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Standard Operating Procedure

In situ High-resolution Gamma Spectroscopy During an On-Site Inspection

Metadata *(provisional until PTS QMS DMS platform is operational)*

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Summary

The standard operating procedure is described for *in situ* high-resolution gamma spectroscopy, including operational readiness, planning, preparation, conduct, and reporting. Data analysis of *in situ* gamma spectrum files will be performed together with those of other gamma assay methods by a dedicated Data Analysis process, documented in companion OSI procedures.

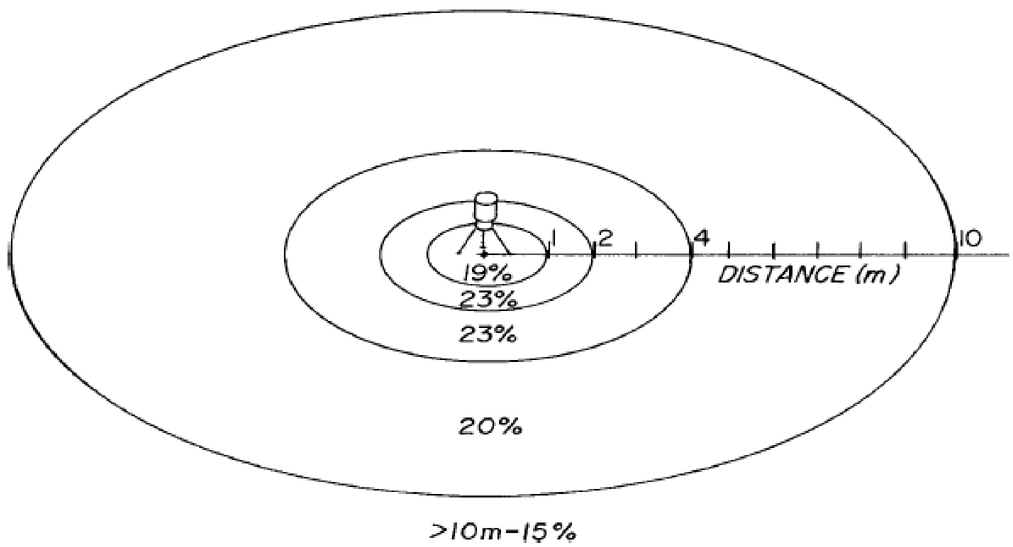

Figure 1. Schematic representation of *in situ* high-resolution gamma spectroscopy assay, with a detector mounted on a tripod 1-meter above the surface; the graphic conveys the relative radial contributions to gamma count rate in the detector, for a uniform deposition of Cs-137 (662 keV gamma energy), moderately diffused into the soil with coefficient $\alpha/\rho = 0.21\ cm^2/g$; the mean-free-path-length of a 662-keV gamma ray in air at standard temperature and pressure is 104 meters (with attenuation factor of 1/e).

Ref: IAEA-TECDOC-1017 Site Characterization for Remediation (1998).

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ABBREVIATIONS [TO BE EXPANDED]

Administrative

CTBTO	Comprehensive Nuclear-Test-Ban Treaty Organization
BOO	Base of operations (equivalent of the Treaty “basing point”)
DM	Documentation Section, OSI Division
DMS	Document management system
DQO	Data Quality Objective
EP	OSI Equipment Section designator
IA	Inspection Area
ISP	Inspected State Party
IT	Inspection Team
ITL	Inspection Team Leader (equivalent of the Treaty “head of the inspection team”)
OSI	On-site inspection
PTS	Provisional Technical Secretariat
QMS	Quality Management System
RST	Radionuclide Sub-Team
SOP	Standard operating procedure
STGL	Sub-team group leader
WIN	Work instruction

Technical

DU	Detector Unit
GPS	Global Positioning System
LED	Light-emitting diode
QA	Quality Assurance
QC	Quality Control
PDA	Personal digital assistant
PPE	Personal protective equipment

