Hanford Geophysical Logging Project DOE-RL Annual Report for FY 2005

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.

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

Available Logging Equipment

Attachment 1 summarizes logging systems available during 2005. 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, thorium, and uranium, 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, and 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 measures 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. The hydrogen capture line 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 2005, Stoller operated three trucks as platforms for characterization logging. These are designated Gamma 1, Gamma 2, and Gamma 4. The logging equipment also includes a total of 13 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 two characters designate the truck and sonde used to collect the data. For example filenames 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 3 lists log combinations used in 2004.

Summary of Logging Progress

Stoller provides borehole geophysical logging services for DOE-RL under four general areas. These are 1) baseline characterization, 2) RI/FS support, 3) borehole decommissioning, and 4) groundwater well development. Baseline characterization refers to logging efforts carried out in existing boreholes to establish a baseline data set of subsurface conditions in the vicinity of liquid waste disposal sites in the Hanford 200 Area in accordance with the *Hanford 200 Areas Spectral Gamma Vadose Zone Characterization Project, Baseline Characterization Plan* (DOE 2002). RI/FS support refers to logging conducted in new and existing boreholes at the request of a specific site remediation project. Borehole decommissioning refers to logging performed in existing boreholes prior to final decommissioning. Groundwater well development represent logging performed prior to completion in new groundwater monitoring wells.

In fiscal year (FY) 2005, a total of 87 boreholes were logged for the four programs. Specific boreholes are listed in Attachment 4. Table 1 (below) lists the number of wells logged for each program.

Table 1. FY 2005 Well Logging Activities

Program	Number of Wells
Baseline characterization	12
RI/FS support	24
Borehole decommissioning	31
Groundwater well development	20
Total	87

The division between programs tends to be vague. For example, existing boreholes in or near waste sites in the Hanford 200 areas are listed as baseline characterization and would be logged sooner or later. Existing wells logged under RI/FS support also qualify as baseline characterization; the distinction is that the logging effort was prioritized to provide data in support of a specific investigation or remediation effort conducted by a Hanford site contractor. Nearly all boreholes slated for decommissioning are also listed in the baseline characterization program. In this case, the logging effort is prioritized to obtain data before the opportunity is lost.

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 *Baseline Characterization Plan*. 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 2005, baseline characterization logging was performed primarily in 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 boreholes logged in this area could be considered under remedial investigation support.

Borehole 299-W10-72 was logged as a part of the baseline effort. This borehole is located in the T-7 Tile Field near the southwest corner of T Tank Farm. It is intended to serve as a site for testing and comparison of other logging systems. This borehole was selected because it has relatively thick intervals with high ^{137}Cs concentrations (up to about 3.6 E+4 pCi/g), and it is representative of borehole conditions inside the tank farms. Logs were also collected with the retrieval monitoring system (RMS) in this borehole as part of its operational testing.

For the most part, the baseline characterization effort has been superseded by logging for borehole decommissioning and remedial investigation support.

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 2005, logging operations in support of remedial investigation activities were performed in 24 boreholes. In addition to spectral gamma logging, high rate logging, neutron moisture logging, and passive neutron logging were also performed in selected boreholes. In all cases, logs are forwarded to the cognizant individuals for remedial investigation activities, and Stoller typically provides limited technical support and data evaluation.

Decommissioning Boreholes

Fluor Hanford, Inc. (FH) is responsible for decommissioning boreholes that are no longer in use. These boreholes are viewed as real or potential pathways for contaminant migration; thus, the borehole decommissioning effort has become a high priority activity. There is no firm requirement for boreholes to be logged prior to decommissioning, but the decommissioning project recognizes the need for logs, particularly in planning decommissioning activities in contaminated boreholes. Lists of boreholes scheduled for decommissioning are regularly sent to various organizations, including Stoller, and opportunities are provided to “save” individual boreholes. Stoller’s approach has been to assess the holes on the list and assign a priority for logging based on proximity to existing waste sites, among other factors. Unfortunately, boreholes are being decommissioned at a much faster rate than they can be logged, and the opportunity to obtain data is lost. In August 2005, Stoller received a request to provide logs in 64 boreholes for various site investigation efforts. Of these, 28 had already been decommissioned and nine were on the next list of holes to be decommissioned. Only one of the 28 had been logged before decommissioning. This led Stoller to adopt the policy of making every effort to log all boreholes prior to decommissioning. Whenever possible, other work is delayed in favor of logging in boreholes scheduled for decommissioning. Unfortunately, there are still cases where boreholes are decommissioned before log data can be collected.

