2008 Groundwater Monitoring Report Project Shoal Area, Corrective Action Unit 447

March 2009

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1.0 Introduction

This report presents the 2008 groundwater monitoring results collected by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) at the Project Shoal Area (PSA) Subsurface Corrective Action Unit (CAU) 447 located in Churchill County, Nevada. Responsibility for the environmental site restoration of the PSA was transferred from the DOE Office of Environmental Management to LM on October 1, 2006. The environmental restoration process and corrective action strategy for CAU 447 are conducted in accordance with the Federal Facility Agreement and Consent Order (FFACO 1996, as amended February 2008) entered into by DOE, the U.S. Department of Defense, and the State of Nevada. The corrective action strategy for the site includes proof of concept monitoring in support of site closure.

This report summarizes investigation activities associated with CAU 447 that were conducted at the site during 2008. This is the second groundwater monitoring report prepared by LM for the PSA.

2.0 Site Location and Background

The PSA is located south of U.S. Highway 50, approximately 30 miles southeast of Fallon, in Churchill County, Nevada (Figure 1). The Project Shoal underground nuclear test was performed on October 26, 1963, as part of the Vela-Uniform program sponsored jointly by the U.S. Department of Defense and the U.S. Atomic Energy Commission. The test consisted of detonating a 12-kiloton nuclear device in granitic rock at a depth of approximately 1,211 feet (ft) below ground surface (bgs) (AEC 1964). A cavity created by the test collapsed shortly after the detonation and formed a rubble chimney (Pohll et al. 1998). The radius of the cavity is reported to be 85 ft (26 meters) (Hazelton-Nuclear Science Corporation 1965).

Site deactivation and post-shot drilling activities began on October 28, 1963. Re-entry drilling indicated that the Shoal test created a rubble chimney that was approximately 171 ft in diameter and extended approximately 356 ft above the shot point (Hazelton-Nuclear Science Corporation 1965). The decontamination and restoration activities were minimal, because no large areas of contamination were found during or following the test. A radioactive materials survey was conducted at the site in 1970. The survey results indicated there were no radiological levels that exceeded background levels for the area. During this effort the emplacement shaft was covered with a concrete slab and the Particle Motion (PM), Exploratory Core Holes (ECH), and U.S. Bureau of Mines (USBM) boreholes on the site were plugged and abandoned (AEC 1970).

Surface and subsurface CAUs were identified at PSA and are addressed through separate investigation and evaluation processes. Remediation of surface CAU 416 was completed in 1998 and is summarized in the *Closure Report for CAU No. 416, Project Shoal Area* (DOE/NV 1998). The Nevada Division of Environmental Protection (NDEP) approved the Closure Report on February 13, 1998, stating that no post-closure monitoring is required and no land use restrictions apply at CAU 416 (NDEP 1998).

The corrective action process for subsurface CAU 447 has not been completed. This CAU is currently within the 5-year proof-of-concept monitoring phase. Monitoring comprises part of the corrective action alternative that was selected for this CAU, as presented in the Corrective Action Decision Document/Corrective Action Plan (CADD/CAP; DOE/NNSA 2006). Because

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Figure 1. Location Map of the Project Shoal Area

there is no known technology to remediate the remaining subsurface radioactivity, a groundwater flow and transport model was developed to determine a contaminant boundary, which establishes a restricted region surrounding the nuclear detonation. The contaminant boundary (Figure 2) is determined by numeric simulation of radionuclide movement in the groundwater over a period of 1,000 years. The boundary represents a distance beyond which groundwater is considered safe for use throughout 1,000 years (i.e., dissolved radionuclide concentrations are at or below maximum contaminant levels [MCLs]). The groundwater flow and transport model was developed by Desert Research Institute. The recommendation for the selected corrective action alternative within the CADD/CAP was based largely on the results of the numerical model of groundwater flow and radionuclide transport. The FFACO establishes that numerical models be validated as part of the proof-of-concept monitoring.

