Hanford Project DOE-RL Annual Report for FY 2004

S.M. Stoller Corporation
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Introduction

As the prime contractor for the U.S. Department of Energy (DOE) Grand Junction Site (GJS), the S.M. Stoller Corporation (Stoller) provides geophysical logging services and technical support for the Hanford Site. Geophysical logging in new and existing boreholes is used for stratigraphic correlation and to detect and quantify radioactive contaminants.

Log data, log plots, and reports are accessible via the Internet at:
http://www.gjo.doe.gov/programs/hanf/

Available Logging Equipment

Attachment 1 summarizes logging systems available during 2004. The borehole logging equipment currently in use for vadose zone characterization at the Hanford Site includes the spectral gamma logging system (SGLS), neutron moisture logging system (NMLS), and passive neutron logging system (PNLS). The SGLS uses a cryogenically cooled, high-purity germanium (HPGe) detector to detect, identify, and quantify gamma-emitting radionuclides in the subsurface. Identification of naturally occurring and man-made radionuclides is based on detection of characteristic gamma rays emitted during decay of specific radionuclides. The SGLS is calibrated by measuring detector response to gamma rays from potassium (^{40}K), thorium (^{232}Th), and uranium (^{238}U), resulting in a continuous detector response function over an energy range between 185 keV and 2.6 MeV. Minimum detection limits (MDLs) are provided for typical counting times and borehole environments. Corrections are available for dead time, well-casing thickness, and the presence of water in the borehole. A variation of the SGLS, known as the high rate logging system (HRLS), uses a much smaller detector than the SGLS and can collect log data in zones of very high gamma activity where the spectral gamma logging detector is saturated. When used in combination, the SGLS and HRLS provide a measurement capability from about 0.1 to 10^9 picocuries per gram (pCi/g) cesium-137 (^{137}Cs).

Spectral gamma and total gamma logs are used for stratigraphic correlation, as well as detection of man-made gamma-emitting radionuclides. Evaluation of high-resolution gamma energy spectra allows identification of radon accumulation in boreholes and differentiation between processed and naturally occurring uranium. Long-lived radionuclides identifiable by spectral gamma logging include cobalt-60 (^{60}Co), ^{137}Cs, europium (^{152}Eu and ^{154}Eu), and neptunium-237 (^{237}Np). Plutonium-239 (^{239}Pu) and americium-241 (^{241}Am) can also be detected, albeit at much higher concentrations because of the relatively low intensity of their characteristic gamma-ray emissions. Attachment 2 summarizes data for both man-made and natural radionuclides typically encountered in spectral gamma logging at Hanford. In some cases, it is possible to qualitatively detect beta-emitting radionuclides (i.e., strontium-90) by the bremsstrahlung generated from interaction of beta particles and the steel casing.

The NMLS uses a 50-mCi americium/beryllium source and helium-3 detector. Neutrons emitted from the source bombard the surrounding formation and are scattered back to the detector. In geologic media, the dominant scattering mechanism is interaction with hydrogen atoms; the count rate at the detector is a function of the amount of hydrogen in the formation, which is generally an indicator of the moisture content. Neutron moisture logs are useful as an indication of *in situ* moisture content and for stratigraphic correlation. The NMLS is calibrated for moisture content in 6-inch (in.) and 8-in.-diameter cased holes. For other borehole diameters, it can be used qualitatively to identify differences in moisture content. Neutron moisture logs are useful in correlation because fine-grained layers tend to have higher moisture content.

The passive neutron log displays the ambient neutron flux in the borehole. This log is a qualitative indicator of the presence of alpha-emitting radionuclides. Alpha particles emitted from decay of transuranic (TRU) elements such as ^{239}Pu or ^{241}Am interact with light elements in the soil (primarily oxygen), generating secondary neutrons by (alpha, n) reactions. These neutrons may penetrate the steel casing and be detected by the passive neutron log, or they may be slowed by interactions with the formation and eventually captured. Of the elements commonly present in soil, hydrogen is often the most likely to engage in detectable capture reactions. Hydrogen has a small capture cross section, but is usually relatively abundant even in unsaturated formations, and the capture gamma-ray yield is high. Following a neutron capture, hydrogen promptly emits a gamma ray at 2223.25 keV, with an intensity of 1 gamma per capture. These gamma rays are detectable with the SGLS and subject to relatively little interference. Thus, the presence of the hydrogen capture line in passive gamma spectra is a qualitative indication of the presence of both soil moisture and alpha-emitting radionuclides. During 2004, the hydrogen capture line was observed in several passive gamma spectra and has been added to the gamma energy library used for routine processing. Experience has also shown that the passive neutron log is a good qualitative indicator of the presence of transuranic elements in the subsurface.