Groundwater Well Development

Spectral gamma logs are run in newly drilled RCRA groundwater wells prior to 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 2005, 20 groundwater wells were logged.

In most 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; therefore, 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.

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 in the Stoller Grand Junction Office 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 (H), nitrogen (N), sodium (Na), aluminum (Al), silicon (Si), chlorine (Cl), calcium (Ca), titanium (Ti), chromium (Cr), and manganese (Mn). Cl and N may be useful as indicators of contamination, and the other elements may be useful as lithologic or stratigraphic indicators.

During FY 2005, Dr Koizumi prepared a journal article "Neutron Capture Logging Calibration and Data Analysis for Environmental Contaminant Assessment". This article was submitted to the *Journal of Applied Geophysics* and is now in the peer review process.

The neutron capture log was identified as a potential tool to assess porosity/permeability variations in saturated sediments penetrated by wells associated with the in-situ redox manipulation (ISRM) project, and plans were made to demonstrate the system on these wells with additional demonstrations in wells thought to intersect nitrate plumes. At Hanford, elevated nitrate concentrations may be associated with elevated levels of technetium-99 (^{99}Tc). The ability to detect nitrate from inside cased boreholes would be very helpful, since ^{99}Tc is a significant contaminant of concern that does not emit any gamma rays.

In preparation for this work, Stoller procured a 10 microgram ^{252}Cf source, which was shipped to the Hanford site in July 2005. At the time, Stoller intended to take custody of the source, and provisions had been made for source handling and custody. Issues related to nuclear safeguards and security were raised, and the source has since been held in temporary FH custody. As of January 2006, these issues have not been resolved, and Stoller has been unable to complete calibration and deployment of the neutron capture logging system.

Downhole MCA

In its current configuration, the SGLS utilizes a downhole, high voltage power supply and transistor-reset preamplifier. Pulses generated by the detector are transmitted up the logging cable as analog voltage "steps," where the voltage change is proportional to pulse height and the rise time is equivalent to pulse duration. This is processed by an amplifier and multi-channel analyzer (MCA) in the cabin of the logging truck to generate the gamma energy spectrum. Any type of analog signals that are transmitted through 600 ft of cable are subject to some degree of distortion. This may result in outright rejection of the pulse if it becomes too distorted, or it may increase the "spread" in the energy distribution. Deterioration of the dielectric in the cable as a result of aging, mechanical stress, and exposure to high radiation fields can exacerbate this problem.

Recent advances in solid state electronics have made it possible to incorporate the amplifier and MCA into a downhole package, with gamma energy spectra transmitted up the cable in a digital format. With digital data transmission, the signal can be sent reliably up a single conductor, or even muliplexed on the power conductor. This allows the use of a much simpler logging cable, with significant savings in the winch and other surface equipment.

During FY 2005, signal quality issues were encountered in Gamma 2, which appeared to be related to the logging cable. Instead of replacing the cable, Stoller initiated an effort to deploy a downhole MCA by adapting existing electronic packages to the HPGe detectors used in the SGLS. This work is in progress, and it is anticipated that the downhole MCA can be tested next year. Once calibrated, the downhole MCA will improve overall data quality, including signal throughput, and eliminate the need for a special cable. As the existing trucks are retired, they can be replaced with smaller logging units typical of those used in the mineral and geotechnical logging industry.

Log Data Format

When the Hanford Geophysical Logging Project was established in 1995, logs were generally delivered as paper copies, and log data was provided in an electronic format on special request. As the project has matured, Adobe Acrobat® *.pdf files were created to allow for logs to be more easily transmitted via electronic mail or downloaded from the internet. As more emphasis is placed on computer-aided analysis and spatial visualization of geologic data, it is becoming more important to deliver log data to the end user in an electronic format that more readily allows it to be integrated and compared with other data. At the same time, the Hanford Environmental Information System (HEIS) has expressed interest in incorporating geophysical log data into the site-wide database.

