^2 or 0.5 acre] is reasonable because it could account for up to half of the site area. The amount that drill cuttings are spread out at SRS is not stated in the PAs; however, the SRS PAs define the garden area that is contaminated by drill cuttings as only

100 m^2 [1,076 ft^2], and for the direct exposure pathway, the chronic intruder spends only 1% of his or her time (about 14 minutes each day) working in the garden.

In its sensitivity analyses at INL, DOE showed that dose increases by a factor of two when spreading area drops by a factor of two {i.e., from 2,200 to 1,100 m^2 [0.5 to 0.3 acres]}. Dose also increases by a factor of two when tilling depth drops by a factor of two {from 61 to 30 cm [24 to 12 in]}. Note also, DOE showed that dose increases by a factor of about three when well diameter increases from 15 to 25 cm [6 to 10 in]. These well diameters are supported by the surveys. For a 15-cm [6-in] residential well, the well diameter is 25 cm [10 in] for the first 12 m [38 ft]; then 20 cm [8 in] down to about 152 m [500 ft]; then 15 cm [6 in] for the remainder.

7 REFERENCES

Ackerman, D.J., J.P. Rousseau, G.W. Rattry, and J.C. Fisher. "Steady-State and Transient Models of Groundwater Flow and Advective Transport, Eastern Snake River Plain Aquifer, Idaho National Laboratory and Vicinity, Idaho." U.S. Geological Survey Scientific Investigations Report 2020-5123. Reston, Virginia: U.S. Geological Survey. 2010.

Archway Engineering (UK) LTD. "Full-hole Drill Bits." http://www.archway-engineering.com/product-category/rotary/full_hole_drill_bits/. (accessed 12/8/2020).

Birk, M. "General Separations Area Well Drilling Probabilities." SRS-REG-2007-00029, Revision 0. Aiken, South Carolina: Washington Savannah River Company. 2007.

Clawson, K.L., R.M. Eckman, N.F. Hukari, J.D. Rich, and N.R. Ricks. "Climatography of the Idaho National Laboratory 3rd Edition." NOAA Technical Memorandum OAR ARL-259. Air Resources Laboratory. 2007. <https://niwc.noaa.inel.gov/climate/INL_Climate_3rdEdition.pdf> (Accessed July 2, 2020).

DOE. "FY 2014 Special Analysis for the Saltstone Disposal Facility at the Savannah River Site." SRR-CWDA-2014-00006, Rev. 2. ML14316A586. Aiken, South Carolina: Savannah River Remediation, LL. 2014. <https://www.nrc.gov/docs/ML1431/ML14316A586.pdf> (Accessed July 22, 2019).

_____. "Performance Assessment for the Tank Farm Facility at the Idaho National Engineering and Environmental Laboratory." DOE/ID-10966, Rev. 1. Idaho Fall, Idaho: U.S. Department of Energy, Idaho Operations Office. 2003.

Driscoll, F.G. "Groundwater and Wells." Second Edition. St. Paul: Minnesota: Johnson Filtration Systems, Inc. 1,089 pages. 1986.

Garabedian, S.P. "Application of a Parameter-Estimation Technique to Modeling the Regional Aquifer Underlying the Eastern Snake River Plain Idaho." U.S. Geological Survey Water-Supply Paper 2278. Alexandria, Virginia: U.S. Geological Survey. 1986.

Gray, K.E., F. Armstrong, and C. Gatlin. "Two-Dimensional Study of Rock Breakage in Drag-Bit Drilling at Atmospheric Pressure." *Journal of Petroleum Technology*. pp. 93–98. January 1962.

Harris, M.K., M. Millings, L. Bagwell, and G.C. Blount. "PS Savannah River National Laboratory Core Repository: Core Used in Real World Fluid and Chemical Transport Assessments." AAPG Datapages/Search and Discovery Article #90216 ©2015 AAPG Annual Convention and Exhibition, Denver, Colorado., May 31–June 3, 2015. <http://www.searchanddiscovery.com/abstracts/html/2015/90216ace/abstracts/2102690.html> (Accessed 7/21/2020).

