INNOVATIVE TECHNOLOGY
Summary Report

DOE/EM-0613

Long-term, Post-closure Radiation Monitoring System (LPRMS)

Industry Programs
Subsurface Contaminants Focus Area

Prepared for
U.S. Department of Energy
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INNOVATIVE TECHNOLOGY
Summary Report

Long-term, Post-closure Radiation Monitoring System (LPRMS)

OST Reference Number 288

Industry Programs
Subsurface Contaminants Focus Area

Demonstrated at
Ohio Field Office, Fernald Environmental Management Project (FEMP)
Fernald, Ohio

INNOVATIVE TECHNOLOGY
Summary Report

Purpose of this document

Innovative Technology Summary Reports are designed to provide potential users with the information they need to quickly determine whether a technology would apply to a particular environmental management problem. They are also designed for readers who may recommend that a technology be considered by prospective users.

Each report describes a technology, system, or process that has been developed and tested with funding from DOE's Office of Science and Technology (OST). A report presents the full range of problems that a technology, system, or process will address and its advantages to the DOE cleanup in terms of system performance, cost, and cleanup effectiveness. Most reports include comparisons to baseline technologies as well as other competing technologies. Information about commercial availability and technology readiness for implementation is also included. Innovative Technology Summary Reports are intended to provide summary information. References for more detailed information are provided in an appendix.

Efforts have been made to provide key data describing the performance, cost, and regulatory acceptance of the technology. If this information was not available at the time of publication, the omission is noted.

All published Innovative Technology Summary Reports are available on the OST Web site at http://www.em.doe.gov/ost under "Publications."

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Problem

Subsurface monitoring of Department of Energy (DOE) waste sites is necessary to: 1) determine compliance based on presence and potential movement of contaminants found, 2) ensure remediation goals have been met, and 3) ensure long-term effectiveness of remediation. While most recently developed monitoring technologies have focussed on the first two, this ITSR focuses on the third. Depending on regulatory agency requirements, some form of post-closure monitoring will continue long after site cleanup has been completed (30 years is typical). While sampling and laboratory analysis is the generally accepted approach for monitoring, this approach, when carried out over the long time periods typical of post-closure monitoring, may prove to be too labor intensive and expensive to be the sole means for documenting compliance. Some combination of automated monitoring backed up with less frequent sampling and laboratory analysis would measure long-term effectiveness of remediation, while remaining cost effective.

The Long-term, Post-closure Radiation Monitoring System (LPRMS) utilizes commercially available components in a reliable, low-cost, multi-point system for real-time, long-term, unattended monitoring of closed waste sites. The system measures a wide range of radionuclides and activity levels applicable to a large number of DOE sites.

How It Works

The LPRMS is designed for gamma detection in subsurface soils. The radiation probe consists of a sealed assembly which contains a butt coupled, thallium-doped sodium iodide NaI(Tl) scintillator/photomultiplier tube (PMT) and a multi-channel analyzer (MCA). This assembly, termed the Nanoprobe, can be dropped into polyvinyl chloride (PVC) casings, which have been pushed into the soil using cone penetrometer technology (CPT). At the surface, solar-powered remote stations (Figure 1) at each measurement location incorporate the system power supply and a cell phone modem for communication to an off-site host computer, which could be located hundreds or thousands of miles away. A large number of remote stations can each operate independently and, without human intervention, send their daily or weekly results to the host computer for analysis, data trending and alarming. If required, the Nanoprobes are easily serviceable by retrieval from the PVC casing for repair or replacement.

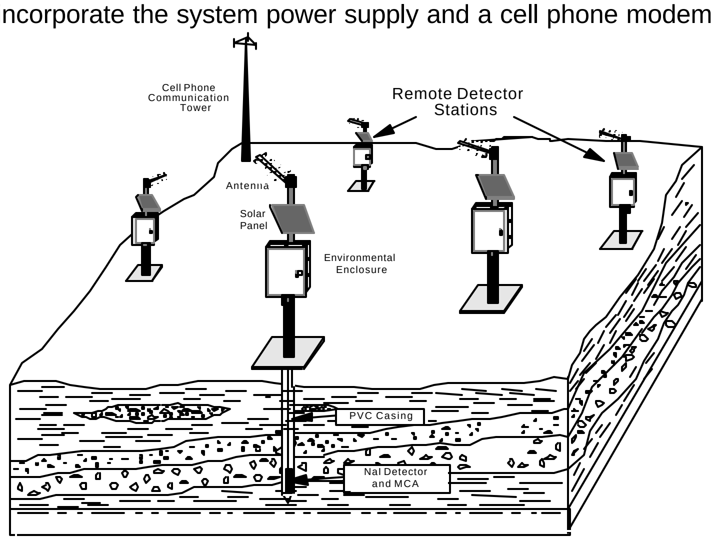

Figure 1. Conceptual Drawing of Installed System

This system is designed to be capable of monitoring large numbers of permanently installed probes over long time periods. The aboveground location of most of the electronic components and the absence of below-ground components that require maintenance will minimize long-term costs.

Advantages Over the Baseline

This technology can remain unattended for long time periods, while providing automated data generation, analysis, formatting, and reporting from many monitoring locations. Additional advantages are:

- Real-time detection of nine typical (within DOE) radionuclides in the media surrounding the sensor eliminates the long turnaround time encountered with conventional sampling and laboratory analysis.
- Sensor-based automated data generation, while it currently may not be as sensitive as typical laboratory analysis, reduces the potential for error from manual sampling, sample tracking, laboratory data generation, analysis, and reporting.
- Minimal long-term manpower is required to operate the LPRMS as compared to the baseline conventional sampling program.
- Potential worker exposure during sampling operations and laboratory analyses is eliminated.

Technology Status

Testing of the prototype system with five remote detector stations has been successfully completed in a one-year field trial at the Fernald Environmental Management Project (FEMP) in Fernald, Ohio. MTI personnel have had discussions with Oxford Instruments (now called Tennelec, a Canberra Company) personnel concerning the commercialization of the system, although plans are not yet finalized. Discussion with Fernald is ongoing concerning future deployment. Interest has been expressed for redesigning the system to allow raising and lowering the Nanoprobe at a controlled rate, which would allow the system to be used for characterization of soils over the entire depth profile. Future system enhancements may include: 1) sealing to allow long-term use in groundwater, and 2) incorporation of sensors for chemical contaminants, improved (to lower minimum level of detection and increase resolution) gamma detection sensors, and a tritium sensor, depending on demand.

Demonstration Summary

Per DOE direction, the LPRMS was developed for deployment in the vadose zone of a closed waste site. At the start of development, the assumed maximum acceptable surface soil activity and the target for minimum level of detection by the LPRMS was 35 pCi of naturally occurring uranium per gram of soil. The demonstration was primarily designed to identify operability issues and potential design improvements and was not intended to provide quantitative information on Nanoprobe performance.

Demonstration testing of the LPRMS was performed from February 19, 1998 to February 19, 1999 at the FEMP site. A full-scale prototype system with five measurement probes was fabricated, laboratory tested, installed at varying depths from 6 to 40 feet and tested in place, and then subjected to the one-year field trial.

LPRMS development was managed by the DOE National Energy Technology Laboratory (NETL) with funding through the DOE Office of Science and Technology (OST). McDermott Technology, Inc. (MTI) performed the technical work scope under contract to NETL. Field support for the demonstration was provided by Fluor Daniel Fernald personnel. Additionally, Applied Research Associates (ARA) provided CPT installation and Oxford Instruments, Inc. provided remote detector stations, a host personal computer (PC), and supporting software, all per MTI specifications. These companies have supported LPRMS development and have an interest in commercialization.

