Appendix E

In Situ Gamma Measurement Systems

1.0 ABSTRACT

Procedures are described for in-situ identification and measurement of gamma-ray radioactivity. The scope involves a discussion of instrumentation, setup, calibration, and analysis. Field screening is performed using a portable 30% HPGe p-type germanium detector. Spectra are analyzed using the USDOE Environmental Measurements Laboratory M1 protocol and software.

2.0 APPLICABILITY

Field (*in-situ*) γ-ray spectroscopy using portable high resolution Ge detectors is applicable to the rapid determination of natural and man-made radionuclides in the environment. When the source geometry is taken into account, the concentrations (activity per unit area or volume) of these radionuclides in the soil can be inferred along with the contribution to the above ground exposure rate. Applications have included: the measurement of natural background and weapons test fallout emitters, the determination of aged fallout levels in terrain with mixed ground cover, site characterization for environmental restoration, routine monitoring, and assessment of radionuclides deposited during emergencies. Once areas of concern are identified, they are scanned using a HPGe (high-purity germanium) γ-ray spectroscopy detector coupled to the EG&G ORTEC "DART" multichannel system.

The high resolution high-purity germanium coaxial crystal does require a 6 hour cryogenic cool-down time before becoming operational, but can sustain warm-up when not in use. This is a convenient feature during extended field trips. The 4-liter dewar can be hand-held although it is best suited for tripod mounting. The instrument is positioned ~1 meter (3.3ft) above ground for the initial scanning activity. The resulting field of view at this elevation is a circle with a diameter of 20 meters (66 ft). The detector may be lowered in-place to reduce the field of view proportionately and narrow the area of potential contamination, which can be flagged for further scanning.

Generally, measurements are made in the field using a portable battery-powered computer-based spectroscopy system. High voltage and preamplifier power are supplied to the detector by the system. Low power amplifiers provide for extended operational time when using battery power in the field. A spectroscopy grade amplifier is also contained within the system. The complete spectrometer system can be carried and operated by two field operators.

3.0 DISCUSSION

The in-situ gamma radiation survey involves measuring gamma radiation from a position above the surface of interest. Radionuclides within the soil emit photons. The soil dissipates photon energy through absorption and scattering processes, but some energy escapes the soil zone and radiates outward to interact with the γ-ray detector. The detector "counts" these interactions to give a measure of the radioactivity present. The number of gamma rays "counted" at a given measurement point depends on several factors listed below:

3.1 **Sensor Field of View**; only photons traveling along a path contained within the sensor field of view will have a chance to interact with the detector.

3.2 **Soil Density**; soil density affects photon attenuation and thus the number of "counts" recorded per **disintegration**.

3.3 **Gamma-ray Energy**; photon energy affects photon attenuation and thus the number of "counts" **recorded** per disintegration.

3.4 **Detector Efficiency**; some, but not all photon-detector interactions produce a valid "count" depending the detector efficiency.

3.5 **Amount and Distribution of Radionuclide in the Soil**; the source geometry (concentration and distribution) is the parameter solved for in the conversion process - normally, exponential distribution must be assumed in order to determine concentration.

One of the distinct advantages of in-situ measurement relates to the detector field of view. The field of view may be made quite large through appropriate detector design and placement, permitting the detector to count photons emitted over an extended area. Thus, even for low radionuclide concentrations, a large number of photon-detector interactions occur and the measurement may be made rapidly. At this measurement rate it becomes possible to fully map radionuclide concentrations over a large area by attaching the detector to a mobile system and traversing the area of interest.

Ease of handling is best accomplished with a detector mounted in a cryostat that is small (hand-held) and which has an all-attitude capability. Ideally, the detector assembly should be mounted on a tripod with the crystal endcap facing down toward the ground and the dewar above. This orientation maximizes the flux that will be intercepted and registered by the detector. A standard dewar with an upward facing endcap can still be used without a large loss of efficiency, since most of the flux is incident at the sidewall of the detector, with the dewar blocking out only a few percent of the ground area that is effectively being measured. In either the upward or downward facing geometries, the axis of rotation for the cylindrical crystal is perpendicular to the ground plane. As such, the detector can be assumed to have a symmetrical azimuthal or angular response. A "gooseneck" cr yostat, where the crystal axis is parallel to the ground plane, should be avoided since this introduces asymmetry and would require making complicated angular corrections. There are a number of naturally-occurring radionuclides that contribute to the gamma-ray background using a Ge detector. These include contributions from: cosmic rays, ^{40}K, radon, primordial emitters ^{238}U, ^{232}U, ^{235}U and their daughters.