Harris, M.K, G.P. Flach, A.D. Smits, and F.H. Syms. "Modeling Aquifer Heterogeneity at the Savannah River Site Using Cone Penetrometer Data (CPT) and Stochastic Upscaling Methods." In Carolina Geological Society 2000 Field Trip Guidebook: Savannah River Site: Environmental Remediation Systems in Unconsolidated Upper Coastal Plain Sediments-Stratigraphic and Structural Considerations. M.K. Harris and D.E. Wyatt, (eds). WSC-MS-2000-00606. Carolina Geological Society. 2000.

Holt Services Inc. “Cable Tool Drill Rigs.” 2020. <http://www.holtservicesinc.com/cable-tool-drill-rigs.htm> (December 8, 2020).

IDWR. “Well Construction Search.” Idaho Department of Water Resources. 2018. <https://idwr.idaho.gov/Apps/appsWell/WCInfoSearchExternal/> (October 24, 2018).

Lucon, Peter Andrew. “Resonance: the science behind the art of sonic drilling.” Diss. Montana State University-Bozeman, College of Engineering, 2013. <https://scholarworks.montana.edu/xmlui/bitstream/handle/1/3483/LuconP0513.pdf?isAllowed=y&sequence=1> (October 19, 2020)

Maurer, W.C. “Bit-Tooth Penetration Under Simulated Borehole Conditions.” *Petroleum Transactions*. pp. 1,433–1,442. December 1965.

NRC. “Technical Evaluation Report, For F-Area Tank Farm Facility, Savannah River Site, South Carolina.” ML112371715. Final Report. Washington, DC: U.S. Nuclear Regulatory Commission. 2011.

_____. “Technical Evaluation Report for the U.S. Department of Energy Idaho National Laboratory Site Draft Section 3116 Waste Determination for Idaho Nuclear Technology and Engineering Center Tank Farm Facility.” 2006.

Rampp Company. “Carbide Button Bits.” <http://www.ramppco.com/products-drilling-tools/product/16-carbide-button-bits.html> (December 9, 2020).

Rampp Company. “Bailers & Sand Pumps.” <http://www.ramppco.com/bailers-sand-pumps.html> (December 9, 2020).

Sandvik. “Top Hammer Drilling Tools.” < https://www.rocktechnology.sandvik/en/products/rock-tools/top-hammer-drilling-tools/> (December 9, 2020).

Sandvik. “Down-The-Hole Drilling Tools.” < https://www.rocktechnology.sandvik/en/products/rock-tools/down-the-hole-drilling-tools/> (December 9, 2020).

SCDHEC. “Groundwater Capacity Use Areas–Western South Carolina. Columbia, South Carolina: South Carolina Department of Health and Environmental Control. 2019. <https://www.scdhec.gov/environment/water-quality/groundwater-use-reporting/groundwater-management-planning/groundwater> (August 12, 2019).

SCDNR. “Coastal Plain Water Well Inventory.” South Carolina Department of Natural Resources. 2018. <http://www.dnr.sc.gov/water/hydro/WellRecords/locatewells/index.html> (Accessed date October 29, 2018).

SRR. “Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site.” Aiken, South Carolina: Savannah River Remediation. 2020.

_____. “SRR Fact Sheet: Radioactive Liquid Waste: Operational Closure of Tanks.” Aiken, South Carolina: Savannah River Remediation. 2019. <https://www.srs.gov/general/news/factsheets/srr_tank_closure.pdf> (Accessed July 16, 2019).

_____. “SRR Fact Sheet: Saltstone Disposal Unit 6.” Aiken, South Carolina: Savannah River Remediation. 2017. <https://www.srs.gov/general/news/factsheets/srr_saltstone_6.pdf> (Accessed July 16, 2019).

_____. “Performance Assessment for the H-Area Tank Farm at the Savannah River Site.” SRR-CWDA-2010-00128, Revision 1. Aiken, South Carolina: Savannah River Remediation. 2012.

_____. “Evaluation of Well Drilling Records in the Vicinity of SRS from CY2005 Through CY2009.” 2010a. Aiken, South Carolina: Savannah River Remediation. <https://www.nrc.gov/docs/ML1112/ML111230097.pdf> (October 31, 2018).