Key Results

Prior to field testing, laboratory tests to determine key performance characteristics and for calibration were performed on four drums of uranium-contaminated soil from Fernald. Results were within an acceptable range for NaI sensors. The one-year field trial was conducted with an original completion date of February 19, 1999, but an additional six months of data was obtained prior to removal of the probes for inspection. During the field trial, the Nanoprobe system reliably provided the data it was designed to provide. One remote detector station lost one day of data due to a corrupted data file. Two detectors were removed from their original locations and placed in Building 64 due to remediation activities and one of these detectors was moved by workers during an activity in that building. That remote station stopped sending data for 23 days. It resumed sending data without the need for MTI intervention. Even counting the downtime for this station, system operability is 98.7%, well beyond the 90% operability target.

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Web Site Locations

The McDermott Technology, Inc. Internet address is http://www.mcdermott.com
The National Energy Technology Laboratory Internet address is http://www.netl.doe.gov

Licensing

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Other

All published Innovative Technology Summary Reports are available on the OST Web site at http://www.em.doe.gov/ost under “Publications.” The Technology Management System (TMS), also available through the OST Web site, provides information about OST programs, technologies, and problems. The OST/TMS ID for Long-term, Post-closure Radiation Monitoring System (LPRMS) is 288.

SECTION 2
TECHNOLOGY DESCRIPTION

Overall Process Definition

The current LPRMS prototype is designed to provide long-term vadose zone monitoring data, while operating unattended for long time periods. The use of PVC pipe to form the subsurface conduit for the Nanoprobe is a key element in terms of installation cost, system maintenance, system flexibility, and functionality. Gamma rays will pass through PVC with little attenuation. PVC is a relatively inexpensive material and the ability to install it using CPT techniques keeps installation costs low, assuming favorable site conditions. In the past, difficulties of maintaining electronics underground for long time periods has made an approach using active electronics problematic. The use of cone penetrometer tooling configurations, containing a radiation sensor in the first section, and using CPT installation methods eases installation and allows easy retrieval of probes for repair, upgrading or moving to a new location.

Advances by a number of vendors now make it feasible to push sealed 2" Schedule 80 PVC pipe using CPT equipment. Once PVC pipe is in place, a Nanoprobe up to 1.8" diameter can be easily inserted and withdrawn, as required.

Miniaturized, low-powered MCAs and PMTs are included in the Nanoprobe placed downhole. There, drift and damaging temperature swings can be greatly minimized. Aboveground components, primarily for communication support and solar power requirements, can be minimal. A trend toward further miniaturization and reduction of power requirements could lead to downhole placement of most or all of the aboveground communication and power control equipment.

Referring to Figure 2, the LPRMS consists of the following major components:

- 2" Schedule 80 PVC casing installed using CPT techniques. The PVC exits the ground and is surrounded by a concrete pedestal and a 4" Schedule 40 steel pipe, which is grouted into the ground.

- The Nanoprobe assembly, a sealed, stainless steel probe body (approximately 1.8" outside diameter [O.D.] x 16" long) which contains a 1.5" O.D. x 6" long NaI(Tl) scintillator, a PMT, and an intelligent MCA which also acts as the system controller. Power and signal cables exit the body of the Nanoprobe and terminate at the surface enclosure. A separate strength member is attached to accommodate lowering and raising of the Nanoprobe and to prevent stress on the signal and power cable.

- An aboveground environmental enclosure (NEMA 3R) which attaches to the 4" Schedule 40 steel pipe and provides a protected environment for the internal components (itemized below) of the enclosure. Attached to the external surface of the enclosure is a solar panel for obtaining power from sunlight and a cell phone modem antenna. The solar panel and battery system must supply the required power to operate the downhole Nanoprobe and the components inside the NEMA enclosure. The biggest power draw is the cell phone modem which is turned on for short time periods to allow remote access from the off-site computer. The battery backup system must supply system power on cloudy days and when the solar panel is covered by snow. As required, the cellular telephone modem antenna can be either a whip antenna or, for reduced transmitter power, a directional antenna.

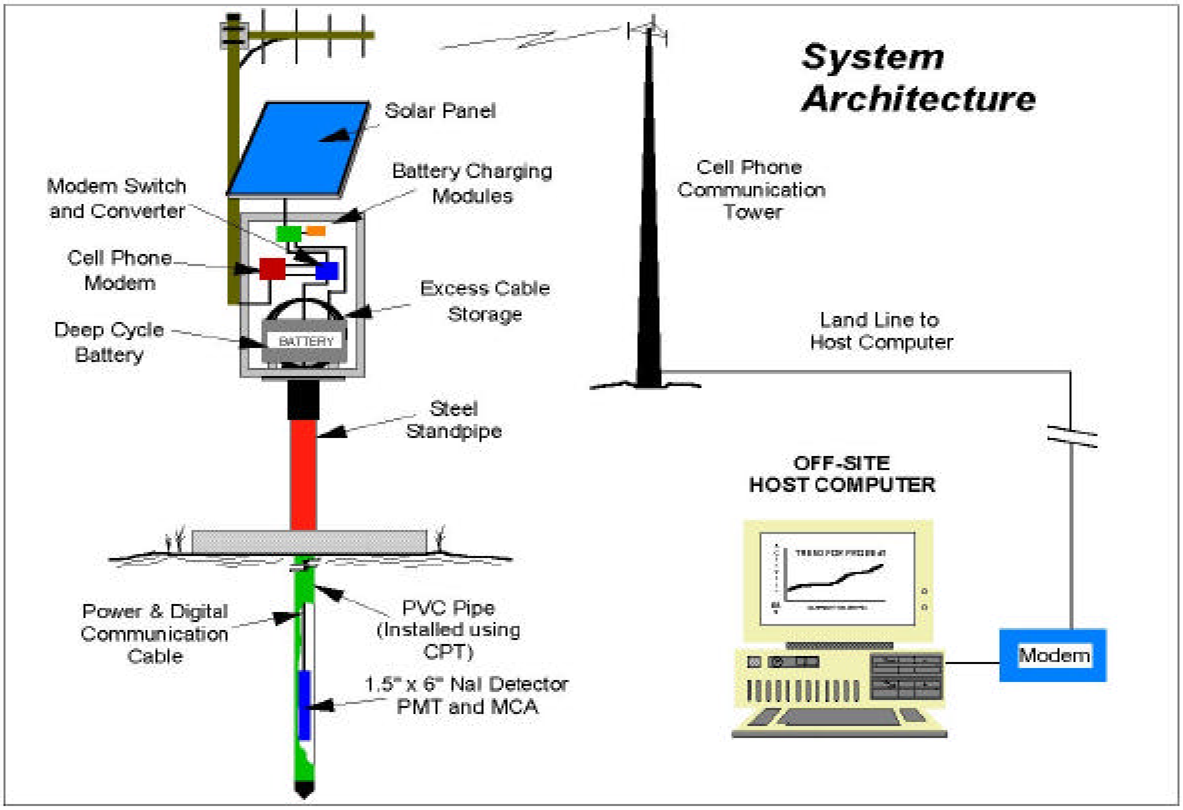


Figure 2. Long-term Post-closure Radiation Monitor System (LPRMS) Architecture.

- The components included inside the NEMA enclosure:
  - 12-volt battery.
  - Charge controller circuit for interfacing the solar panel output to the battery and controlling the rate of charge.
  - Cellular telephone modem for periodic transmission of data to a remote site.
  - Modem switch and RS-232 to RS-485 converter. This device is controlled by the intelligent MCA to apply power to the modem only when a call is being made to transmit data and it converts power from the MCA's RS-485 communication protocol to the RS-232 protocol required by the modem.