During 2004, Stoller operated three trucks as platforms for characterization logging. These are designated as Gamma 1, Gamma 2, and Gamma 4. The logging equipment also includes a total of 11 sondes. Each combination of sonde and logging truck is defined as a separate logging system, and each system is calibrated as a unit. To avoid confusion, spectra files from each logging system follow a naming convention in which the first character designates the truck and the second character designates the sonde used to collect the data. For example, file names beginning with "DE" indicate spectra collected with the Gamma 4 logging truck, using the "E" sonde. Not all sondes are compatible with all systems. Each truck has two independent data collection pathways, meaning that two different types of detectors can be calibrated at the same time. On Gamma 1, one data pathway is used for the SGLS and the other is dedicated to the HRLS. Therefore, Gamma 1 cannot easily be used to run neutron moisture or passive neutron logs because there is no available data pathway, and NMLS and PNLS combinations are listed as unavailable. The HRLS requires a special high-activity verification source, which is not easily transferred between trucks. The HRLS (sonde C) is limited to use on Gamma 1, and this combination is listed as not available on Gamma 2 and Gamma 4. On Gamma 2 and Gamma 4, one data pathway is set up for SGLS and the other for neutron logging. Detectors cannot be "stacked"; each system requires a separate log run. Attachment 2 lists the log combinations used in 2004.

Summary of Accomplishments

Stoller provides borehole geophysical logging services for DOE-RL under three programs. The baseline characterization program refers to logging efforts carried out to establish a baseline data set of subsurface conditions in the vicinity of liquid waste disposal sites in the Hanford 200 Area. Remedial investigation support and groundwater well development represent logging performed at the request of Hanford contractors.

Baseline Characterization Program

The primary goal of the baseline characterization program is to collect initial SGLS data at waste sites in the Hanford 200 Area. These data are used to establish a baseline against which future log data is compared to assess contaminant mobility in the subsurface. The intent of the baseline characterization program is to log boreholes in a specific area, review and update historical log data, integrate the log results, and report the findings for that area. This approach is described in the *Hanford 200 Areas Spectral Gamma Vadose Zone Characterization Project, Baseline Characterization Plan* (DOE 2003). A prioritized list of areas to be investigated and available boreholes organized by waste site is maintained by Stoller. This list is subject to change, depending on demands for remedial investigation and groundwater development support and the need to collect log data in boreholes listed for decommissioning before the opportunity is lost.

During FY 2004, baseline characterization logging was performed at the 216-A-27 Crib, the B/C Cribs area, and in the vicinity of the 216-T-6 Crib. The B/C Cribs area is also the subject of remedial investigation activities, and the seven existing boreholes logged in this area could be considered under remedial investigation support.

For the most part, the baseline characterization effort has been superceded by logging for remedial investigation support. Priority for baseline logging operations is also subject to change as boreholes are identified for decommissioning. Boreholes selected for decommissioning are reviewed by Stoller, and those in or near known waste sites are prioritized and logged as part of the baseline program prior to decommissioning.

Remedial Investigation Support

In addition to baseline characterization, borehole geophysical logging also supports remedial investigations and feasibility studies for 200 Area Plateau operable units. Geophysical logging is performed in new and existing boreholes as requested by the responsible Hanford Site contractors. Log data plots and reports are provided to project representatives. During FY 2004, logging operations in support of remedial investigation activities were performed in 91 boreholes. High rate logging, neutron moisture logging, and passive neutron logging were also performed in selected boreholes in addition to spectral gamma logging. Areas in which logging was performed included the 216-A-4, -A-8 and -A-10 Cribs; B/C Cribs area; 216-S-7 and -S-20 Cribs; 216-T-28 Crib; and U Plant Area. In the U Plant Area, drive casings were driven specifically for geophysical logging to determine the maximum extent of lateral contaminant migration in the shallow vadose zone to support cover design. In all cases, logs are forwarded to the cognizant individuals for remedial investigation activities, and Stoller typically provides only limited technical support and data evaluation.