1. INTRODUCTION

In Onsite Inspection (OSI) operations, the *in situ* high-resolution gamma spectroscopy method is used for both search area reduction and field assay of OSI Relevant Radionuclides (RRs). It is used in coordination with other OSI Radionuclide survey and physical sampling methods. Based on gamma-ray mean-free-path-lengths in air as a function of energy, RRs lend themselves to *in situ* detection and assay (see Table 1):

Nuclide / Main Gamma Energy	Mean Free Path Length in Air (at STP)
Am-241 / 59 keV	43 m
I-131 / 364 keV	81 m
Cs-137 / 662 keV	104 m
La-140 / 1596 keV	160 m

Table 1: Conveys representative gamma-ray mean-free-path-lengths in air at standard temperature and pressure, attenuated by a factor of 1/e.

Strengths of the *in situ* method include: broad area coverage and effective daily throughput; high-resolution gamma analysis for inspection team decision-making; radionuclide assay performance comparable to physical sample assays in accuracy, precision, detection limits, and throughput; less sensitivity to field inhomogeneity than physical sampling; and, immediate field results to guide next measurements. Recognized limitations of *in situ* detection and assay of radionuclide deposition concentrations include: inhomogeneous source distribution, surface roughness factors, undetermined soil diffusion depths, the need to operate under daytime conditions without strongly inclement weather, and the potential for simultaneous air-shine and ground-shine for substantial radiological releases.

Daily operations over the course of an OSI will task the *in situ* gamma spectroscopy method with assigned daily objectives by ROI including:

Objective 1 – Radionuclide Anomaly Detection

Objective 2 – OSI Relevant Radionuclide Detection

Objective 3 – OSI Relevant Radionuclide Quantification

Objective 4 – OSI Relevant Radionuclide Ratios

Companion OSI documentation establishes Data Quality Objectives (DQOs) related to these scenario-driven objectives. Radionuclide aerial survey methods may also use *in situ* assays as ground-truth normalization. *In situ* quality assurance steps are performed at the OSI Base of Operations (BOO), while quality control steps are incorporated into daily field operations.

2. PURPOSE

This standard operating procedure describes the operational readiness, planning, preparation, conduct, and reporting of the *in situ* gamma spectroscopy method associated with OSI Radionuclide Technique operations.

3. SCOPE

This procedure addresses functions of the Radionuclide Sub-Team (RST) group leader and team members in planning, preparation, conduct, and reporting of *in situ* gamma measurements. It is in support of the OSI Operations Manual, which includes integrated mission planning across OSI techniques, and a daily planning cycle that designates regions-of-interest (ROIs) for radionuclide measurements. Companion documents for OSI Relevant Radionuclide DQOs are to be drawn upon in the daily planning cycle for radionuclides.

This SOP is intended for use at the Base of Operations (BOO), while related work instructions contain instrument-specific guidance for use during field operations. Comprehensive detector calibrations of *in situ* instruments are to be performed prior to OSI deployment, with this procedure describing checks of these calibrations to be performed during operations. This procedure concludes with the reporting of *in situ* field assays to the companion BOO Data Analysis function, whose separate procedures address gamma spectroscopy data reduction, reporting, and interpretation.

Note: If implemented under future conditions, OSI Information Barriers applied to gamma spectroscopy methods would affect content of this SOP and its companion WINs throughout.]