- A host PC (Intel Pentium - 200 MHz class), printer, modem, operating system and uninterruptable power supply (UPS) at an off-site location. The system includes operation/communication software, which has been specially written to accept data transmissions from the Nanoprobe. Oxford Assayer software is used for analyzing gamma spectroscopy data transmitted from the site and Microsoft Access based routines are used for trending data and alarming.

System Operation

Operation of the LPRMS is autonomous after installation with data acquisition and trending performed by the host PC. The MCA, which is built into the downhole Nanoprobe, also acts as the system controller for the automated data acquisition. Timing of acquisition and transmission are controlled by the MCA which is pre-programmed to perform according to site-specific requirements. In general, data is acquired in two main steps: 1) raw data acquisition from the remote detector station, and 2) data transmission, storage, analysis, and trending by the host computer.

Remote Detector Station Data Acquisition

- On a pre-determined schedule, each MCA goes from sleep mode to full power and acquires a two hour spectrum of counts versus energy, with 1024 energy values over the 50 kilo-electron volts (keV) to 2000 keV range. This data is stored in the MCA memory. A daily data acquisition schedule and the two-hour spectrum were used for the demonstration, but can be varied, depending on long-term monitoring objectives.

- For each data acquisition event, the host PC will establish communication sequentially with each off-site remote detector station via the local cellular telephone tower and the remote detector station's cellular telephone modem. To provide security, a password will be required prior to the initiation of communication.

- Upon establishing communications with the MCA of the first remote detector station, the host PC will upload the raw energy spectrum. The data set will be uniquely time/date stamped and identified relative to location. Subsequently, each of the remaining remote detector stations will be called and their data uploaded.

- Communication times will be staggered to allow the host PC time to upload the data prior to calling the next remote detector station. If a transmission cannot be made within the allotted number of tries, the MCA will continue to store the spectra until the next transmission. Up to 16 consecutive transmissions could be missed before there is any loss of data.

Host Computer Operation

The host PC is equipped with a telephone line modem, operates unattended, and automatically performs the following general functions:

- On a pre-determined schedule, initiates the call to the site remote detector stations and verifies the user's password.

- Receives the data transmission containing each Nanoprobe's raw MCA spectrum and stores these raw files with the Nanoprobe number and date/day or other unique identifiers.

- Runs an isotopic analysis of the raw MCA spectra and also determines the total count rate from the two-hour spectrum.

- Stores the information in a permanent database.

In addition to the automated conversion of raw spectra to isotopic analyses, a trending capability is built into the software. Occasionally, as required, an operator can access the database and with a few keystrokes can perform the following:

- From the isotopic analysis "report", pull data for a pre-defined list of radionuclides of interest and obtain the activity level for each.

- For each Nanoprobe, generate plot(s) of activity (Y-axis) vs. elapsed time (X-axis) for each of the radionuclides on the pre-defined list and make hard copies. Also, plot the gross count rate data from the two-hour spectra as a function of elapsed time.

- Compare the activity of each radionuclide of interest to preset (operator-defined) limits and provide an alert, if the limits are exceeded (identified by Nanoprobe number, radionuclide, and level relative to alarm limit).

SECTION 3
PERFORMANCE

Demonstration Plan

Fernald Environmental Management Project Demonstration

The focus of this demonstration was long-term monitoring of contaminated soils and was designed to identify operability issues and potential design improvements and was not intended to provide quantitative information on Nanoprobe precision, bias, or MDA.

Soils and groundwater at the FEMP site have become contaminated as a result of years of uranium metal production. Uranium is the primary contaminant of concern. The maximum acceptable surface soil activity being used at FEMP for planning purposes is 35 pCi/g.

The goal of this demonstration was to automatically obtain daily energy spectra from each of five Nanoprobes (Figure 3) over a planned one-year period. These energy spectra were to be automatically processed to identify specific radionuclides present and to determine their activity levels. Data acquisition frequency that may be required for long-term monitoring applications (for example 30 years) is not known. For this demonstration, daily records were believed to be sufficient to illustrate potential application for this technology.

Figure 3. Oxford Nanoprobe Assembly with NaI(TI) Scntillator.

The major objectives of this field trial were to determine:

- The durability of the system,
- The ability of the system to operate unattended,
- The effect of seasonal changes in the soil moisture (saturation) on Nanoprobe output (data quality),
- The effect of long-term operation on system drift (data quality),
- The effect of weather (temperature, humidity) and varying sunlight conditions (sun-days) on the components inside the aboveground enclosure and the system solar power supply performance,
- The presence of any system hardware or software bugs that can be eliminated during the design of the commercial configuration,
- Any needed changes in system hardware or software that would improve the user interface or types of information obtained or displayed, and
- Whether the system observed changes in data that could indicate transport of radionuclides during the one-year test.

The NaI sensor is a standard off-the-shelf item that is used at many DOE sites for field screening of contaminated soils. The demonstration was intended to show that the LPRMS could provide long-term post closure monitoring and was not intended to provide a direct comparison of the resulting data with any other technology, including standard results obtained from an analytical laboratory. Therefore, the field trial was to be judged successful if the daily monitoring goal was reached for at least 90% of the planned measurements. Achieving this goal would prove the system's ability to operate unattended without long-term downtime, common mode failures or system hardware/software bugs. One other key to success is the ability to separate the effect of seasonal variations in soil saturation or system drift from actual radionuclide migration, if any should occur during the time of the field trial. These effects are separated by analyzing trends over the seasons, analyzing rainfall patterns, performing before/after system checks, and performing before/after downhole measurements using a survey probe.

In September 1996, MTI contracted with Alliance Environmental, Inc. of Marietta, Ohio to use an ARA CPT rig for the installation of 2" Schedule 80 PVC pipe at five separate locations on the Fernald site. The locations were jointly chosen by MTI and FEMP personnel from a short list of available locations around the Fernald site that were not planned for cleanup activity within the field trial time frame and that were expected to have measurable radiation readings. Initially, three remote detector stations were installed at the Fernald site locations near Paddys Run, the Sanitary Landfill – West Side, and the Sanitary Landfill – East Side.

Two remote detector stations were installed side by side at the site locations designated as the Inactive Flyash Pile. These two stations were removed when remediation activities were started in the area of the Inactive Flyash Pile and were stored on site for about six months while suitable alternative locations were identified and prepared. The Nanoprobe portion of these stations were eventually installed inside PVC pipe located in the rafters of Building 64, a former thorium storage facility. The NEMA enclosures and solar panels were installed just outside the building.

Figure 4 shows hardware contained in the NEMA 3R enclosure for the radiation monitor system and Figure 5 is indicative of typical remote detector station installation on well completion pipe at the FEMP. The five probes provided a relatively good statistical sample, especially for a prototype field trial. Figure 6 shows two completed LPRMS stations at the FEMP Sanitary Landfill.

Five temperature data loggers, which are small, self-contained, battery-powered digital recorders with integral temperature probes, were used in the field trial. Three of the data loggers were connected to remote temperature probes, which were placed downhole near the Nanoprobes to provide information on the year-round temperatures at various depths. The other two data loggers monitored internal temperature of the NEMA 3R enclosures. In general, the internal temperatures of all of the NEMA 3R enclosures were expected to be quite similar, so the two being monitored should be representative of all five of the enclosures.