Three wells (MV-1, MV-2, and MV-3) were installed in 2006 for the dual purpose of monitoring and validating the flow and transport model. Hydraulic heads observed in these wells did not match with heads predicted by the groundwater flow model, meaning the model could not be validated. As a result, a new corrective action strategy is being developed and will be negotiated with NDEP. The new corrective action strategy will include a new approach for calculating the contaminant boundary and will be presented to NDEP for approval.

3.0 Geologic and Hydrologic Setting

The PSA is located in the northern portion of the Sand Springs Range in west-central Nevada's Churchill County. The Sand Springs Range is the southern extension of the Stillwater Range, a north-northeast-trending fault block range that traverses Churchill County. The Sand Springs Range rises to an elevation of approximately 6,751 ft above mean sea level (amsl) and is flanked by Fourmile Flat to the west and Fairview Valley to the east (Figure 1). The Shoal Site is located in Gote Flat at an elevation of approximately 5,250 ft amsl and is within an area that is part of the Cretaceous-age Sand Springs granitic batholith.

The Sand Springs batholith is composed of granodiorite and granite, aplite and pegmatite dikes, andesite dikes, rhyolite dikes, and rhyolitic intrusive breccia. Internal deformation of the Sand Springs granite is largely by high-angle normal faults that strike northeast and northwest, joints that parallel the northwest-trending faults, and fracture cleavages that generally parallel the northeast-trending faults. These faults, joints, and fractures are distributed between two dominant structural trends that generally strike N 50° W and N 30° E and are vertical to steeply dipping. Several dikes of varying composition predominantly follow the same two orientations and intrude along these lines of preexisting weakness. These orthogonal-type sets of faults and fractures appeared early in the history of the Sand Springs granite and affected much of the subsequent structural and chemical evolution of this large intrusion (Beal et al. 1964).

Figure 2. Wells and Other Features at the Project Shoal Area.

The water table is present beneath the site at depths ranging from approximately 975 to 1,090 ft bgs. Groundwater moves primarily through fractures in the granite. Groundwater recharge occurs by infiltration of precipitation on the mountain range; regional discharge occurs in the valleys. A groundwater divide along the upland area of the range separates flow to the east and west, and a shear zone, located about 1,500 ft east of the site (Figure 2 and Figure 3), is also a barrier to flow due to its low hydraulic conductivity. Groundwater within Fairview Valley has been used for ranching, seasonal residential purposes, and military purposes within the last 5 years.

4.0 Monitoring Objectives

The monitoring network at the PSA consists of wells and piezometers in MV-1, MV-2, and MV-3, and the wells HC-1 and HC-4 (Figure 2). Monitoring at these locations includes the collection of hydraulic head data and groundwater samples for radioisotopic analyses as specified in the CADD/CAP (DOE/NNSA 2006). The general objectives of the monitoring are (1) “detection monitoring” to identify any releases of radiologic contamination from the test cavity and (2) “system monitoring” to obtain hydraulic head data for monitoring the overall stability (quasi-steady state) of the hydrogeologic system. Samples for radioisotopic analysis are collected annually during the proof-of-concept monitoring period. Well construction information and hydraulic head data obtained in 2008 are presented in Table 1.