In addition to logging operations in the 200 Area and vicinity, three existing extraction wells in the 100-D Area *In Situ* Redox Manipulation (ISRM) project were logged to assess the ability of geophysical logs to detect subtle variations in stratigraphy, which may affect contaminant migration in the shallow aquifer.

Groundwater Well Development

Spectral gamma logs are run in newly drilled RCRA groundwater wells before well completion. In many cases, neutron moisture logs are also run. These logs provide a record of vadose zone conditions at the well location and help stratigraphic interpretation. During FY 2004, 14 groundwater wells were logged.

In some cases, groundwater wells are drilled with the Becker method. This is a reverse-circulation rotary percussion method with dual-wall casing. The combined casing thickness is 0.620 in., increasing to 1.115 in. at each joint. This results in a distinct reduction in count rates as the sonde passes through the casing joint. Correction of individual peak count rates would have to be done on a point-by-point basis. Since the Becker drill is only used in low-risk boreholes, the usefulness of this level of effort is doubtful, so boreholes drilled with the Becker rig are logged in total gamma mode with a logging speed of 1 ft/min. This provides a total gamma log sufficient for correlation purposes and maintains the capability to detect and identify significant quantities of man-made radionuclides. At the same time, the overall logging rate is significantly increased with an associated cost and schedule savings.

Passive Neutron Logging System

During 2004, Stoller received several requests to run the passive neutron log. The basic principle of this log and its application for detection of TRU contaminated soil is described by Bauer et al. (2000).

During 2004, the passive neutron log was run in one borehole in the 216-A-4 Crib, six boreholes at the 216-Z-7 Crib, and one borehole at the 216-Z-9 Crib. Results indicate that the passive neutron log can useful as a qualitative indicator of total TRU contamination. Although the ^{3}He detector in the passive neutron log is not considered particularly susceptible to interference from gamma activity, results from C4176 at the 216-A-4 Crib suggest that interference does occur in zones of intense gamma activity where ^{137}Cs levels exceed about 10^6 pCi/g. At present, the passive neutron log has been shown to be useful as a qualitative indicator of total TRU, and it may be possible to establish an empirical correlation between passive neutron log response and total TRU contamination. Ideally, the passive neutron log can be run to identify zones of TRU contamination, in which the spectral gamma log can be run with extended count times if necessary to identify and quantify specific radionuclides. Additional work is necessary to provide additional information on passive neutron log response. This includes:

- Model studies to estimate the relationship between total TRU concentration and detector response. It may be possible to establish a threshold count rate equivalent to 100 nCi/g total TRU.

- Exposure studies to quantify the effect of gamma activity on ^{3}He detector response.

Neutron Capture Logging System

During 2004, initial planning began for a demonstration of neutron capture logging. This technique is well developed in the oil industry, where neutron generator or AmBe isotopic source is used to irradiate the formation with high energy neutrons. Characteristic gamma rays associated with inelastic scattering and/or capture reactions in the surrounding formation can be used to identify and quantify elements of interest. Elemental yields can be used to calculate basic petrophysical parameters such as lithology, shale volume, pore fluid type, and saturation.

A basic premise of the neutron capture log is that high-energy neutrons (14 MeV) are moderated relatively quickly in the surrounding formation, such that scattering and capture reactions of interest occur within range of the detector. In a typical deep oil well, the formation is saturated with fresh water, salt water, or oil. These liquids contain a relatively high proportion of hydrogen, which is a very effective neutron moderator. In vadose zone applications, however, the presence of significant amounts of hydrogen is not assured and the intensity of conventional neutron capture reactions within range of the detector is greatly reduced.