HEIS is a consolidated set of electronic systems that manage data collected during environmental monitoring. Data in HEIS are organized in a sample-result paradigm, meaning that unique samples are collected from a specified location and submitted to a laboratory, which provides one or more results associated with each sample. This paradigm can be adapted to geophysical logging by considering each measurement point as a sample and reporting identified radionuclide concentrations as results. Borehole conditions and measurement parameters are stored with the sample data. Geophysical log data are clearly differentiated from laboratory data by sample and result type. Stoller has worked with organizations responsible for HEIS to develop a proposed log format, which captures log results and supporting data in a manner consistent with the existing database structure. However, the HEIS sample-result paradigm is not well-suited to log evaluation, where parameters are associated by depth. This has led to a hybrid format, which includes data organized by depth, as well as the sample and results tables for input to HEIS. The sample, result, and log data tables are prepared as spreadsheets in an Excel workbook, which also includes various log plots. By organizing the data into a standardized structure with consistent columns and data locations, it is possible to create templates and thereby expedite log processing.

It is recognized that there are a number of specialized logging programs and graphics packages that can prepare more visually appealing and sophisticated plots, but Excel has the advantage of being the "common tongue." At part of the Microsoft® Office Suite for Windows, Excel resides on nearly every computer used by Hanford personnel or stakeholders. The Excel file structure is widely used, and other spreadsheets can generally read or import the files.

Spreadsheets are ideally suited for log data analysis because most of the mathematical calculations are relatively simple, and the data are easily organized by columns, with depth changing from row to row. Stoller's current approach is to use specialized software for gamma spectroscopy to identify peaks and determine net count rates, and the remaining calculations are performed in a spreadsheet. In the coming year, analysis procedures will be revised, and spreadsheet templates will be developed to provide final log data in the hybrid format described above. Existing log data will be copied into the hybrid format. It is expected that this process can be automated to some degree, at least for relatively simple logs.

Subsurface Visualization Capability

As part of the single-shell tank baseline characterization effort, the Hanford Geophysical Logging Project prepared three-dimensional (3D) visualizations of subsurface contaminant plumes detected in the log data. These visualizations are helpful in portraying the nature and extent of subsurface contamination. This work was extended in the baseline characterization effort for the liquid waste sites, and additional subsurface visualizations have been prepared for various sites in the B/BX/BY Waste Management Area (WMA). However, the emphasis within the Hanford Geophysical Logging Project has shifted from evaluation and integration of log data and reports on specific waste sites to log data processing with the resulting logs incorporated into reports prepared by others. Because of this shift, there has been little effort in subsurface visualization in the past two years.

Stoller has maintained the capability for subsurface visualization. The software package used is the Environmental Visualization System (EVS), provided by C Tech Development Corporation. EVS is a 3D data analysis and visualization system specifically designed for environmental and geological applications. It uses a modular and customizable user interface. Features include borehole and sample posting; mapping (isovolumes and isolines),geologic strata, 2D and 3D kriging algorithms, integrated volumetrics and mass calculation, finite difference and finite element grid generation for modeling, 3D fence diagrams, multiple analyte data analysis, and arbitrary slicing and cutting capabilities. EVS also provides pre- and post-processing for MODFLOW, MT3D and CFEST, and animation capabilities.

Stoller has maintained a single-user license for EVS-PRO that is installed on a laptop computer. This provides the capability to show 3D visualizations of geophysical log data with real-time rotation, translation and zooming so that the user can view the data from any angle. Relationships that are frequently obscured in more traditional two dimensional presentations become immediately apparent when viewed in three dimensions. Given the large amount of existing log data collected over the past 60 years, it may be possible to use the animation features to add the fourth dimension of time to the visualizations

Summary and Conclusions

As originally conceived, the purpose of the Hanford Geophysical Logging Project was to log available boreholes in and near liquid waste disposal sites in the Hanford 200 Areas 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 is 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 into other groundwater and vadose zone programs. When appropriate, data integration and reporting can be performed for specific sites or areas.

During 2005, logging efforts were conducted primarily in boreholes scheduled for decommissioning or in support of ongoing remedial investigation activities by other Hanford contractors; 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 DOE and Hanford contractor personnel involved in ongoing remedial investigation activities.

Logging support for 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 tools 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 configurations may significantly affect log quality and only a total gamma log may be useful.

Development and deployment of additional logging systems is an important topic that needs to be addressed. At present, the available logging systems are more than 10 years old and some consideration must be given to their eventual replacement. Many of the components currently in use on the logging trucks are now obsolete. Adaptation 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. It is also likely that advances in solid state detectors in recent years can be adapted to logging purposes. For example, room-temperature detectors such as Cd-Zn or Cd-Zn-Te, may be capable of sufficient energy resolution for radionuclide identification and assessment, at least in some cases. These detectors would not require cyrogenic cooling and can be adapted to slim-hole investigation techniques, such as direct push technology.