Laboratory testing was performed prior to the field trial using characterized drums of soil from Fernald. System precision, bias and minimum detectable activity (MDA) were obtained using these drums. The measurement of the system precision, under controlled laboratory conditions, directly addressed the ability of the Nanoprobe to measure radionuclide activities in the immediate vicinity of the Nanoprobe (Roman and Kidwell 1998). Field trial data supplements the quantitative laboratory test data with qualitative information on system drift and the effect of seasonal and environmental variations on the Nanoprobe stability and precision. However, the field trial was not intended to provide quantitative information on Nanoprobe precision, bias, or MDA.

The MDA results from the laboratory testing are summarized in Table 1. Note that the MDA is obtained from the Assayer software provided by Oxford Instruments, Inc. as a calculated parameter that is provided with each analysis. Normally, to find the absolute minimum MDA for a minimally contaminated soil, a blank sample would be measured. However, the Assayer software could not provide an MDA value for lines that were not present in a given analysis. Therefore, the MDA values were obtained from the individual analyses performed on each of the contaminated drums of soil. Note that MDA for a specific isotope will generally be unique for each measurement situation and will depend on the other radionuclides present in the sample as well as their energy and overall activity relative to the nuclide for which the MDA is desired. The sample drums supplied by Fernald were somewhat representative of the

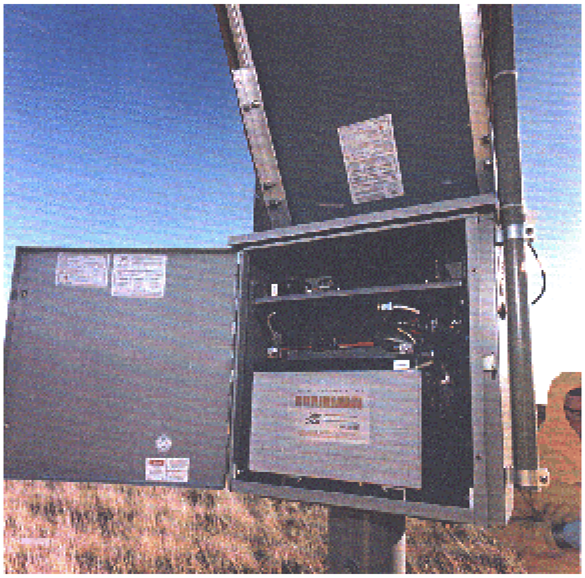


Figure 4. Aboveground radiation monitor system hardware.

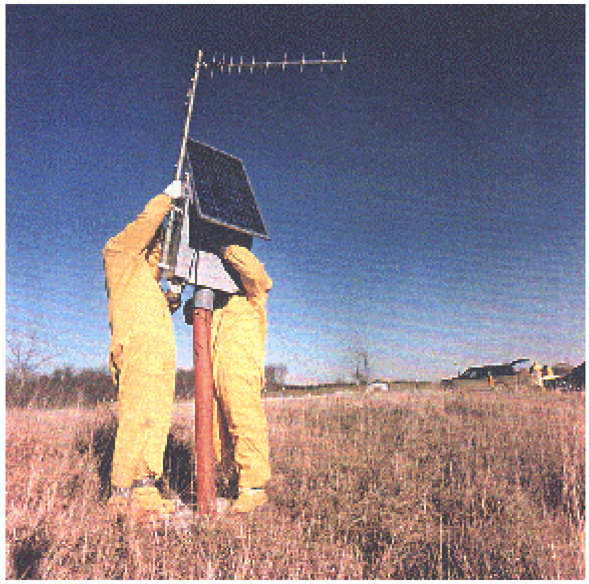


Figure 5. Remote detector station installation on well completion pipe.

Figure 6. LPRMS stations installed at FEMP Sanitary Landfill.

soil at Fernald in that the primary contaminant was uranium. Therefore, the results of these measurements provide some indication of the MDA for the LPRMS in a typical uranium contaminated soil.

Assuming a maximum acceptable surface soil activity for planning purposes of 35 pCi of total uranium per gram of soil, the drums from Fernald varied in activity from about 3 times the maximum acceptable surface soil activity to 30 times the maximum acceptable surface soil activity.

Table 1 shows the MDA obtained for each Nanoprobe, for each of the four drums of contaminated soils, for both the U238b and U235 isotopes that were detected by the analysis. For a gram of natural uranium, approximately 52% of the activity is from U234, 2% of the activity is from U235, and 46% of the activity is from U238. Therefore an MDA of 16.2 pCi/g for U238 and 0.75 pCi/g of U235 would be equivalent to a total uranium activity of 35 pCi/g, the assumed maximum acceptable soil activity. As mentioned previously, ideally MDA is measured on a blank drum (no contamination). The lowest activity drum had 101.5 pCi/g or about 2.9 times the assumed maximum acceptable soil activity. Even at this relatively high level, the total U equivalent MDA calculated from the U238 lines is 24.8 pCi/g and that obtained from the U235 line is 10.7 pCi/g (both based on the worst MDA from any of the Nanoprobes). As expected, as the activity in the drums is increased, the calculated MDA also increases. However, only the drum with an activity of 26.6 times the release limit causes the calculated MDA to exceed the release limit. Of course, when the activity in an area is 30 times the release limit, we are no longer concerned about measuring the release limit. Therefore, these results confirm the ability of the LPRMS to measure at the release limit in soils typical of Fernald. Each measurement situation must be judged on the basis of expected activity and the expected interference with other radionuclides, if for some reason they are not of interest. Longer count times could also help improve the MDA, although that variable was not investigated here.

Table 1. MDA Results From the Laboratory Testing Of Drums Of Contaminated Soil

Drum Total U (pCi/g)	Activity Relative To Release Limit of 35 pCi/g	Isotope	Probe 1 MDA (pCi/g)	Probe 2 MDA (pCi/g)	Probe 3 MDA (pCi/g)	Probe 4 MDA (pCi/g)	Probe 5 MDA (pCi/g)	Req'd MDA for Detection at Release Limit (pCi/g)	Estimate of Detection Limit for Total U (pCi/g)
101.5	2.9X	U238b	10.5	10.7	10.8	11.0	11.5	16.2	24.8
		U235	-----	0.21	0.22	0.22	0.23	0.75	10.7
134.2	3.8X	U238b	9.0	12.0	11.3	12.0	12.7	16.2	27.4
		U235	-----	0.23	0.22	0.24	0.25	0.75	11.7
320.6	9.2X	U238b	12.0	15.1	14.0	15.0	16.0	16.2	34.6
		U235	-----	0.31	0.29	0.32	0.34	0.75	15.8
929.6	26.6X	U238b	27.0	34.0	34.4	36.0	38.0	16.2	82.1
		U235	-----	0.77	0.74	0.80	0.85	0.75	39.6

Results

In addition to the MDA results, the following are some additional data that help explain the data produced by the Nanoprobe system. This includes a calibration spectrum (Figure 7) for Probe 01 using a nine-nuclide point source that was obtained in the laboratory and a spectrum (Figure 8) from Probe 01 obtained from the Sanitary Landfill (East Side) during the field trial. Also included is Table 2 that provides a tabulation of the radionuclides identified by the ASSAYER software from the Figure 8 spectrum.