4.0 SAFETY PRECAUTIONS

4.1 Field Work

Work under this procedure requires reading and signing approves radiological work permits, job safety analyses, and health and safety plans. Personal Protective Equipment is donned per the requirements discussed in the area RWP, JSA, and specific HASP to mitigate the potential site hazards. Prejob briefings must be attended and logsheets signed at sites which utilize this method as required in MCP-3448, *Working In A CERCLA Area Of Contamination.* MCP-2704, *Heat And Cold Stress*; is also covered at all prejob briefings.

4.2 Radioactive Materials

All radioactive materials must be handled in accordance with and approved Radiological Work Permit (RWP) for the area see MCP-7, *Radiological Work Permit*.

4.3 Liquid Nitrogen/Chemical Handling

As the HPGe detector requires cryogenics (LN_2). Ensure that cyrogenic gloves, face shield, apron and loose fitting gloves are worn when performing this operation.

WARNING

Liquid nitrogen is an extremely cold liquid and odorless gas under pressure. Contact can cause severe frostbite.

Individuals are encouraged to seek more information on safety from Material Safety Data Sheets (MSDS), laboratory supervision, and Industrial Safety personnel. A reference file of the MSDSs can be found on the INEEL intranet under Netscape/MSDS Resources.

4.4 Instrument Handling

Care should taken when transporting and assembling the many components involved with the M1/DART setup. The HPGe detector must be powered-up to very high voltages for proper operation (Power sources are shielded or inaccessible). Care must be taken to ensure that the system is powered-down before the system is disassembled, or any modifications to the physical connections are made.

5.0 APPARATUS AND REAGENTS

5.1 Apparatus

5.1.1 Battery charger adapter for cigarette lighter.

5.1.2 EG&G HPGe γ-ray spectroscopy detector.

5.1.3 EG&G ORTEC "DART" batteries (Duracell 6V NiMH DR11) and charger units.

5.1.4 EG&G ORTEC "DART" integrated spectroscopy system.

5.1.5 Field notebook and waterproof black ink pens.

5.1.6 Hammer and stakes as needed for future mapping and sampling.

5.1.7 Leather gloves.

5.1.8 Mounting tripod for EG&G HPGe γ-ray spectroscopy detector.

5.1.9 Mouse for Panasonic CF-25.

5.1.10 Multi-plug power strip.

5.1.11 Panasonic batteries (10.8V Li-ion CF-VZS251, or 9.6V NiMH CF-VZS250A) and charger units.

5.1.12 Panasonic CF-25 portable laptop computer. Battery charger adapter for cigarette lighter.

5.1.13 Parallel port cable for Panasonic.

5.1.14 Utility cable link (housing high-voltage, output, shut-down, pre-amp, and test cables) for DART and M1.

5.1.15 NIST Traceable mixed nuclide isotopic source standards for calibration (Analytics, Amersham 4218-E or equivalent)

5.2 Reagents

None

6.0 SAMPLE HANDLING

None.

7.0 PROCEDURES

7.1 Set-up of M1

The M1 software set with incorporated GammaVision software programs is a very comprehensive software system. As an aid to the user in bringing the system into operation as quickly as possible, a simplified initial start-up sequence based on default settings is provided in the EG&G ORTEC Software Users Manual.

Prior to system use, the detector must be filled with liquid nitrogen. This is discussed in detail in ACLP 0.02. Proper PPE requirements must be met in order to fill dewars, including full face shield, apron, safety shoes, and use of cryogenic gloves. The dewar for this detector can be filled from the main building 602 dewar per ACLP 0.02 or from the gamma spectrometry room dewar. This filling is procedurally identical except that a fill funnel is used in place of a fill hose. The PPE requirements are identical.