Table 1. Well Construction Details and Head Data for Wells at the PSA

Well/Piezometer	TOC Elevation (ft amsl)	Water Depth (ft) ^a	Date	Elevation Water (ft amsl) ^b	Elevation TSZ (ft amsl)	Elevation BSZ (ft amsl)	Screen Length (ft)
MV-1	5,257.54	995.13	9/16/2008	4,262.41	3,684.81	3,531.00	153.81
MV-1 PZ	5,257.30	983.13	9/16/2008	4,274.17	3,919.80	3,859.80	60.00
MV-2	5,266.62	1,003.92	9/16/2008	4,262.70	3,446.75	3,275.98	170.77
MV-2 PZ ^c	5,266.51	NM	NM	NM	4,078.82	4,019.32	59.50
MV-3	5,261.50	981.99	9/16/2008	4,279.51	3,797.91	3,626.75	171.16
MV-3 PZ	5,261.17	979.45	9/16/2008	4,281.72	4,120.75	4,060.72	60.03
HC-1	5,309.21	1,066.10	9/16/2008	4,263.89	4,236.01	3,997.12	238.89
HC-2	5,347.12	1,088.48	9/16/2008	4,259.07	4,392.12	4,124.12	268.00
HC-3	5,081.52	1,179.97	9/16/2008	3,920.96	3,918.52	3,898.02	20.50
HC-4 ^c	5,260.90	1,013.72	12/04/2008	4,243.35	4,247.90	3,957.90	281.00
HC-5	5,247.37	1,367.55	9/16/2008	3,879.82	1,862.37	1,716.77	145.60
HC-6	5,228.68	972.60	9/16/2008	4,257.03	4,112.70	3,996.38	116.32
HC-7	5,229.72	972.95	9/16/2008	4,257.00	4,123.25	4,006.12	117.13
HC-8	5,259.91	1,370.47	9/16/2008	3,890.00	2,965.51	2,848.99	116.52

TOC = Top of casing (well/piezometer)

NM = Not measured

TSZ, BSZ (top and bottom of open interval; screened, perforated, or open hole)

^aDepth-to-water measurements not corrected for borehole deviation

^bCorrected for borehole deviation

^cIndicates that a transducer was not installed in the well/piezometer

Figure 3. Cross Section A-A' Depicting Monitor Well and Shear Zone Locations, Shoal, NV

4.1 Radioisotopic Monitoring

Groundwater samples are collected annually for radioisotopic analyses from wells MV-1, MV-2, MV-3, HC-1, and HC-4. Samples were collected from the designated wells on March 11, 2008. The LM Sampling and Analysis Plan (LM 2006) was used to provide quality assurance/quality control of the monitoring program at the PSA. Monitoring wells MV-1, MV-2, MV-3, and HC-4 were purged prior to sampling using dedicated submersible pumps. At least one well volume was removed, and field parameters (temperature, pH, and specific conductance) were allowed to stabilize before samples were collected. Samples were collected from well HC-1 using a depth-specific bailer. The final set of field parameters and well purge volumes are presented in Appendix A.

Groundwater samples are analyzed for tritium, carbon-14 (C-14), iodine-129 (I-129), uranium isotopes, gross alpha, and mass concentrations of uranium as specified in the CADD/CAP. Tritium is the analyte selected as an indicator of contaminant migration from the cavity due to its mobility and abundance in the first 100 years of the post-shot monitoring period. However, because of tritium's short half-life, monitoring of C-14 and I-129 is also conducted in support of long-term post-closure monitoring. Elevated gross alpha has been detected in many of the Shoal HC wells. The gross alpha MCL of 15 picocuries per liter (pCi/L) is exclusive of uranium and radon. Therefore gross alpha and uranium are also selected for analysis; radon volatilizes during sample collection and is an insignificant contributor to gross alpha.

The CADD/CAP (DOE/NNSA 2006) established regulatory levels for site groundwater of 20,000 pCi/L tritium, 2,000 pCi/L C-14, and 1 pCi/L I-129. These levels are not to be exceeded outside the compliance boundary, which is based on the modeled contaminant boundary (Figure 2). Modeling results indicate with a 95 percent certainty that groundwater will not pose a human health risk outside the contaminant boundary (Pohl and Pohlmann 2004). The compliance boundary is contained entirely within the land withdrawn by DOE. The MCLs for adjusted gross alpha and uranium are 15 pCi/L and 30 micrograms per liter ($\mu\text{g/L}$), respectively. These constituents are believed to be naturally elevated in groundwater in the region (see further discussion in Section 5.1).