Table 2. Tabulated Data from August 17, 1998 Spectrum from Probe 01

Isotope	Probability of Actual Detection	Energy Line (keV)	Line Activity (pCi/g)	MDA (pCi/g)	Isotope Activity (pCi/g)	Uncertainty (pCi/g)
U238b	High	765.0	1388	36.5	1469.8	± 154.2
U238b	High	1001.0	1513	19.4		
U235	High	185.7	45.7	0.78	45.73	± 3.401
K40	High	1461.0	14.2	0.94	14.18	± 2.018
Ra226b	Low	609.3	2.4E-04	1.3E-04	4.28E-04	± 9.90E-05
Ra226b	Low	1764.5	5.0E-04	8.5E-05		

Additional results are listed below:

- The in-ground hardware (Nanoprobe) operates in a very temperature-stable environment, generally on the order of 55°F and encountered very little change in temperature over a one-year period.

- The aboveground components, including the solar panel and the NEMA enclosure, are exposed to extremes of high temperature, low temperature, rain, wind, snow, and ice. The internal temperature of the NEMA enclosure generally runs about 30°F higher than the outside temperature on a sunny day.

- All of the various system components operated as designed during the extremes of winter and summer with no loss of power during the one-year test period.

- The off-site computer in Alliance, Ohio operated reliably during the year of operation. It was subjected to several power outages due to storm conditions and local power outages. This computer is protected by a UPS system and it continued to automatically call each remote station at the site on a daily basis and upload the site measurements without human intervention through all of the power upsets.

- The only hardware failure seen during the entire Phase 3 effort was a failure of one of the battery charge controllers, which happened during the field debug phase, after system installation but prior to the official start of the field trial. This $100 component was easily replaced with a spare and the station was restored to full operation.

- The performance target was for the system to automatically acquire 90% of all daily measurements during one year of operation. Through the demonstration period, one data file containing the information on one measurement from one Nanoprobe was corrupted and the data lost. One day of lost data out of 63 remote detector station-months of operation correlates to a 99.95% system operability. One of the two remote detector stations, moved to Building 64, stopped operating for 23 days when workers in the area temporarily moved the Nanoprobe and caused a disruption of the communication link. Although the details of the upset are not known, the system recovered on its own and resumed daily contact without requiring MTI intervention. Even if this anomaly is included as lost data, the system operability was 98.6%. Therefore, the system operability significantly exceeded the 90% performance target.

- Almost all of the problems encountered both during initial system debugging and during off-line processing were related to system software or Nanoprobe firmware problems. The firmware that controls the interface between the acquired files and the daily transmission of data caused lock ups of the system and missed transmissions during the debug phase. The cause of this problem was quickly identified and new firmware was loaded into each Nanoprobe to eliminate the problem. One software problem that still exists is software lock up that occurs during the automated post processing of the acquired data files. When processing the files en masse, certain daily files cause the computer system to lock up. The files appear to be normal and can be viewed and independently analyzed. This problem has been forwarded to Tennelec and on to their software vendor for resolution. A previous related problem was traced to a Microsoft Access bug and not to the Tennelec software.

- An additional goal of the field trial was to determine the effect of seasonal precipitation variations on the gamma detector output. It is suspected that variations in soil moisture may cause a change in detector output due to increased attenuation, especially for shallow probes. Lack of seasonal variation in the field trial data, even at the shallowest probe, is indicative that changes in soil moisture should not significantly affect the detector output.

Figure 7 - Probe 01 – Nine-Nuclide Source Calibration in Lab

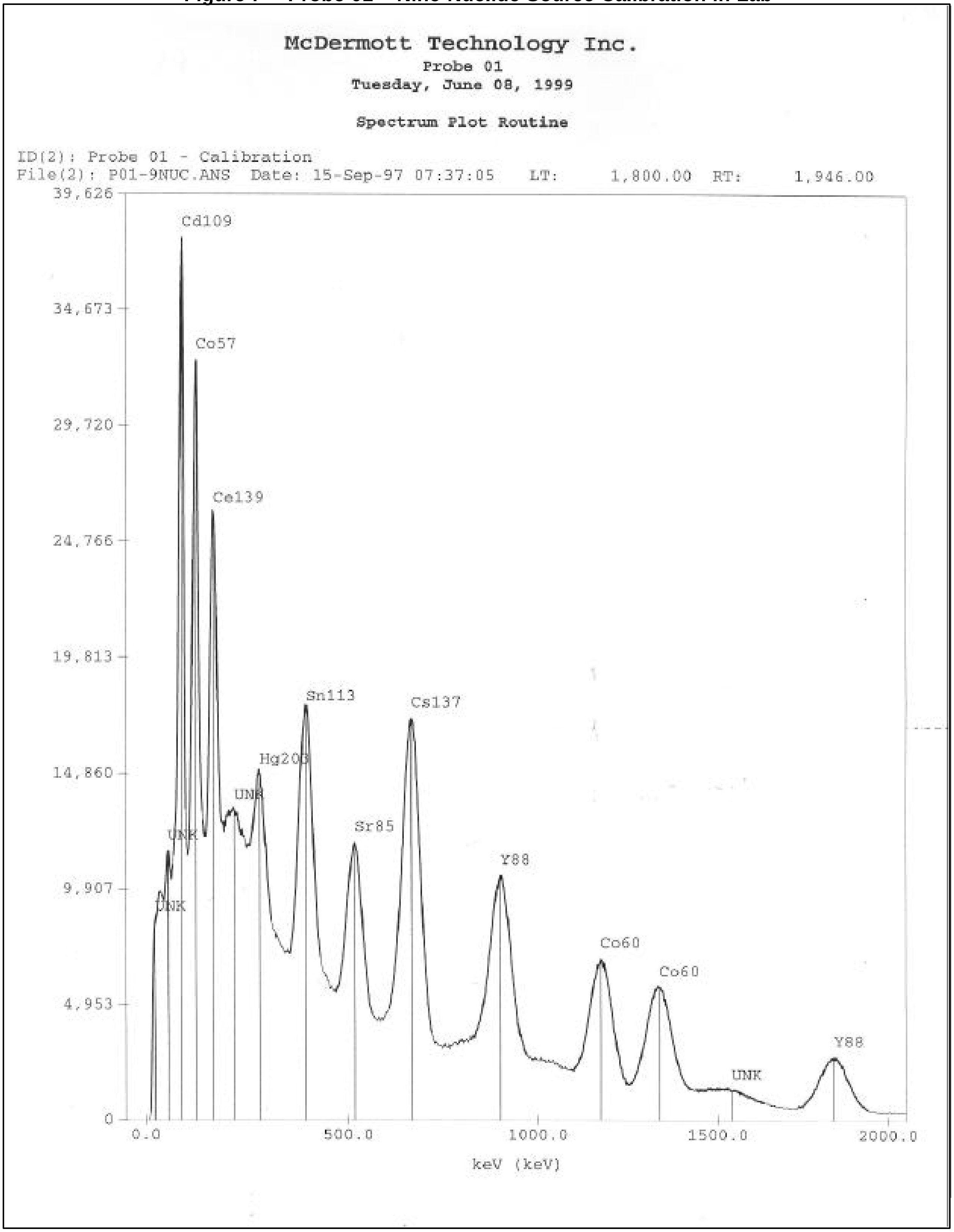
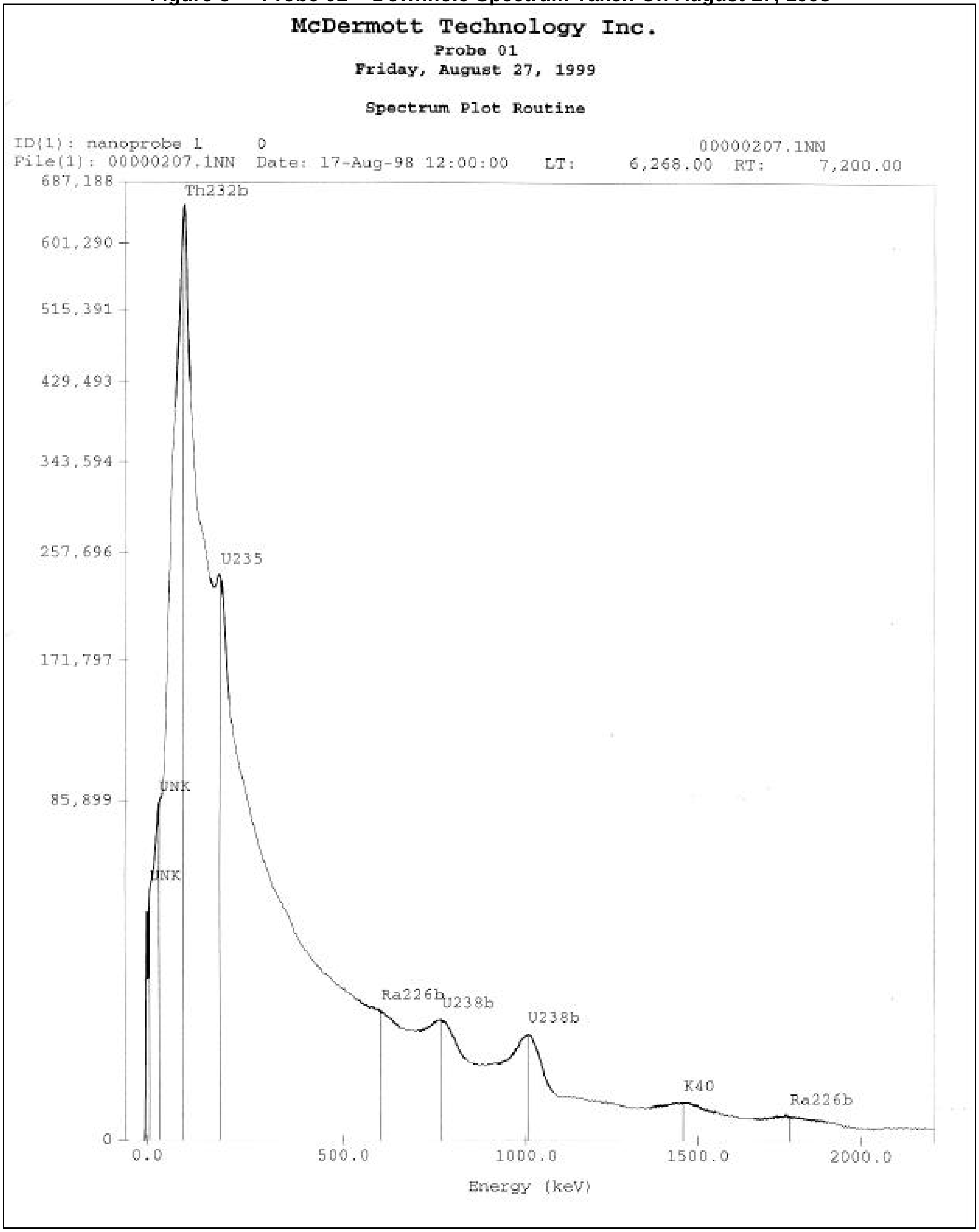