4. REFERENCES

a) OSI Operations Manual, Version x.x, Date dd/mm/yyyy
b) OSI Inspection Team Functionality Reference, Version x.x, Date dd/mm/yyyy
c) OSI Relevant Radionuclide Reference, Version x.x, Date dd/mm/yyyy
d) OSI Radionuclide Data Quality Objectives Reference, Version x.x, Date dd/mm/yyyy
e) IAEA-TECDOC-1017 Site Characterization for Remediation (1998)
f) IAEA-TECDOC-1118 Compliance Monitoring for Remediated Sites (Oct 1999)
g) US EPA 625-R-93-013 EPA Handbook on Remediation Approaches
h) US NRC NUREG-1506 Measurement Methods for Decommissioning Surveys (1998)
i) US NUREG-1507 MDCs for Field Survey Instruments (Jun 1998)
j) US NUREG-1575 MARSSIM Ch. 6 Field Measurement Methods and Instrumentation
k) ANSI N42.28 American National Standard for Calibration of Germanium Detectors for In-Situ Gamma-Ray Measurements, Dated 26/02/2004
l) IEEE Standard 325-1996, IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors, Dated 06/01/1997
m) LLNL-SM-636474, HOTSPOT Health Physics Manual, S. Homann, *et al.*, 2013
n) LLNL-TM-411345 Rev. 1, HOTSPOT Health Physics Codes, User's Guide Version 2.07.1 (8 March 2010)
o) CTBTO OpenSpectra Users' Guide, Version 1.0, Dated May 2013
p) ORTEC Application Note, *The Best Choice of High Purity Germanium (HPGe) Detector* (Published more recently than 2001)
q) ORTEC Application Note AN63, *Simply Managing Dead Time Errors in Gamma-Ray Spectrometry*, D. Gedcke (Published more recently than 2002)
r) Canberra, *Basic Counting System Note* (Nov 2010)
s) U.S. Atomic Energy Commission, CEX-62.81, *Civil Effects Study: Ground Roughness Effects on the Energy and Angular Distribution of Gamma Radiation from Fallout*, Published by EG&G, Dec 1963
t) Health Physics, *Ground Roughness Effects on the Energy and Angular Distribution of Gamma Radiation from Fallout,* Huddleston, *et al.*, Vol 11, pp. 537-548, Pergamon Press 1965

5. RESPONSIBILITIES

5.1 Inspection Team Leader (ITL)

Across OSI techniques, use Inspection Team Functionality procedures to direct the integrated daily planning cycle, which designates regions-of-interest (ROIs) for ongoing tasking, reviews Radionuclide Sub-Team (RST) results to date, and tasks ROIs for Day+1, Day+2, etc. for planning by the RST.

5.2 Radionuclide Sub-Team Group Leader

For ROIs tasked for RST survey/assay: determine by ROI the Radionuclide methods to be applied; and, for the *in situ* gamma spectroscopy method, use this SOP in planning, preparation, conduct, and reporting. Ensure RST members are prepared to conduct upcoming daily operations, maintain RSTL communications and oversight during field operations, ensure full reporting to BOO Data Analysis, and convey Radionuclide daily outcomes to the ongoing IT planning cycle.

5.3 Radionuclide Sub-Team Member

Participate in daily planning, including for *in situ* gamma measurements; conduct RST daily operations for *in situ* measurements in accordance with SOP and WINS guidelines; report *in situ* results to BOO Data Analysis. Conduct *in situ* operations in conjunction with companion RST radionuclide methods such as vehicle-based survey, air sampling, and physical soil sampling.

6. PROCEDURE

6.1. Perform *In situ* Detector Characterization (Ongoing Readiness)

OSI *in situ* high-resolution gamma spectroscopy instruments are to be fully characterized for detector response and performance, and maintained in readiness ahead of an OSI deployment. Certain aspects of detector performance are to be checked on a daily basis under field conditions. The deployed RST does not deploy with the capacity to perform full detector characterization under field conditions. Rather, for instrument-level replacement over the course of OSI operations, sufficient numbers of instruments are to be deployed to the Inspection Area (IA). Detector characterizations here are required for *in situ* measurement quality control in the field, quality assurance at the base of operations, and for Data Analysis sufficient to meet OSI objectives and data quality.

<u>6.1.1 Detector Calibration – Energy/Resolution/Peak Shape</u>

HPGe detectors have straightforward approaches using known reference nuclide sources for establishing energy, resolution, and peak shape calibrations. As HPGe detector parameters gradually change while in use or in storage, calibrations are to be maintained on a recurring basis by the Equipment section ahead of OSI deployment (monthly, quarterly, semi-annually, or annually, as appropriate).