With increasing emphasis on electronic data delivery and site-wide databases, it is becoming more important to provide log data in an electronic format. In addition, some effort should be initiated at converting historical data into an electronic format to make this data more useful for the Hanford site.

References

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U.S. Department of Energy (DOE), 2002. *Hanford 200 Areas Spectral Gamma Vadose Zone Characterization Project, Baseline Characterization Plan,* GJO-HGLP-1.7.1, Rev. 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, <1% relative efficiency. 4" 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 man-made radioactivity is anticipated. Provide total gamma log suitable for stratigraphic correlation. Not suitable for determination of individual radionuclide 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") and sonde is centralized. 4" 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" boreholes for 5-20% moisture, but tool response is strongly dependent on hole diameter. Generally limited to 10" ID or less
Passive neutron logging system (PNLS)	^{3}He detector. 4" 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 the cross section of the target element and the 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, and 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" 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.

Logging System	Description	Capability
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 Radionuclides

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**		**DE**
F	NMLS	H380932510	**Not available**	**BF**	**DF**
G	SGLS (35%)	34TP10967A	**AG**		
H	NMLS	H310700352	**Not available**		
J	NCLS	34TN1104A			**DJ**
K	AZLS	32TP10832A	**Not used at Hanford (Deployed at INEEL in 2003)**		
L	PNLS	U1754	**Not available**	**BL**	
M	NMLS	H340207279	**Not available**		**DM**
N	SGLS (60%)	45-TP22010A	**AN**		**DN**

Attachment 4. Boreholes Logged in FY 2005

Borehole name	Borehole ID	Program	Waste Site	Log Date	Issue Date
299-W11-14	A4903	RI/FS	T-33	05/05/05	05/19/05
299-W15-07	A5476	RI/FS	Z-7	04/25/05	05/11/05
299-W15-09	A5477	RI/FS	Z-9	06/30/05	07/28/05
299-W15-08	A5486	RI/FS	Z-9	04/14/05	07/20/05
299-E13-01	A5849	BL	B/C Cribs	04/18/05	05/11/05
299-E13-02	A5850	BL	B/C Cribs	03/17/05	05/13/05
299-E13-04	A5852	BL	B/C Cribs	03/23/05	05/05/05
299-E13-05	A5853	BL	B/C Cribs	08/03/05	
299-E13-06	A5854	BL	B/C Cribs	04/12/05	08/23/05
299-E13-07	A5855	RI/FS	B/C Cribs	10/28/04	12/13/04
299-E13-08	A5856	RI/FS	B/C Cribs	11/02/04	01/11/05
299-E13-11	A5858	RI/FS	B/C Cribs	11/22/04	01/11/05
299-E13-19	A5864	BL	B/C Cribs	02/15/05	03/23/05
299-E13-21	A5866	BL	B/C Cribs	07/28/05	
299-E13-54	A5869	RI/FS	B/C Cribs	11/03/04	02/03/05
299-E13-55	A5870	RI/FS	B/C Cribs	11/22/04	01/11/05
299-E13-56	A5871	BL	B/C Cribs	11/03/04	03/23/05
299-E13-57	A5872	BL	B/C Cribs	02/03/05	03/23/05
299-E17-02	A5879	RI/FS	A-27	04/04/05	04/21/05
299-E24-54	A5911	RI/FS	A-4	04/11/05	04/29/05
299-E26-51	A6644	DC	A-24	08/15/05	09/13/05
299-E26-52	A6645	DC	A-24	08/17/05	09/13/05
299-E26-53	A6646	DC	A-24	09/01/05	10/18/05
299-E26-54	A6647	DC	A-24	09/28/05	11/01/05
299-E26-55	A6648	DC	A-24	09/20/05	10/18/05
299-E26-56	A6649	DC	A-24	08/31/05	09/27/05
299-E26-57	A6650	DC	A-24	09/01/05	09/27/05
299-E26-58	A6651	DC	A-24	09/15/05	10/18/05
299-E26-59	A6652	DC	A-24	09/20/05	11/01/05
299-E26-60	A6653	DC	A-24	08/30/05	09/27/05
299-E26-61	A6654	DC	A-24	09/28/05	11/01/05
299-E26-62	A6655	DC	A-24	09/29/05	11/22/05
299-E26-64	A6657	DC	A-24	08/31/05	09/27/05
299-E26-71	A6664	DC	A-24	09/02/05	10/18/05
299-E26-72	A6665	DC	A-24	09/30/05	12/15/05
299-E26-74	A6667	DC	A-24	09/28/05	11/22/05
299-E26-76	A6669	DC	A-24	08/16/05	09/13/05
299-W10-72	A7162	BL	T-7 Tile Field	05/17/05	07/08/05
299-W11-68	A7310	DC	T-15	08/08/05	08/24/05
299-W11-69	A7311	DC	T-14	06/20/05	08/23/05
299-W11-80	A7322	DC	T-16	08/09/05	09/07/05
299-W11-81	A7323	DC	T-17	08/29/05	09/07/05
299-W11-82	A7324	BL	216-T-28	10/20/04	11/04/04
299-W14-62	A7346	RI/FS	T-27	12/13/04	03/31/05
299-W15-01	A7348	BL	Z-5	06/16/05	07/14/05
299-W15-06	A7349	RI/FS	Z-9	04/26/05	05/19/05
299-W15-53	A7354	DC	Z-5	06/07/05	06/21/05
299-W15-54	A7355	DC	Z-5	06/27/05	07/13/05
299-W15-55	A7356	DC	Z-5	06/07/05	06/21/05
299-W15-56	A7357	DC	Z-5	06/08/05	06/21/05
299-W15-57	A7358	DC	Z-5	06/08/05	06/21/05
299-W15-59	A7360	DC	Z-10	06/09/05	07/13/05
299-W15-60	A7361	DC	Z-10	06/09/05	07/13/05
299-W15-61	A7362	DC	Z-10	06/13/05	07/13/05
299-W18-08	A7525	RI/FS	Z-12	09/12/05	11/09/05
299-W19-72	A7772	DC	U1/U2	08/05/05	08/23/05