Figure 8 - Probe 01 – Downhole Spectrum Taken On August 17, 1998



SECTION 4
TECHNOLOGY APPLICABILITY AND ALTERNATIVES

Competing Technologies

Although radionuclide analysis can be accomplished through collection of subsurface soil samples during soil boring or well drilling, it is unlikely that this sampling method would be used for long-term monitoring, as it is impossible to duplicate sample location, thus leading to repeatability problems.

Technologies that directly compete with LPRMS are not known to exist. Technologies that are similar to LPRMS, but are not directly competitive include:

- Spectral Gamma Probe, an NaI (sodium iodide)-type sensor incorporated into Site Characterization and Analysis Penetrometer System (SCAPS) or other CPT for screening subsurface soils for gamma emitters. This technology was demonstrated at the Savannah River Site and is reported in an Innovative Technology Summary Report, DOE/EM-0542, July 2000.

- Gamma Radiation-Cone Penetrometer Technique (Gamma-CPT) offered as a commercial service by Applied Research Associates, Inc., includes subsurface screening using CPT or lowering the sensor into an existing well or hollow CPT rod string for use as a borehole radiation logging system (see the Applied Research Associates, Inc. website at http://www.ara.com for details).

Rotasonic geoprobe is the method of choice at Fernald for well installation. This method is reliable, can overcome difficult drilling conditions, and is cost effective, while still enabling retrieval of soil samples. The rotasonic drilling method uses rotary power, hydraulic pull down pressure, and mechanically generated oscillations to advance a dual line of drill pipe.

The following discussion is a comparison of the disadvantages of subsurface soil sampling and the advantages of the LPRMS. However, these approaches can be complimentary, such as if LPRMS were used for routine monitoring, and sampling and laboratory analysis were conducted less frequently for verification or to satisfy a specific regulatory requirement.

Disadvantages of subsurface soil sampling

- If sample retrieval and shipment to a stand-alone laboratory is conducted, typical laboratory turnaround time is 30 days. Each step in the process has the potential for error, however minor.

- There is the potential for worker exposure during both sampling and analysis.

- Disposal of samples once analysis is complete is usually a significant expense passed on to customers of analytical laboratories.

Advantages of the LPRMS

- Because it is unattended, LPRMS minimizes potential for worker exposure.

- The developed system can make automated measurements on a time frame determined by site need.

- Data is always obtained from the same physical location; all labeling and tagging of data is automatic and the tracking can occur without human intervention.

- The LPRMS provides near real-time automated data analysis, archiving and trending.

- Alarms can be set to alert personnel when preset limits are exceeded.

One PC can monitor hundreds or even thousands of locations with little or no human intervention, except for periodic equipment checks. It is envisioned that initially, this system would be used primarily for screening data, which, if limits are exceeded, conventional sampling methods could be employed to delineate the problem.

Technology Applicability

The LPRMS could improve characterization of DOE sites as well as improve upon methods for long-term monitoring. Conversely, reporting can be set to eliminate extraneous data, so that only radionuclides of interest are reported. The system is uniquely suited to sites contaminated with gamma emitters. It is envisioned that the system would be used in conjunction with some limited field quality control sampling for verification of results.

The current prototype LPRMS was designed for use in the vadose zone. For applications requiring submersion in water, the nanoprobe could be modified similar to designs used for submersible pressure transducers, which are commercially available and designed for different dynamic pressure ranges. This approach may require modified calibration procedures for scintillators and determination of MDAs in groundwater, which are feasible. However, the nanoprobe measures gamma emission within a given radius, therefore, depending on groundwater monitoring practices, such as filtering groundwater prior to analysis, results may not compare well to results obtained from sampling and analysis of groundwater. Changes over time, however, can be monitored within sensitivity limitations of the NaI sensor.

The Nanoprobe is currently designed to remain stationary. Applications have been identified where the probe could be modified to be raised and lowered automatically inside a PVC casing, similar to electric logging applications in the oil industry, to provide radionuclide activity levels throughout the vertical horizon of a cased boring. This could provide data for characterization of radionuclides in soils. Additionally, the data could be used to measure migration of contaminants throughout the entire vertical profile of a cased boring during long-term monitoring of sites.

Patents/Commercialization/Sponsor

The LPRMS is comprised of primarily off-the-shelf components. Special firmware and software was developed by Oxford Instruments and one of their standard products, an intelligent MCA board, was modified to fit the envelope of the downhole Nanoprobe. The decision to use as much commercially available hardware as possible was intentional. This approach provided the clearest path to commercialization with the least risk of failure.