Recent work by Dr. Carl Koizumi suggests that it may be possible to determine neutron capture efficiency in the formation, and to use this information to detect and quantify various elements from prompt capture gammas. These reactions depend on thermal neutrons: in unsaturated zones, intensity can be enhanced by utilizing sources that emit neutrons at lower energies. For this reason, californium-252 (^{252}Cf), which undergoes spontaneous fission and emits neutrons with an average energy of about 2 MeV is proposed as a neutron source. The neutron capture logging system utilizing a ^{252}Cf source has been successfully deployed at Idaho National Engineering and Environmental Laboratory (INEEL). It is anticipated that a similar system can be deployed at Hanford. Target elements of interest would include hydrogen, nitrogen, sodium, aluminum, silicon, chlorine, calcium, titanium, chromium, and manganese. Chlorine and nitrogen may be useful as indicators of contamination, and the other elements may be useful as lithologic or stratigraphic indicators.

Summary and Conclusions

As originally conceived, the Hanford baseline characterization project was to log available boreholes in and near liquid waste disposal sites in the vicinity of the Hanford 200 Area and integrate those log results with other data including pre-existing logs, geologic data, and process history to develop a baseline description of subsurface contamination conditions against which future measurements can be compared to assess long-term contaminant stability. Such a baseline was created for the Hanford Single-Shell Tank Farms between 1995 and 1999. This has proven useful in assessing the overall degree of subsurface contamination associated with the single-shell tanks.

The pace of the Hanford cleanup effort has increased in recent years, however, and it no longer practical for a comprehensive baseline characterization effort to be completed in a timely manner with existing logging resources. The existing geophysical logging effort must be integrated with three other semi-independent programs: 1) remedial investigation, 2) groundwater monitoring well development, and 3) the borehole decommissioning program.

During 2004, logging efforts were conducted primarily in support of ongoing remedial investigation activities by other Hanford contractors, and little progress was made against the baseline characterization effort, primarily as a result of resource constraints. Baseline characterization efforts will therefore be focused on a limited number of sites where current geophysical logging efforts and evaluation of previous log data can contribute to an improved understanding of subsurface conditions that will complement other investigative activities. Specific priorities for baseline characterization will be developed in consultation with personnel involved in ongoing remedial investigation activities.

Logging support to groundwater well development activities is an important component of the geophysical logging program. Although most groundwater monitoring wells are located in areas where significant vadose zone contamination is not anticipated, logs are still important for correlation purposes. When conventional drilling methods such as cable tool are used, every effort should be made to obtain high-quality spectral gamma logs by running the SGLS. Where other methods such as the Becker drill are used, casing configuration may significantly affect log quality and a total gamma log may be run.

The well decommissioning program also represents a controlling factor in the overall geophysical logging program. As boreholes are identified for decommissioning, the list should be reviewed and prioritized for logging purposes, so that log data can be obtained from boreholes in critical locations before the opportunity is lost. It is also likely that geophysical logging may be useful in support of decommissioning activities. For example, total gamma and or spectral gamma logs may be useful in detecting or confirming changes in casing configuration when well construction details are not available. In cases where there are radiological concerns, spectral gamma logging may be used to detect and quantify intervals of contamination.

Development and deployment of additional logging systems is an important topic that must be continually addressed. At present, the available logging systems are more than 10 years old and some thought must be given to their eventual replacement. Many of the components currently in use on the logging trucks are now obsolete. Advances in digital electronics and detector technology should be continually reviewed. Future spectral-gamma logging systems may incorporate downhole digital processing and detectors that do not require cryogenic cooling. This would result in a smaller and more compact logging system capable of operating in smaller diameter boreholes.

Development and deployment of new technology should also be pursued. For example, neutron capture logging has the potential to detect and quantify elemental components in the sediment matrix. This may be important in tracking non-radioactive contaminants (e.g., nitrate) and in differentiating Hanford stratigraphy.

With increasing emphasis on electronic data delivery and site-wide databases, it is becoming more important to provide log data in an electronic format. A consistent format for high-resolution spectral-gamma data and other log data should be established, and a mechanism should be established to allow data users to obtain processed log data. If possible, efforts should also begin to convert historical data into the electronic format.

To facilitate communication between the generators and users of geophysical log data, periodic meetings will be held to discuss issues related to geophysical logging on the Hanford Site. This will provide a forum to solicit input from data users and to discuss new technology.

References

Bauer, R, R. Randall, and R. Price, 2000. *Proof-of-Principle Demonstration of a Passive Neutron Tool for Detection of TRU-Contaminated Soil at the 216-Z-1A Tile Field*; BHI-01436, Bechtel Hanford Company, Richland, WA.