_____. “Performance Assessment for the F-Tank Farm at the Savannah River Site.” SRS-REG-2007-00002, Revision 1. Aiken, South Carolina: Savannah River Remediation. 2010b.

_____. “Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site.” SRR-CWDA-2009-0017, Revision 0. Aiken, South Carolina: Savannah River Remediation. 2009.

Sterrett, R.J. “Groundwater and Wells: Third Edition.” Bloomington, Minnesota: Johnson Screens, a Weatherford Company. 795 pages and companion DVD. 2007.

Tandanand, S. “Section 11.3 Principles of Drilling.” *Society of Mining Engineers Mining Handbook, Volume 1.* A.B. Cummins and I.A. Given, (eds). New York, New York: Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers. 1973.

Twining, B.V., R.C. Bartholomay, and M.K.V. Hodges. “Completion Summary for Borehole TAN-2312 mar Test Area North, Idaho National Laboratory, Idaho.” U.S. Geological Survey Scientific Investigations Report 2018-5118. Reston, Virginia: U.S. Geological Survey. 2018.

U.S. Army. “Multiservice Procedures for Well-Drilling Operations {NAVFAC P-1065; AFMAN 32-1072}. FM 5-484. 1994.

Wyatt, D.E., R.K. Aadland, and F.H. Syms. “Overview of the Savannah River Site Stratigraphy, Hydrostratigraphy, and Structure.” In Carolina Geological Society 2000 Field Trip Guidebook: Savannah River Site: Environmental Remediation Systems in Unconsolidated Upper Coastal Plain Sediments-Stratigraphic and Structural Considerations. M.K. Harris, and D.E. Wyatt, (eds). WSC-MS-2000-00606. Carolina Geological Society. 2000.

ATTACHMENT 1

SCOPING AND SURVEY QUESTIONS

ATTACHMENT 1—SCOPING AND SURVEY QUESTIONS

Background Information

As part of a contract for the U.S. Nuclear Regulatory Commission (NRC) to better understand current practices related to drilling of residential water wells, we are collecting information from drilling companies and residents located near the U.S. Department of Energy's (DOE's) Savannah River Site (SRS)/Idaho National Laboratory (INL). This collection of data is for informational purposes; however, analysis of the information may make a radioactive waste disposal facility safer for future generations. The NRC has no regulatory authority or requirements related to residential water-well drilling. However, collection of this information will help provide support for assumptions made when trying to calculate the potential risk to members of the public who may inadvertently intrude into a waste disposal facility after the DOE facilities close way out into the future after memory of the site is lost. NRC staff does not need to include the names of companies or individuals in the final report related to this survey.

The survey will take approximately one hour to complete.

Scoping Questions

To organizations such as the National Groundwater Association (NGWA) or their state counterparts, the Idaho Department of Water Resources (IDWR), or South Carolina Department of Health and Environmental Control (SCDHEC):

1. To your knowledge, what percentage of water wells are drilled by property owners instead of licensed drillers (in the counties around INL and SRS)?

2. If a property owner wanted to drill their own well for their own use, where would they obtain drilling equipment? For example, would they be able to rent drilling equipment?

3. What types of drilling technology is typically used to drill private wells in the vicinity of SRS (Aiken, Barnwell, and Allendale Counties) or INL (Butte, Jefferson, Bingham, and Bonneville Counties)?

4. How frequently does staff observe well drilling operations, and has staff observed drillers encountering material that is significantly more resistant than initially expected?

5. Does staff have knowledge about the ability of typical drilling technology to drill through materials such as reinforced concrete?

6. {To state agencies issuing permits such as IDWR or SCDHEC}: What is the process you follow prior to issuing a permit to drill a well and is the process different for licensed drillers versus property owners requesting a permit? Please describe any preparation work that you require drilling companies to do before drilling.

7. {To state agencies issuing permits such as IDWR or SCDHEC}: Is a drilling log required and subsequently recorded if the driller encounters a problem and has to later backfill the hole?