4.2 Hydraulic Head Monitoring

Monitoring of the groundwater flow system is performed by measuring hydraulic heads in the MV wells/piezometers and HC wells located on the site (Figure 2). Heads were measured in the on-site wells on March 11, 2008, as part of the annual sampling and on September 16, 2008, as part of a scheduled monitoring event. Hydraulic head was also measured in well HC-4 on December 4, 2008, as part of the installation of a water access tube and transducer. Hydraulic head could not be measured from the MV-2 piezometer because of remnant drilling fluid materials in the piezometer tubing. It is unlikely that the MV-2 piezometer can be rehabilitated because the screened interval produces very little water, though an effort at redevelopment will be made in the spring of 2010.

5.0 Monitoring Results

Monitoring conducted at the PSA in 2008 consisted of annual sampling in March 2008, head monitoring in September 2008, and installation of a water access tube in well HC-4 in December 2008. As described in the CADD/CAP, the annual sampling and monitoring program requires the measurement of seven parameters—concentrations of tritium, C-14, I-129, uranium isotopes, and gross alpha; mass concentrations of uranium, and measurements of hydraulic head. Radioisotopic and concentration data are presented in Section 5.1, and head data are presented in Section 5.2.

5.1 Radioisotopic Results

Analytical results from the 2008 monitoring event indicate that tritium concentrations are below the detection limits at all wells based on results of samples analyzed by Paragon Analytics. However, a second sample from well HC-4 was sent to the EPA lab as part of the Long-Term Hydrologic Monitoring Program sampling and their results indicate a tritium level above the detection limit. In the past, tritium levels in well HC-4 have been trending lower and were below the detection limit for the 2005 and 2007 sampling events (Figure 4). Both of the 2008 values are plotted on Figure 4. The presence of tritium in HC-4 (nearest well to the detonation, Figure 2) is an indication of a nuclear-test-related signature. This is supported by the elevated level of C-14 in well HC-4 compared to levels in the other monitoring wells. However, all constituents in all wells are below established regulatory levels. Estimated activities of C-14 and I-129 are comparable to previous sampling results and continue to provide a baseline for long-term monitoring. Data used to calculate radioisotope activities for C-14 are provided in Appendix A.

DL =detection limit
ND = below detection limit

Figure 4. Time-Concentration Plot of Tritium at Well HC-4

Table 2 presents a summary of analytical results for C-14, I-129, tritium, uranium, and gross alpha from the sampling event in March 2008 along with the results from March 2007 for comparison. Uranium (U) mass concentrations detected in samples collected from wells MV-1 and MV-2 exceeded the MCL of 30 µg/L in 2007 but declined below that level in 2008. Unadjusted gross alpha activities shown in Table 2 are below the MCL of 15 pCi/L for the March 2008 sampling event; if these values are adjusted by subtracting activities of ^{234}U and ^{238}U shown in Table 3, values are even lower. The elevated concentrations of uranium observed in the past are believed to be naturally occurring. It has been demonstrated that ambient groundwater in the region surrounding the site is elevated in concentrations of gross alpha and uranium, among others (Bevans et al. 1998). Elevated uranium concentrations are attributed to leaching from granitic bedrock and associated sediments.

Isotopic ratios of uranium further support a natural source of uranium in groundwater as opposed to a nuclear-test-related source. Natural uranium-bearing systems typically have $^{234}\text{U}/^{238}\text{U}$ ratios with a value near 1 (Coward and Osmond 1977), which is indicative of secular equilibrium between the two isotopes. Table 3 indicates that ratios observed in the PSA samples range from 0.94 to 1.25—consistent with a natural uranium source. In contrast, average estimates of radionuclides resulting from nuclear tests at the Nevada Test Site suggest a residual source term with a $^{234}\text{U}/^{238}\text{U}$ ratio of approximately 56.25 (Smith 2001). Assuming the residual contamination associated with the PSA is similar to that estimated by Smith (2001), the $^{234}\text{U}/^{238}\text{U}$ ratio would be expected to be much higher than those observed if the uranium was derived from leaching of the test cavity.