In readiness for deployment, establishing energy/channel conversion factors and maximum energy ranges of detectors confirms instrument health, and provides a close starting point for field operations. Determining full-width-at-half-maximum (FWHM) and other peak shape parameters as a function of energy also confirms detector health, while also confirming whether a given detector can meet DQOs in operations.

The Data Analysis function requires these energy/resolution/peak shape parameters in spectrum analysis, and the parameter formats are to match the OpenSpectra User's Guide spectrum analysis specifications.

References are IEEE Std 325-1996, ANSI N42.28, and the OpenSpectra User's Guide.

6.1.2 Detector Calibration – *In situ* Efficiency

The intrinsic gamma-ray detection efficiency as a function of energy for HPGe detectors is established by straightforward approaches using known reference sources. The *in situ* assay method has the further requirement of determining an infinite-flat-plane efficiency calibration. Such calibration approaches address the two factors of infinite-flat-plane radial radionuclide deposition and inter-related air attenuation, accounting for the angle of incidence on the HPGe detector. Such approaches are not intended to account for the well-known complicating effects of simultaneous air-shine, surface roughness, and soil diffusion.

Establishing detection efficiency as a function of energy for the *in situ* geometry is to be performed by validated empirical or modeling simulation methods. The efficiency parameter formats are to match spectrum analysis specifications of the OpenSpectra User's Guide.

Infinite-flat-plane efficiency calibration is a main source of systematic uncertainty in Data Analysis, and must be estimated during calibration (as a function of incident gamma energy).

References include IEEE Std 325-1996, ANSI N42.28, and the OpenSpectra User's Guide.

Proven empirical and numerical *in situ* efficiency calibration approaches include:

Method A) Single-Nuclide Source Radial Calibration

Sources of the same nuclide with known intensities are assayed at straight-line radial increments in a laboratory setting, from directly below the detector to the radial distance at which calibration parameters reach asymptotic values; algorithms are used to establish the infinite-plane efficiency.

Strengths: Empirically accounts for both exact HPGe crystal geometry and air attenuation on the infinite plane geometry; delivers uniform efficiency parameters for gamma-ray energies higher than approximately 200 keV

Limitation: Requires multiple single-nuclide sources of increasing strength as radial distance increases up to tens of meters; establishing such a calibration below 200 keV entails suites of single-nuclide sources at the OSI-relevant energy ranges.

References:
- LLNL-SM-636474, HOTSPOT Health Physics Manual, S. Homann, et al., 2013
- LLNL-TM-411345 Rev. 1, HOTSPOT Health Physics Codes, User's Guide Version 2.07.1 (8 March 2010)

Method B) Single-Source Fixed Distance Angular Calibration

A single-nuclide reference source of known intensity is assayed on an armature of 100-cm radius at stepped angles between 0-90 degrees from below the tripod center; algorithms are used to establish the infinite-flat-plane efficiency, including estimates of gamma-energy-dependent air attenuation factors.

Strength: Empirically accounts for exact HPGe crystal configuration on the infinite plane geometry.

Limitations: Air attenuation is accounted for by algorithm, including gamma energy dependence.

Reference: [Consequence Management Reference]

Method C) Monte Carlo Numerical Modeling Calibration

Numerical simulation of the HPGe detector response function for an infinite-plane radionuclide source term.

Strengths: Provides energy-dependent efficiency calibration across the full range of continuum energies; can be performed for specific instruments that have not been accessible for empirical calibration.

Limitations: Requires detailed technical specifications of the specific high-purity germanium crystal and its surrounding housing; lack of necessary detector details limits Monte Carlo accuracy.

Reference: [MC Modeling Reference]

In uses of *in situ* gamma assays for environmental monitoring and remediation, approaches have been developed to adjust quantitative assays for the effects of surface roughness and soil diffusion. Under the widely varying conditions of OSI Inspection Areas and ROIs, such approaches would only be viable if Data Analysis found specific needs for determining treaty compliance/non-compliance. Otherwise, such issues are handled better by physical sample assay in the BOO Laboratory.