Initial Entry Questions

Initial entry questions might be sent to well drillers by email or made via phone call and could include the following:

1. Please describe any preparation work or steps you might take prior to drilling a well to pick the best location to drill or to avoid potentially problematic areas.

2. What are the drilling capabilities of your company? That is, is your company able to drill through a variety of soils and rocks for different purposes?

3. What types of drilling methods and drilling rigs do you have available (e.g., air rotary, mud rotary, downhole hammer drilling, sonic)?

4. Can your company drill through hard rock such as granite? What is the hardest material your company can drill through? Could your equipment drill through a one-inch thick steel cable or reinforced concrete?

5. How frequently have you encountered material that is significantly more resistant than what you expected to find prior to drilling the well?

6. Would you be interested in participating in a survey that will help provide support to the NRC for assumptions made when trying to calculate the potential risk to members of the public who may inadvertently intrude into a waste disposal facility after the DOE facilities close way out into the future after memory of the site is lost?

7. When is a good time to contact you?

8. Would you prefer to see the questions in advance?

9. Would you prefer to answer via e-mail (with a follow-up phone call to clarify responses) or discuss via phone directly?

Survey Questions

A. To the Drilling Company {Note: Initial Entry Questions asking if the driller encountered resistant material precede these questions.)

   1. If you did find material that is significantly more resistant than you initially expected, what approach would you take on encountering this more resistant material? For example, would you try to drill through the material, move the drill, or cease operations? If the resistant material were encountered close to the surface {i.e., less than 15.2 m [50 ft]} versus deeper, would your approach change?

      a. If you were to drill through the material, would you have the capability onsite to continue or would you need to obtain additional equipment first?

      b. If you were to move the drill, about how far over would you expect to move it?

2. If you encountered significantly more resistant material, would you discuss this finding with other drilling companies or organizations prior to continuing?

3. If you encountered significant resistance one or more times or encountered foreign material such as concrete or rebar, would you stop drilling and investigate?

4. Does your standard contract with the customer have provisions to account for extra drilling time due to unforeseen circumstances?

5. Do you believe the customer would spend additional money for extra drilling time if you encountered material that is significantly more resistant than what you initially expected?

6. Please describe drilling practices in the area such as use of cuttings ponds or if spread on the surface, the extent to which cuttings are distributed on the surface (i.e., depth and area).

7. What are the particle sizes for cuttings (especially for rock)?

8. What potential is there for the original distribution of drill cuttings to be redistributed (e.g., would a pile be spread out)?

9. Do you use any personal protective equipment (PPE) that might keep the dose down (used for nonradiological hazards but would help minimize the dose)?

10. Please describe drilling rates, or the time it would take to drill a well of a certain depth to the groundwater aquifer (informs calculations on potential exposure times of drillers to contaminated drill cuttings).

11. Please indicate the distance a driller might be from drill cuttings during drilling operations and after the material is brought to the surface.

12. Please indicate the range of typical well diameters for drinking water wells in the area.

13. Please indicate the approximate depth of drinking water wells typically drilled in the area.

ATTACHMENT 2

WELL DRILLING RECORDS NEAR SAVANNAH RIVER SITE

ATTACHMENT 2—WELL DRILLING RECORDS NEAR SAVANNAH RIVER SITE

Table A.2-1 shows the well drillers in Aiken, Allendale, and Barnwell counties from 2009 to 2014 obtained from the South Carolina Department of Natural Resources (SCDNR) website (SCDNR, 2018). The Savannah River Site (SRS) is located within these three counties. The dataset is incomplete because one driller was not specified, and this unspecified driller drilled the only well for domestic use. Five of the 8 wells were for irrigation. This additional well drilling data is shown in Table A.2-2.