State-of-the-art gamma radiation measurement hardware and software, as well as the installation of PVC pipe using CPT techniques, are now sufficiently advanced to provide a readily assembled system. The LPRMS is believed to be a unique combination of components which performs a unique function. The LPRMS has not been patented, because the system is based on commercially available hardware components. Tennelec does have patents on the specific hardware components they supplied and copyrights on the software used for the analysis. It is believed that alternative sources of all of the main system hardware and software components can be found in the radiation measurement industry. MTI personnel have had initial discussions with Tennelec concerning commercialization of the LPRMS, but at this point, future commercialization plans have not been finalized. MTI included the recommended commercial system design in its Phase III Final Topical Report for Development of a Long-Term, Post-Closure Radiation Monitor. This project was sponsored by the DOE Office of Science and Technology, through the National Energy Technology Laboratory, Industry Programs.

SECTION 5
COST

Methodology

The following scenario reflects the cost of installing the LPRMS at a hypothetical DOE site and monitoring radioactive isotopes in the vadose zone for 30-years following site closure activities. No baseline technology was found to match the long-term monitoring capability of the LPRMS. Most of the information for this scenario was provided by the technology development contractor. While the demonstration of LPRMS was conducted at Fernald, the preliminary nature of the cost information developed to date prevented development of accurate Fernald-specific costs. This information is presented so that other DOE site personnel can develop a better understanding of how this technology could apply to their specific situation. This scenario is based on the use of 5 monitoring points. The following summarizes the major cost components for LPRMS:

- Install PVC casing using CPT techniques
- Fabricate/calibrate and install LPRMS remote detector stations
- Perform required 30-year operation and maintenance of equipment
- Perform automated data acquisition, trending and reporting for 30-year period.

LPRMS Cost Assumptions

First-of-a-kind installation costs provide the basis for this analysis. Actual cost is included for Alliance Environmental, Inc. to install five PVC casings at Fernald utilizing an ARA CPT rig and one ARA technical person during installation. Estimates for remote detector station hardware acquisition and installation labor are based on the experience gained by MTI personnel in performing the actual field test installation. Current site rates for labor were used when applicable. Commercial systems should be somewhat cheaper and large quantity purchases of detector stations and CPT casing installations should also result in cost reductions. Therefore, the cost information presented is conservative.

Fixed costs included the mobilization/demobilization and required radiation and site worker training for the drilling crew. Variable costs include standby time, per diem, CPT push time, PVC casings, and aboveground completions. Five PVC casings were installed during the demonstration at the FEMP and they varied in depth from 6 to 40 feet with about 100 feet of total PVC casing installed for the demonstration.

Two semi-skilled laborers would be required for installation of remote detector stations. It is assumed that mobilization/demobilization of the crews is 40 hours per person, and radiation and site worker training is 32 hours per person. The assembly of the system is largely physical labor but initial checkout of the system would require at least one of the two-person crew to be somewhat skilled in electronics. For this estimate, it is assumed that a fully burdened labor rate similar to that used for monitoring well sampling at the FEMP is appropriate. It is also assumed that three days are needed to install the remote detector stations.

A fee of $20,000 was included in the FEMP demonstration for the development of system operation/ communication software used by the Nanoprobe. This is considered a non-recurring charge for future systems, but for conservatism, a $10,000 software reconfiguration fee is included in the cost scenario in the event that another (improved) type of scintillator probe is used in conjunction with the remote detector stations.

Operating costs for the LPRMS are strongly influenced by the system configuration and monitoring needs of a particular site. The system is fully automated. Once installed and operating, it is estimated that a skilled person could spend approximately one day per month or about 100 hours per year reviewing results for a multiple sampling point installation with a high frequency of data generation, looking for anomalies or equipment malfunctions, and reporting trend data. Other costs would include cell phone service and long distance charges for those systems requiring remote off-site monitoring stations. All components are essentially solid-state devices. For simplicity, it is assumed that the life of the detector stations, PC, modem, printer and UPS is 10 years with replacement of all components at the end of years 10 and 20.

To determine present value, capital costs for the LPRMS were escalated to February 1999, based on the previous installation date (Oxford Instruments, Inc. - February 1997 and Alliance Environmental, Inc./ ARA - September 1996), using values from the Engineering News-Record (ENR) Construction Cost Index (CCI). Long-term operation and maintenance costs were discounted to present value using Appendix C of Office of Management and Budget Circular No. A-94, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, assuming a 30-year project life.

Work is assumed to be accomplished using safety level D. Estimates assume long-term monitoring of a site containing gamma emitters. Site engineering for the system is assumed to be 10 percent of the project costs; overhead and profit is 15 percent; and project management is 10 percent.

Baseline Cost Assumptions

No technology has been found that will perform automated long-term monitoring of subsurface gamma emitters. A baseline consisting of repetitive soil sampling over a long time period was considered, but does not reflect a true baseline, because it is not common practice. Therefore, no baseline is included in this cost evaluation.

Cost Analysis

LPRMS Costs

Table 3 is a summary of capital costs for installation of the LPRMS using the scenario discussed in the previous section. Material costs are derived from actual costs incurred by MTI during the field demonstration at the FEMP. Labor hours used in the estimate are based on experience gained from the demonstration. Labor costs for the CPT casing installation were derived from subcontractor invoices. Labor costs for the remote detector station installation were developed using FEMP labor rates for sampling personnel. It is reasonable to assume that the skill level for sampling personnel would be appropriate for installing remote detector stations.

The total cost for PVC casing installation includes costs for rig standby, crew per diem, CPT placement of casing, well pads and surface completion, including assorted fittings. Labor for remote detector station installation includes labor hours (2-person crew for 3 days) and crew per diem ($100/person/day).

The annual operation and maintenance cost for the LPRMS includes the operator cost and cell phone service. Using an operator rate of $50/hr for 100 hr/year, and a cell phone and long distance charge of $100/month, the annual operation and maintenance charge for the LPRMS is $6,200. The PVC casings should not require replacement during the life of the project. Replacement of the remote detector station equipment occurs at the end of years 10 and 20. This cost would be approximately the same as the cost incurred for the original installation of the remote detector stations, or about $167,520 when broken out of Table 3.

Table 3. Capital cost estimate for LPRMS installation

Cost Item	Units	Quantity	Unit Cost ($)	Price ($)
PVC Casing Installation (9/96)				
Materials:				
-2-inch PVC casing (includes plug)	LF	200	10	2,000
Labor:				
-Mobilization/Demobilization of CPT	Each	1	4,000	4,000
-Radiation/site worker training for CPT crew	Hr	32	65	2,080
-CPT installation of PVC casing	Hole	5	1,820	9,100
Subtotal PVC Casing Installation [1]				17,180
Remote Detector Station Installation (2/97)				
Materials:				
-Remote detector stations	Each	5	18,830	94,150
-PC, printer, modem, UPS and canned software	Each	1	7,860	7,860
-Operation/communication software	Each	1	10,000	10,000
Subtotal [1]				112,010
Labor:				
-Mobilization/demobilization for detector station installation	Hr	160	35	5,600
-Radiation/site worker training for detector station installation	Hr	128	35	4,480
-Remote detector station installation	Hr	40	35	1,400
	Per Diem	6	100	600
Subtotal Remote Detector Station Installation				124,090
Total Installation				141,270
-Engineering/Design (10%)				14,130
-Overhead and Profit (15%)				21,190
-Project Management (10%)				14,130
Total present value (7/99)				190,720

[1] All subtotal values for PVC casing installation are escalated according to Engineering News Record Construction Cost Index. Remote detector system materials are escalated, but labor for installation is current (Index values: 9/96 = 5683, 2/97 = 5769, and 7/99 = 6076). Therefore, all costs for the PVC casing installation are escalated, but only material costs for remote detector station installation are escalated.