Table 2. Radioisotopic and Chemical Sampling Results

Monitoring Location	Date	Carbon-14 ^a (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)	Uranium (µg/L)	Gross alpha (pCi/L, total unadjusted)
MV-1	3/21/2007	<RDL (5.83E-3)	<RDL (7.3E-11)	<359	42	25.6
	3/21/2007	NS	NS	NS	41 ^b	21.5 ^b
	3/11/2008	<RDL (2.49E-02)	<RDL (19.0E-11)	<320	21	14.0
MV-2	3/21/2007	<RDL (1.77E-02)	<RDL (8.3E-11)	<351	34	16.3
	3/21/2007	NS	NS	NS	34 ^b	17.3 ^b
	3/11/2008	<RDL (2.44E-02)	<RDL (29.5E-11)	<320	23	11.1
MV-3	3/21/2007	<RDL (5.90E-3)	<RDL (13.5E-11)	<357	14	10.2
	3/21/2007	NS	NS	NS	14 ^b	9.57 ^b
	3/11/2008	<RDL (1.37E-02)	<RDL (18.0E-11)	<320	3.8	2.11
HC-1	3/21/2007	<RDL (1.52E-02)	<RDL (9.6E-11)	<355	3.3	3.9
	3/21/2007	NS	NS	NS	3.4 ^b	4.46 ^b
	3/11/2008	<RDL (2.35E-02)	<RDL (4.9E-11)	<320	4.8	12.5
HC-4	3/21/2007	<RDL (0.565)	<RDL (32.4E-11)	<359	0.75	1.41
	3/21/2007	NS	NS	NS	0.85 ^b	1.93 ^b
	3/21/2007 ^c	<RDL (0.436)	<RDL (34.2E-11)	<359	0.69	1.75
	3/21/2007 ^c	NS	NS	NS	0.81 ^b	<0.876 ^b
	3/11/2008	<RDL (2.06)	<RDL (21.5E-11)	<310	4.5	2.88

^aEstimated based on sample volume of 200 milliliters

^bIndicates the sample was filtered

^cIndicates a duplicate sample

<RDL = below required detection limit with laboratory result in parentheses; RDL is 5 pCi/L for C-14, 0.1 pCi/L for I-129, 300 pCi/L for tritium, 50 µg/L for uranium, and 4 pCi/L for gross alpha (DOE/NNSA 2006)

NS = not sampled

Table 3. Uranium Isotopic Sampling Results

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	U^{234}/U^{238}
MV-1	3/21/2007	16.8 ^a	14.2 ^a	1.18 ^a
	3/21/2007	15.4	12.6	1.22
	3/11/2008	7.35	6.2	1.19
MV-2	3/21/2007	13.6 ^a	11.4 ^a	1.19 ^a
	3/21/2007	13.2	11.7	1.13
	3/11/2008	8.95	7.89	1.13
MV-3	3/21/2007	4.64 ^a	4.37 ^a	1.06 ^a
	3/21/2007	5.47	4.68	1.17
	3/11/2008	1.47	1.17	1.25
HC-1	3/21/2007	1.28 ^a	1.19 ^a	1.08 ^a
	3/21/2007	1.4	1.19	1.18
	3/11/2008	1.84	1.51	1.21
HC-4	3/21/2007	0.349 ^a	0.308 ^a	1.12 ^a
	3/21/2007 ^b	0.313 ^a	0.33 ^a	0.95 ^a
	3/21/2007	0.293	0.305	0.96
	3/21/2007 ^b	0.31	0.336	0.92
	3/11/2008	1.53	1.63	0.94

^aIndicates the sample was filtered

^bIndicates a duplicate sample

5.2 Hydraulic Head Results

Hydrographs of hydraulic head data from site wells and piezometers are shown in Figure 5 and Figure 6. Head data collected during site monitoring events appear as individual symbols, and data from transducers, installed in May 2007, appear as lines due to the sampling frequency of every few hours. A transducer was placed in the recently installed water access tube at well HC-4 to provide a more continuous record of water levels in that well. The transducer data allow seasonal variability and other effects, such as the recovery of water levels from yearly sampling events, to be identified and considered when calculating and interpreting hydraulic gradients at the site.