Table A.2-1. Companies drilling wells in three counties near SRS (starting from 2009)

Driller	Aiken	Allendale	Barnwell	Total
Grosch	2	0	2	4
McCall Brothers	1	0	0	1
Breland	0	1	0	1
AAA Well Drilling	0	1	0	1
Unspecified	1	0	0	1

Table A.2-2. Well drilling records near SRS (starting from 2009)

Well ID	Use	Depth	Year	Driller	County
AIK-2716	Irrigation	520	2014	Grosch Irrigation	Aiken
AIK-2717	Irrigation	560	2014	Grosch Irrigation	Aiken
BRN-1011	Irrigation	517	2014	Grosch Irrigation	Barnwell
BRN-1012	Irrigation	520	2014	Grosch Irrigation	Barnwell
AIK-2713	Domestic	155	2011	Unspecified	Aiken
AIK-2720	Unused	115	2011	McCall Brothers, Inc.	Aiken
ALL-442	Irrigation	140	2010	Breland Well Drilling	Allendale
ALL-449	AC {Unknown Code}	162	2009	AAA Well Drilling, Inc.	Allendale

Because well drilling records were sparse from 2009 and afterwards on the SCDNR website (SCDNR, 2018), additional resources were evaluated. Table A.2-3 shows data compiled from Appendix A of “Evaluation of Well Drilling Records in the Vicinity of SRS from CY2005 Through CY2009”, SRR-CWDA-2010-00054 (SRR, 2010). Because well drilling records are being examined from 2009 onwards, 2009 and 2010 data from SRR (2010) were extracted for Aiken and Barnwell Counties and summarized in Table A.2-3. There were 320 domestic wells drilled during this period with the 11 drillers shown in the table accounting for more than 80% of them. However, a search of well-driller licenses on October 31, 2018 revealed that the licenses have lapsed for about half of the drillers shown in the table. Currently, three drillers have active, Class A licenses, and these three account for 36 percent of the wells drilled. Although not shown in the table, the data showed that 50 percent of all the drillers that drilled domestic wells during the period from 2009 to 2010 only drilled a single well. This is likely due to a change in the well permitting procedures. Currently, the owner is listed on the permit instead of the well driller, even if a licensed driller is used to drill the well.

Table A.2-3. Companies drilling the greatest number of domestic wells in Aiken and Barnwell counties near SRS (From 2009 to 2010)

Driller	Aiken	Barnwell	Total	Status[*†]
James Hallman Abes Drilling Services 105 Jasmine Lane Windsor, SC 29856 (803) 649-5861	55	1	56	Active, Class A
Larry M Still Larry M Still Well Drilling 12217 US Highway 278 Barnwell, SC 29812 (803) 259-1235	5	28	33	Active, Class A
Anthony Bouknight Bouknight Well Drilling 1020 AC Bouknight Road Gilbert, SC 29054 (803) 657-5848	26	1	27	Active, Class A
Louie Duane Beck License is lapsed	25	0	25	Lapsed, Class A {Coastal, Rock}
Scott E Kaigler	6	15	21	Active, Class B {Coastal}
Donald R Rivers License is lapsed	2	18	20	Lapsed, Class A
William Inabinet License is lapsed	18	1	19	Lapsed, Class B {Environmental, Coastal, Rock}
Junnie G Starnes License is lapsed	19	0	19	Lapsed, Class A
Russell Sharpe	15	0	15	Active, Class D
Greg Still License is lapsed	2	11	13	Lapsed, Class D
Edward E Clark License is lapsed	12	0	12	Lapsed, Class A

[*] Because well drilling records are from several years ago, staff also searched on the following website to determine whether or not the driller was still active: https://verify.llronline.com/LicLookup/(X(1)S(inrgaar3hhiblrtwj3jc2upb))/Environmental/Enviro.aspx?div=70&AspxAutoDetectCookieSupport=1

[†] See the following for a description of well-drilling certifications:
SECTION 40-23-320 of https://www.scstatehouse.gov/code/t40c023.php

REFERENCES

SCDNR. "Coastal Plain Water Well Inventory." 2018. South Carolina Department of Natural Resources. <http://www.dnr.sc.gov/water/hydro/WellRecords/locatewells/index.html> (Accessed date October 29, 2018).

SRR. “Evaluation of Well Drilling Records in the Vicinity of SRS from CY2005 Through CY2009.” 2010. Aiken, South Carolina: Savannah River Remediation. <https://www.nrc.gov/docs/ML1112/ML111230097.pdf> (October 31, 2018).