U.S. Department of Energy (DOE), 2003. *Hanford 200 Areas Spectral Gamma Vadose Zone Characterization Project, Baseline Characterization Plan,* GJO-HGLP 1.7.1, Revision 0, prepared by S.M. Stoller Corp. for the Grand Junction Office, Grand Junction, Colorado.

Attachment 1. Logging Capabilities

Logging System	Description	Capability
Spectral gamma logging system (SGLS)	LN cooled coaxial HPGe detector, 35% or 70% relative efficiency. 4" minimum borehole ID (4.5" for 70%). 4096 channel MCA. Generally run in move-stop-acquire (MSA) mode with count time of 200 sec RT (100 sec RT for 70%) and 1 ft depth increment.	Very good gamma energy resolution (approx. 2-4 keV FWHM). Efficiency calibration from 180 to 2800 keV. Detects and quantifies a wide range of radionuclides based on specific gamma energy lines. Measurement range 0.1 to 10^4 pCi/g ^{137}Cs.
High rate logging system (HRLS)	LN cooled planar HPGe detector, less than 1% relative efficiency. 4-in. minimum borehole ID. Internal and external tungsten shields available to extend measurement range. Generally run in MSA mode with count time of 300 sec RT and 1 ft depth increment.	Used when SGLS dead time exceeds 40%. Very low efficiency allows detector to function in areas of extremely high gamma flux, but sensitivity is very poor above 1500 keV. Measurement range is 10^3 to 10^9 pCi/g ^{137}Cs.
Gross gamma logging system	SGLS detector run in continuous mode at 1 ft/min with count time of 60 sec RT	Developed for use in Becker drill holes where variable casing thickness complicates data analysis and little or no manmade radioactivity is anticipated. Provides total gamma log suitable for stratigraphic correlation. Not suitable for determination of individual radionculide concentrations, but gamma energy spectra are obtained and can be evaluated if an anomaly is encountered.
Neutron moisture logging system (NMLS)	^{3}He detector with 50 mCi AmBe neutron source. Source-detector spacing is "close" (approx 3 in.) and sonde is centralized. 4-in. minimum borehole ID. Generally run in continuous mode with 1 ft/min logging speed and 15-sec count time.	Neutron count rate is proportional to volumetric moisture content. A good qualitative indicator of thin beds. Calibrations are available for 6- and 8-in. boreholes for 5 to 20% moisture, but tool response is strongly dependent on hole diameter. Generally limited to 10-in. ID or less.
Passive Neutron Logging System (PNLS)	^{3}He detector. 4-in. minimum borehole ID	Responds to neutrons generated from α, n reaction in soil matrix. A good qualitative indicator of TRU.
Neutron Capture Logging System (NCLS)	Irradiates formation with neutrons from a ^{252}Cf source and measures gamma energy spectra. Still experimental.	Detects and quantifies various elements based on capture gamma rays, activation, and/or inelastic scattering. Response depends on cross section of the target element and degree to which neutrons are moderated in the formation; this may be highly variable in unsaturated media. Potential targets include H, N, Na, Al, Si, Cl, K, Ca, Ti, Cr, Mn.
Radionuclide Assessment System (RAS)	Uses NaI detectors to collect gamma energy spectra with a 256 channel MCA. Results are reported as total counts in a series of 8 contiguous "windows." 4-in. minimum borehole ID. Intended for routine monitoring in Tank Farms.	NaI detectors are the most common detector for conventional spectral gamma logging They do not require LN cooling and have better sensitivity to gamma rays, but energy resolution is poor. Conventional spectral gamma logs are based on windows and calibration for three natural radionuclides (^{40}K, ^{232}Th and ^{238}U); may be able to detect ^{137}Cs and ^{60}Co, but not likely to detect others such as ^{154}Eu or ^{234}Pa (man-made uranium). Also subject to drift and magnetic effects in steel casing.
Retrieval Monitoring System (RMS)	Delivery anticipated in mid- to late February. Combination of NaI and GM detectors for wide range of total gamma. Includes neutron moisture log run simultaneously with total gamma. Portable system mounted on an ATV. Intended for tanks farms leak detection during retrieval operations.	Reports total gamma activity only, with no spectra. Measurement range to about 10^5 pCi/g ^{137}Cs. Neutron moisture detector similar to NMLS.