This start-up sequence will give “cook book” instruction steps to accomplish initial software installation, file setup, and energy and resolution calibration of the system. After completing the energy and resolution calibration steps, the user can operate all portions of the software during the fine tuning of the system in preparation for actual field work.

At the end of this initial start-up procedure, the user will be directed to other sections of the manuals, which explain M-1 features and file concepts, which must be reviewed and refined prior to actual *in-situ* measurements. In particular, it is important that the user understand the *“alpha/rho”* concept which is the basis for applying radionuclide depth distribution corrections to radionuclide activity as measured by the M-1 spectrometer system.

The initial start-up sequence consists of three major steps:

1.) Install M1 software.
2.) Setup required files.
3.) Perform initial energy and FWHM calibrations.

These simplified initial instructions are based on default values for parameter files which correspond to the EG&G ORTEC M-1 system including the NOMAD Portable Spectroscopy System. For systems consisting of other components, the user will need to refer to the appropriate sections and appendices of the M-1 manual to determine and set correct parameters for that system.

7.2 M1 Software Methodology

The M1 In-situ Applications Software package is intended to provide both qualitative and quantitative analysis of results of radionuclides deposited through various scenarios in non-laboratory environments. The Software package is based upon methods developed by Beck et al. during their tenure at the Environmental Measurements Laboratory within the U. S. Department of Energy.

The M1 In-situ Applications Software accomplishes these goals in a five-stage process.

7.2.1 Field acquisition of a calibration spectrum followed by Energy and Full Width Half Maximum (FWHM) calculations and storage of all coefficients.

NOTE 1: *This is accomplished by a two peak field calibration scanning of ^{40}K, and ^{137}Cs.*

NOTE 2: *It should be noted that an in-lab calibration with a multi-nuclide is performed before entering the field. Nuclides scanned can include ^{60}Co, ^{241}Am, ^{137}Cs, ^{40}K, and ^{232}Th and 238U series.*

7.2.2 Field aquisition of an In-situ spectrum followed by the peak search routines necessary to yield net count rate per gamma ray energy.

7.2.2.1 Connect the HPGe to the DART via the utility cable and attach the corresponding cables.

NOTE: *The "Test" cable will remain and is not required for M1 operation.*

7.2.2.2 Connect the DART to the Panasonic CF-25 via the parallel port cord.

7.2.2.3 Turn on the DART unit.

7.2.2.4 Turn on the Panasonic CF-25. IF the system does not auto load, THEN press F1.

7.2.2.5 Launch Battery Monitor.

7.2.2.6 Launch Shortcut to M1 Setup and check desired settings.

7.2.2.6.1 Detector:

- Efficiency: 30%
- Orientation: Down.
- Aspect Ratio: Usually ≈0.9
- Calibration Use File C:\user\field.clb

7.2.2.6.2 Acquisition:

- Live time preset: 0.
- Real time Preset: Per project.

7.2.2.6.3 Analysis:

- Alpha/Rho File: Usually C:\user\M1.rho

7.2.2.6.4 Check other presets:

- Library file
- Fraction limit
- Energy tolerance
- Date analyze channels
- FWHM
  - Peak sensitivity usually 1
  - Background type, 5

7.2.2.6.5 Report:

- Activity units: Typically pCi.
- Reporting Uncertainty: 2.
- Send to: Program

7.2.2.7 Launch Shortcut to M1 OP

NOTE: *If system will not power up, the HPGe crystal may not be sufficiently cooled yet.*

7.2.2.7.1 Acquire:

7.2.2.7.1.1 Adjust Settings: Power ON and Pull Zero

7.2.2.7.2 Enter:

- Spectrum ID
- Location
- Use calib file

NOTE: *Make sure live time is counting.*

7.2.2.8 Start Count.

7.2.2.9 At the completion of the count, analyze full spectrum in memory.

NOTE: *The DART will store a spectrum while a PC is not attached.*

7.2.2.10 Start next count.

7.2.2.11 At the completion of the field screening, power down the system, turn off Panasonic and DART.

7.2.3 Application of Calibration Factors derived from the methods described by Beck et al. Yielding qualitative and quantiatitve analysis results.