Hydrographs are grouped according to the location of each well's open interval relative to the north-northeast trending shear zone that transects the site. Monitoring points west of the shear zone include the MV-1, MV-2, and MV-3 wells and piezometers, and wells HC-1, HC-2, HC-4, HC-6, and HC-7 (Figure 5). Head levels east of the shear zone are monitored by wells HC-3, HC-5, and HC-8 (Figure 6). Head levels in wells west of the shear zone (detonation side) are generally 250 to 300 ft higher than those in wells east of the shear zone.

Figure 5. Hydrographs for Wells West of the Shear Zone

Figure 6. Hydrographs for Wells East of the Shear Zone

6.0 Summary

Monitoring results for 2008 indicate that concentrations of tritium, C-14, and I-129 remain below established regulatory levels for all PSA monitoring wells. Analytical results from well HC-4 have a nuclear-test-related signature for C-14; however, concentrations are below the established regulatory level of 2,000 pCi/L. Tritium concentrations in this well have decreased significantly since a high of 1,130 pCi/L was reported in 1998 (Pohll et al. 1998) and remain well below the tritium MCL of 20,000 pCi/L. Uranium in all wells was below the MCL in 2008; elevated concentrations observed in the past are attributed to natural sources. An evaluation of the stability of the hydrologic system will be made after data have been collected over a longer period of time.

7.0 References

- AEC (U.S. Atomic Energy Commission/Nevada Operations Office), 1964. *Project Manager's Report, Project Shoal*, NVO-11, Las Vegas, Nevada, May.
- AEC (U.S. Atomic Energy Commission/Nevada Operations Office), 1970. *Site Disposal Report Fallon Nuclear Test Site (Shoal) Churchill County, Nevada*, NVO-73, Las Vegas, Nevada.
- Beal, L.H., S.E. Jerome, I. Lutsey, R.H. Olson, and J.H. Schilling, 1964. "Geology of the Sand Springs Range," *Nevada Bureau of Mines and Geology, Final Report, Geological, Geophysical, Chemical and Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada, for Shoal Event, Project Shade, Vela Uniform Program*, United States Atomic Energy Commission.
- Bevans, H.E., M.S. Lico, and S.J. Lawrence, 1998. *Water quality in the Las Vegas Valley Area and the Carson and Truckee River Basins, Nevada and California, 1992–96*, Circular 1170, U.S. Geological Survey, U.S. Department of the Interior, Carson City, Nevada.
- Cowart, J.B., and J.K. Osmond, 1977. "Uranium Isotopes in Groundwater: Their Use in Prospecting for Sandstone-type Uranium Deposits," *Journal of Geochemical Exploration*, 8: 365–379.
- DOE/NNSA (U.S. Department of Energy, National Nuclear Security Administration), 2006. *Corrective Action Decision Document/Corrective Action Plan for Corrective Action Unit 447: Project Shoal Area, Subsurface, Nevada*, DOE/NV-1025, Rev. 3, Las Vegas, Nevada.
- DOE/NV (U.S. Department of Energy/Nevada Operations Office), 1998. *Closure Report for Corrective Action Unit 416: Project Shoal Area*, DOE/NV-11718-179-Rev. 0, Las Vegas, Nevada, January.
- Hazleton-Nuclear Science Corporation, 1965. *Vela Uniform Project Shoal Fallon, Nevada*, VUF-1014, Post-Shot Hydrologic Safety, October 30, 1965.