Borehole name	Borehole ID	Program	Waste Site	Log Date	Issue Date
299-W19-73	A7773	DC	U1/U2	08/24/05	09/26/05
299-W15-46	C3426	RI/FS	Z-9	01/27/05	03/15/05
	C4175	RI/FS	216-T-28	12/13/04	03/03/05
	C4183	RI/FS	Z-7	03/28/05	04/15/05
299-W19-48	C4300	GW	216-U-17	12/20/04	12/28/04
299-W15-49	C4301	GW	231-Z	11/29/04	12/28/04
299-W15-50	C4302	RI/FS	Z-7	01/19/05	03/31/05
299-W18-16	C4303	RI/FS	Z-1A	12/16/04	04/15/05
	C4545	RI/FS	A-8	07/06/05	08/23/05
	C4557	RI/FS	216-S-7	01/11/05	01/26/05
	C4559	RI/FS	U-3	12/20/04	03/31/05
229-W21-02	C4639	GW	ERDF	12/09/04	02/24/05
299-E24-24	C4647	GW	IDF	05/12/05	08/02/05
299-E17-26	C4648	GW	IDF	06/06/05	08/02/05
299-W22-47	C4667	GW	S-1	01/25/05	06/20/05
299-W14-11	C4668	GW	T-28	05/02/05	06/20/05
299-W11-25	C4669	GW	T Farm	03/15/05	03/21/05
299-W15-83	C4683	GW	PFP	08/11/05	09/26/05
299-W15-152	C4685	GW	PFP	09/21/05	
299-W11-43	C4694	GW	West of T Plant	06/24/05	08/02/05
299-W15-94	C4694	GW	PFP	09/23/05	
299-W19-49	C4695	GW	U-Plant	09/08/05	
699-50-74	C4697	GW	600 Area	07/22/05	09/26/05
	C4738	RI/FS	T-33	02/08/05	04/15/05
699-S20-E10	C4855	GW	300-FF-5	07/19/05	08/03/05
699-50-59	C4882	GW	600 Area	09/14/05	12/15/05
	C4947	RI/FS	100 B&S	08/19/05	09/21/05
299-W11-45	C4948	GW	T Farm	09/19/05	
199-N-122	C4954	GW	100-N	09/26/05	10/27/05
199-N-123	C4955	GW	100-N	09/30/05	10/27/05
299-W19-101	C4966	GW	U-Plant	08/25/05	
299-W11-47	C4990	GW	T-2	01/27/05	