7.2.4 Storage of all acquired data and analysis results in separate files identified per field location.

7.2.5 Capability of supervisor/administrative review or reanalysis of all stored data files and analysis results.

8.0 QUALITY CONTROL REQUIREMENTS

Quality control for this method consists of a daily energy calibration check using a NIST traceable mixed nuclide isotopic source. The location of the Am-241 peak at 59.5 kev, the Cs-137 peak at 661 kev and the Co-60 peak at 1332 kev are verified to within +/- 2 kev. If these peaks do not fall within the proper energy regions, the system is not used until recalibration is completed.

9.0 CALCULATIONS

Calculations are based on the M-1 software in conjunction with the Alpha/Rho value assigned the designation as a man-made or naturally occurring radionuclide, and the library file parameter for that radionuclide.

10.0 RECORDS

Records Description	Uniform File Code	Disposition Authority	Retention Period
Analytical Report	See MCP-2007, *Analytical Records Management*		
Environmental Field Notebook	See MCP-2007, *Analytical Records Management*		

11.0 REFERENCES

11.1 EG&G ORTEC Software User's Manual M-1-B1

11.2 EG&G DART Portable Spectrometer Software/Hardware User's Manual

11.3 United States Department of Energy Environmental Measurements Laboratory (EML) Manual, 28th Edition, HASL-300, Section 3.1, vol. 1, Rev. 0 February 1997

11.4 EG&G ORTEC Catalog of Applied Nuclear Spectroscopy, 1997-1998

11.5 MCP-7, Radiological Work Permit

11.6 MCP 3448, Working in a CERCLA Area of Contamination.

11.7 MCP-2704, Heat and Cold Stress.

11.8 MCP-2007, Analytical Records Management.

11.9 ACLP 0.02, Filling *Portable Dewars with Liquid Nitrogen*.

12.0 SUPPLEMENTAL INFORMATION

12.1 History of Method ACMM-3994

Revision	Author(s)	Date
0	C. P. Oertel	February 2000
1	C. P. Oertel	September 2000

12.2 Revision Summary:

This revision incorporates hazard mitigation identified from the MCP-3562 process, and updates the method format per MCP-2001, Rev. 3.

13.0 APPROVAL SIGNATURE BLOCK

POSITION TITLE	SIGNATURE	DATE
Method Author		
Responsible ALD Tech Leader		
Responsible ALD Supervisor		
ALD QA Officer		
ALD Manager		
ALD Facility Manager		

Appendix A

Procedure Basis

Step(s)	Basis/Summary	Source
Section 4	Operation is field work. Work Scope is covered via work order RWP or HASP hazards are identified particular to each site where work is performed.	JSA# ACMM-3994 JSA Step 1
Section 4.3 & Section 7.1	Operator to don cryogenic compatible gloves, apron, and face shield wearing loose fitting clothing, ensure other personnel are clear of filling area	JSA# ACMM-3994 JSA Step 2.