LM (U.S. Department of Energy Office of Legacy Management), 2006. *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites*, DOE-LM/GJ1197-2006.

NDEP (Nevada Division of Environmental Protection), 1998. Letter of Acceptance of Closure Report for CAU 416, Project Shoal Area Surface, Nevada Division of Environmental Protection, Las Vegas, Nevada, February 13, 1998.

Pohll, G, J. Chapman, A. Hassan, C. Papelis, R. Andricevic, and C. Shirley, 1998. *Evaluation of Groundwater Flow and Transport at the Shoal Underground Nuclear Test: An Interim Report*, Publication No. 45162, DOE/NV/11508-35, UC-703, July.

Pohll, G., and K. Pohlmann, 2004. *Contaminant Boundary at the Shoal Underground Nuclear Test*, Letter Report, DOE/NV-993, August 6.

Smith, D.K., 2001. *Unclassified Radiological Source Term for the Nevada Test Site Areas 19 and 20*, URCL-ID-141706. Lawrence Livermore National Laboratory, Livermore, California.

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Appendix A

Carbon-14 Calculation Data and Well Purge Data

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Table A-1. Monitor Well Purge Data

Well	Date Sampled	Purged Volume (gallons)	Temperature (°C)	pH (s.u.)	Specific Conductance (µmhos/cm)
MV-1	3/11/2008	770	21.6	8.04	764
			21.6	7.99	770
			21.7	7.87	773
			21.7	8.00	774
MV-2	3/11/2008	1,025	22.5	7.94	515
			22.4	8.01	520
			22.4	8.05	523
MV-3	3/11/2008	770	22.1	7.97	793
			22.1	8.02	796
			22.1	8.07	796
HC-1	3/11/2008	N/A	18.51	6.84	520
HC-4	3/12/2008	330	20.5	7.57	780
			20.8	7.66	768
			21.3	7.52	750
			21.4	7.52	775

s.u. = Standard Unit

µmhos/cm = micromhos per centimeter

Table A-2. Carbon-14 Radioisotope Calculation Data

Well ID	Sample Date	Mass C ^b (mg)	δ ¹³ C (‰)	C-14 (pmc)	Fraction mc	±1 s	µCi/mg C ^a	pCi/L ^b
MV-1	3/11/08	2.97	-8.5	27.34	0.2734	0.0021	1.68E-09	2.49E-02
MV-2	3/11/08	2.31	-12.2	34.36	0.3436	0.0024	2.11E-09	2.44E-02
MV-3	3/11/08	1.93	-11.5	23.12	0.2312	0.0022	1.42E-09	1.37E-02
HC-1	3/11/08	1.77	-10.5	43.43	0.4343	0.0028	2.66E-09	2.35E-02
HC-4	3/11/08	3.17	-6.3	2114.80	21.148	0.0880	1.30E-07	2.06+00

^aModern C-14 standard at 1950 AD has activity of 13.6 dpm/gram C = 2.27×10^{-4} dps/mg C.1 µCi = 3.7×10^4 dps; therefore, modern C-14 standard at 1950 AD has activity of 6.135×10^{-9} µCi/mg.^bAssumes 200 mL sample used to obtain mass of carbon.

pmc = percent modern carbon; mc = modern carbon; s = standard deviation

Example activity calculation (MV-1)

$$2.97 \frac{\text{mg C}}{0.2 \text{ L}} \left(0.2734 \frac{\text{mg MC}}{\text{mg C}} \right) \left(6.135 \times 10^{-9} \frac{\mu\text{Ci}}{\text{mg MC}} \right) \left(1 \times 10^6 \frac{\text{pCi}}{\mu\text{Ci}} \right) = 2.49 \times 10^{-2} \frac{\text{pCi}}{\text{L}}$$

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