Attachment 2. Typical Radionuclides

Table 2A. Man-Made Gamma Emitting Radionculides

Radionuclide	Half Life (years)	Primary Gamma Rays		Secondary Gamma Rays		Typical MDL, pCi/g
		E, keV	Y	E, keV	Y	
^{60}Co	5.2714	**1332.50** **1173.24**	**0.9998** **0.9990**			0.15
^{106}Ru	1.0238	511.86	0.2040	621.93	0.0993	
^{125}Sb	2.7582	427.88	0.2960	600.60 635.95 463.37	0.1786 0.1131 0.1049	
^{126}Sn	1.E+05	414.50	0.86	666.10 694.80	0.86 0.8256	
^{134}Cs	2.062	604.70	0.9756	795.85	0.8544	
^{137}Cs	30.07	**661.66**	**0.851**			0.2
^{152}Eu	13.542	1408.01	0.2087	121.78 344.28 964.13 1112.12 778.90	0.2842 0.2658 0.1434 0.1354 0.1296	
^{154}Eu	8.593	**1274.44**	**0.3519**	123.07 723.31 1004.73 873.19	0.4079 0.2022 0.1801 0.1227	0.2
^{155}Eu	4.7611	105.31	0.2115			
^{235}U	7.04E+08	185.72	0.5720	205.31	0.0501	0.6
^{234m}Pa (^{238}U)	4.47E+09	**1001.03**	**0.0084**	766.36	0.0029	10-15
^{237}Np	2.14E+06	**312.17**	**0.386**	300.34 340.81 415.76	0.0662 0.0447 0.01745	1
^{239}Pu	24110	129.30 **375.05** 413.71	6.31E-5 **1.554E-5** 1.466E-5	203.55 345.01 332.85	5.69E-6 5.56E-6 4.94E-6	13000
^{241}Am	432.2	59.54 208.01 **662.40** **722.01**	0.359 7.91E-6 **3.64E-6** **1.96E-6**	102.98 335.37 368.05 376.65 322.52 332.35	1.95E-4 4.96E-6 2.17E-6 1.38E-6 1.52E-6 1.49E-6	50000
^{1}H	N/A	2223.3	1.0	Prompt capture gamma ray		

Table 2B. Naturally Occurring Radionuclides

	Primary Gamma Rays			Secondary Gamma Rays		
Radionuclide	Daughter	E, keV	Y	Daughter	E, keV	Y
^{40}K		**1460.83**	**0.1067**			
^{232}Th	**^{208}Tl** ^{212}Pb ^{208}Tl	**2614.53** 238.63 **583.19**	**0.3534** 0.433 **0.3011**	^{228}Ac ^{228}Ac ^{228}Ac ^{208}Tl	911.21 968.97 338.32 510.77	0.266 0.1617 0.1125 0.0806
^{238}U	^{214}Pb **^{214}Bi** **^{214}Bi**	351.92 **609.31** **1764.49**	0.358 **0.4479** **0.1536**	^{214}Pb ^{214}Bi ^{214}Pb ^{214}Bi ^{214}Bi ^{214}Bi	295.21 1120.29 241.98 1238.11 2204.21 2447.86	0.185 0.148 0.0750 0.0586 0.0486 0.0150

Attachment 3. Characterization Logging Sondes and Vehicles (2004)

Sonde	Type	Serial No	A Gamma 1 HO 68B-3574	B Gamma 2 HO 68B-3572	D Gamma 4 HO 68B-3573
A	SGLS (35%)	34TP20893A		**BA**	
B	SGLS (35%)	36TP21095A		**BB**	**DB**
C	HRLS	39A314	**AC**	**Not available**	**Not available**
D	SGLS (35%)	34TP11019B	**AD**		
E	SGLS (35%)	34TP40587A	**AE**	**BE**	**DE**
F	NMLS	H380932510	**Not available**	**BF**	**DF**
G	SGLS (35%)	34TP10967A	**AG**		
H	NMLS	H310700352	**Not available**		
J	NCLS	34TN1104A	**Not used at Hanford** (Deployed at INEEL in 2003)		
K	AZLS	32TP10832A			
L	PNLS	U1754	**Not available**	**BL**	