Baseline Costs

No baseline technology was found that would provide a reasonable alternative to the LPRMS, therefore, no baseline costs are available for comparison.

Life Cycle Cost

The most meaningful assessment of cost savings for this scenario is comparison of life cycle cost (LCC). Table 4 summarizes LCC for the LPRMS. The LCC is calculated by adding the capital costs to the present value of the discounted operation and maintenance costs over 30 years. The real interest rate for discounting the operation and maintenance costs is 2.9 percent (Office of Management and Budget 1992).

Table 4. Projected life cycle cost (LCC) of LPRMS

Category	Constant 7/99 dollars	30-year net present value
Capital Cost ($)	190,710	190,710
Annual operation and maintenance cost ($)	6,200	123,110
Replace remote detector stations at end of years 10 and 20 ($)	167,520	220,460
Total LCC ($)		534,280
LCC per monitoring point ($)		106,860

Note: 30-year net present value is based on a real discount rate of 2.9 percent (Office of Management and Budget 1992).

Conclusions

LPRMS could result in significant cost savings, depending on how DOE sites address long-term post-closure monitoring issues, such as future site staffing levels and skills, future privatization issues and contractual requirements, and likelihood that regulatory agencies approve more creative (and potentially cost-saving) approaches than direct sampling and laboratory analysis.

Based on the aforementioned methodology and assumptions for the LPRMS, we can conclude that:

- Cost factors such as mobilization and demobilization distance and calibration of each remote detector station are not major contributors to the overall cost of the LPRMS.
- This analysis uses costs from the prototype system used in the demonstration at Fernald. Costs for large quantity purchases of remote detector stations should decrease their unit cost.
- The 30-year net present value for using the LPRMS at a DOE site would be approximately $106,860 per monitoring point.
- Projected life cycle cost (30-year net present value) of LPRMS is $534,280 for a 5-monitor system installed to an average depth of 40 feet.
- Major life cycle cost components are capital cost at 36% of the total, annual operation and maintenance cost at 23% of the total, and replacement of remote detector stations at years 10 and 20 at 41% of the total.
- The major capital cost component is the cost of the remote detector stations. A major assumption is the need for replacement the remote detector stations at years 10 and 20. If this assumption were not included in the life cycle cost projection for the 5-monitor system, total life cycle cost would be $313,820 and the life cycle cost per monitoring point would be $62,760.
- The projection for operation and maintenance costs is intended to be conservative, but is still a small component of life cycle cost, which may be attractive to DOE closure sites that may have restrictive budgets for long-term monitoring following site closure.

SECTION 6
REGULATORY AND POLICY ISSUES

Regulatory Considerations

Development to date for this technology has resulted in the capability for monitoring the vadose zone. For general post-closure monitoring, regulatory agencies currently focus on groundwater quality. Regulatory drivers for future long-term post-closure monitoring of the vadose zone are not clear. Development of additional capabilities for the LPRMS, including a capability for monitoring groundwater, were discussed, but have not yet been pursued, pending identification of specific DOE site applications.

A review by the Fluor Daniel Fernald Environmental Planning (EP) Department determined that National Environmental Policy Act (NEPA) Categorical Exclusion number 430, “Site Characterization and Environmental Monitoring, CY 1993-1994" covered the site demonstration work at the FEMP. It is anticipated that this exclusion would apply to other sites (McDermott Technology, Inc. 1997).

Project-specific data quality objectives (DQOs) were developed to support future acceptance of this technology by environmental regulatory agencies, including the U.S. Environmental Protection Agency. These DQOs were related to the laboratory testing performed using drums of characterized soil to determine the precision, bias, and MDA for each Nanoprobe. All testing performed per the test plan was performed under the MTI Research and Development Division Standard Practice Quality Program which is registered to International Standard ISO 9001:1994.

Nine evaluation criteria are used to assess remedial alternatives for CERCLA sites. Evaluation using these criteria does not apply to this technology since the LPRMS is a monitoring device. Criteria such as protection of human health (worker exposure) and cost effectiveness are discussed in other sections of this document.

Safety, Risks, Benefits, and Community Reaction

Worker Safety

- Utilization of the LPRMS eliminates the potential exposure due to close contact with samples, such as during sampling operations and laboratory analyses.

- While not an issue at Fernald, utilization of CPT techniques to install PVC casing for the LPRMS eliminates drill cuttings, which will reduce the potential radioactive isotope exposure workers.

Community Safety

- The frequent (continuous, if necessary) monitoring that is made cost-effective by the LPRMS will provide additional data, which, when coupled with traditional monthly or quarterly groundwater monitoring programs, provides source data for correlation and remediation as necessary.

Environmental Impact

- Data anomalies identified through use of LPRMS can help verify need for early action.

Socioeconomic Impacts and Community Perception

- The LPRMS will have a minimal impact on the local economy or work force. Though the general public has limited knowledge of the LPRMS, the system relies on solid-state electronics and communication systems, which are common public knowledge. The system uses off-the-shelf components, which simplifies the process of educating the public on LPRMS operation.

SECTION 7
LESSONS LEARNED

Implementation Considerations

The LPRMS consists primarily of off-the-shelf electronics that are installed inside PVC casing placed using CPT techniques. The LPRMS can be applied at any site with gamma-emitting radioactive isotope contamination, provided that site-specific conditions are amenable to utilizing CPT techniques. On-site personnel are not required for long-term operation and maintenance of the remote detector stations as the LPRMS provides for autonomous data collection, analysis, reporting, alarming, and archiving. Use of cell phone technology and communication software allows the site operator to query the system from virtually any location.

Technology Limitations

- The prototype Nanoprobe was designed and field-tested for monitoring subsurface soils. If the current prototype were to be used for groundwater monitoring, care must be taken to ensure that PVC casing is watertight as the field-tested prototype Nanoprobe is sealed, but is not currently designed for submersion with substantial applied hydraulic head.
- CPT installation is not appropriate for all sites. For some sites for which CPT is appropriate, installation to planned depth may be difficult, depending on site conditions. Using CPT techniques to push 2-inch diameter PVC casing beyond 75 feet in depth may stress the casing to the point that casing joints break.
- The site soils must be fully characterized with known activity levels for all gamma-emitting radionuclides in order to properly calibrate the LPRMS.

Needs for Future Development

Potential modifications to broaden applicability of LPRMS include:

- Redesign the Nanoprobe assembly to fit inside smaller PVC casing without sacrificing detection capabilities. If the Nanoprobe were installed using CPT techniques inside 1.5-inch diameter casing, it could be installed to greater depths due to reduced surface friction.
- Redesign the Nanoprobe assembly to be waterproof and submersible under substantial hydraulic head. This modification would allow potential end users to modify existing groundwater monitor wells to become remote detector station hosts.
- Modify the LPRMS to allow raising and lowering of the Nanoprobe at a controlled rate which would allow the system to be used for characterization of soils over the entire depth profile.

Technology Selection Considerations

- LPRMS should be part of an integrated post-closure monitoring strategy that minimizes cost.
- The LPRMS is only suited to monitoring gamma-emitting radionuclides.
- The LPRMS is an enabling technology: the only system currently available for long-term subsurface monitoring of gamma emitting radionuclides on a variably frequent basis.

APPENDIX A
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