Survey Results

Sample Number	Date	Cs-137 (pCi/g)	Co-60 (pCi/g)	K-40 (pCi/g)	Sample Location
A1	6/13/01	0.161	--	5.55	Excavated soils from trenches leading to Building ARA-627 and near the radionuclide tank
A2	6/13/01	0.212	--	5.08	Excavated soils from trenches leading to Building ARA-627 and near the radionuclide tank
A3	6/13/01	0.259	--	4.38	Excavated soils from trenches leading to Building ARA-627 and near the radionuclide tank
A4	6/13/01	0.239	--	5.17	Excavated soils from trenches leading to Building ARA-627 and near the radionuclide tank
A5	6/13/01	0.975	--	7.54	Inside of trench leading to Building ARA-627
A6	6/13/01	0.0028	--	6.74	Inside of trench leading to Building ARA-627
A7	6/13/01	2.73	--	6.45	Inside of trench leading to Building ARA-627
B1	6/18/01	29.3	0.313	6.81	Inside of pipeline trenches that went to the support area of Building ARA-626
B2	6/18/01	37.1	0.447	6.68	Inside of pipeline trenches that went to the support area of Building ARA-626
B3	6/18/01	168.5	1.17	6.5	Inside of pipeline trenches that went to the support area of Building ARA-626
B4	6/18/01	ND	--	6.55	Excavated soils from pipeline trenches that went to the support area of Building ARA-626
B5	6/18/01	0.308	--	6.82	Excavated soils from pipeline trenches that went to the support area of Building ARA-626
B6	6/18/01	1.64	--	5.48	Excavated soils from pipeline trenches that went to the support area of Building ARA-626
B7	6/18/01	1.17	--	6.43	Excavated soils from pipeline trenches that went to the support area of Building ARA-626
B8	6/18/01	1.05	--	6.43	Inside of pipeline trenches that went to the support area of Building ARA-626
B9	6/18/01	2.7	0.113	7.19	Inside of pipeline trenches that went to the support area of Building ARA-626
B10	6/18/01	5.43	--	8.65	Inside of pipeline trenches that went to the support area of Building ARA-626
B11	6/18/01	134.2	5.46	7.42	Inside of pipeline trenches that went to the support area of Building ARA-626
ARA1	6/18/01	0.359	--	5.78	Inside of pipeline trenches that went to the support area of Building ARA-626 - Resurvey of Location B3 following removal of contaminated piping in a neighboring trench
ARA2	6/18/01	ND	--	7.78	Inside of pipeline trenches that went to the support area of Building ARA-626
ARA3	6/18/01	11.86	--	6.5	Inside of pipeline trenches that went to the support area of Building ARA-626

Sample Number	Date	Cs-137 (pCi/g)	Co-60 (pCi/g)	K-40 (pCi/g)	Sample Location
ARA4	7/3/01	1.85	--	6.71	Main pipe trench leading from the ARA-25 foundation to the ARA-16 tank after piping removal
ARA5	7/3/01	1.45	--	6.46	Main pipe trench leading from the ARA-25 foundation to the ARA-16 tank after piping removal
ARA6	7/3/01	2.25	0.135	7.86	Main pipe trench leading from the ARA-25 foundation to the ARA-16 tank after piping removal
ARA7	7/3/01	105.4	1.62	5.85	Main pipe trench leading from the ARA-25 foundation to the ARA-16 tank after piping removal
ARA8	7/3/01	3.85	0.173	5.83	Resurvey of Location ARA7 following removal of contaminated piping in a neighboring trench
ARA9	7/3/01	27.51	0.81	8.53	Resurvey of Location B1 to confirm previous results
ARA10	7/3/01	12.66	0.33	8.06	Resurvey of Location ARA9 following relocation of contaminated piping
ARA11	7/3/01	0.107	--	6.9	Resurvey of Location B11 following removal of contaminated piping in a neighboring trench
ARA12	7/3/01	ND	--	6.43	South End of ARA-25 hot cell foundation walls
ARA13	7/3/01	2.38	--	6.33	South End of ARA-25 hot cell foundation walls
ARA14	7/3/01	0.17	--	7.3	South End of ARA-25 hot cell foundation walls
ARA15	7/3/01	21.41	0.06	5.84	Excavated soils from the south end of ARA-25 hot cell foundation walls
ARA16	7/3/01	1.35	--	4.11	South End of ARA-25 hot cell foundation walls
ARA17	7/3/01	0.19	--	4.73	Main pipe trench leading from the ARA-25 foundation to the ARA-16 tank after piping removal
ARA18	7/3/01	0.84	--	5.03	Main pipe trench leading from the ARA-25 foundation to the ARA-16 tank after piping removal
ARA19	7/3/01	20.21	0.52	5.48	Excavated soils from the main pipe trench leading from the ARA-25 foundation to the ARA-16 tank
ARA20	7/9/01	17.9	--	7.46	Resurvey of Location ARA9 following removal of contaminated soil from the trench
ARA21	7/9/01	8.26	--	5.79	Survey of soils excavated from Location ARA9
ARA22	7/9/01	17.94	--	5.47	Survey of soils excavated from Location ARA9