Surface Roughness

A recognized physical phenomena in nuclear fallout studies at desert nuclear test sites, in which the measured gamma exposure rate at one-meter above the surface is chronically one the order of 1/2 the predicted exposure rate, were the surface to be perfectly flat. It is ascribed to the surface granularity on deposition, with gamma-emitting nuclides in the field of view settling in roughly equal parts on the near side and the far side of soil grains and surface unevenness. This phenomenon occurs immediately on deposition, separate from longer-term behaviors of soil diffusion and weathering.

In OSI settings including those other than desert environments, the factor of exposure rate attenuation caused by surface roughness will vary widely as dictated by the nature of the surface and homogeneity in the field of view. However, it may be expected to vary between roughly 0.5-1.0 times the infinite-flat-plane value. For quantitative *in situ* gamma assay of specified nuclides, it must be recognized that any "surface roughness attenuation factor" is strongly energy dependent. Nuclide ratios with dominant gamma ray energies within some 10s of keV of each other may remain reliable, and ideally from radioisotopes of the same chemical element so as to minimize nuclide-nuclide deposition inhomogeneities.

Soil Diffusion

Deposited radionuclides undergo weathering and soil diffusion at differing rates, depending on their chemical form, deposition matrix, surface conditions, and precipitation and runoff. OSI RRs such as Cs-137, Cs-134, I-131, and I-132 are known to be quite soluble in water, and to diffuse to depths of many centimeters in soil within weeks and months of deposition under expected annual precipitation conditions. Diffusion depth follows an exponential form, well-studied in environmental monitoring literature.

Correction factors may be applied to *in situ* assay values, were the soil diffusion rate measured within the field of view, for example by soil cores assays by vertical section. Furthermore, in OSI settings other than undisturbed desert environments, diffusion in surfaces/soil/vegetation is not expected to follow such regular diffusion rates. As mentioned for surface roughness, radioisotope activity ratios may still be quantitatively viable, with ratios within the same element and with main gamma emission lines at comparable energies being the least affected. Otherwise, such matrix effects are better addressed by physical soil samples returned to the BOO Laboratory.

References: LLNL-SM-636474, HOTSPOT Health Physics Manual; U.S. AEC CEX-61.81, especially Section 6.5; Health Physics (1965), especially Results Section on p. 541.

6.1.3 Detector Performance – Dead Time Correction Acceptable Range

HPGe spectrum acquisition electronics necessarily entail a "dead time" correction function in the instrument firmware. That is, the acquisition system determines the fraction of time over the course of a spectrum acquisition for which the detector electronics were blocked to new signals, while processing of accepted signals was being completed.

This "dead time" correction is manifested in all instrument gamma spectrum files, where the difference between spectrum "real time" and "live time" was estimated by firmware algorithms. Such dead time algorithms are sufficient to the task at lower count rates, while as count rate increases all such detectors face a count rate upper operating limit, beyond which the dead time correction algorithms become inaccurate. Determining this acceptable operating range for each specific *in situ* detector is required in advance of OSI deployment. If a detector is operated above this count-rate limit, the quoted spectrum live time will become gradually more inaccurate. Straightforward methods are available for such characterization.

References:
- ORTEC Application Note AN63, *Simply Managing Dead Time Errors in Gamma-Ray Spectrometry*, D. Gedcke
- Canberra, *Basic Counting System Note* (Nov 2010)

6.1.4 Detector Performance – Throughput vs. Count Rate

HPGe spectrum acquisition electronics necessarily entail a "peak data throughput"; that is, the acquisition system has an inherent peak value for spectrum gross counts acquired per second of "real time". Beyond this peak value, while the dead time correction may remain accurate, increasing the count rate does not improve data collection throughput per "real time", rather there are diminishing returns. Determining this acceptable operating range for each specific *in situ* detector is required in advance of OSI deployment. Straightforward methods are available for such characterization.

References:
- ORTEC Application Note, *The Best Choice of High Purity Germanium (HPGe) Detector* (Published more recently than 2001)
- ORTEC Application Note AN63, *Simply Managing Dead Time Errors in Gamma-Ray Spectrometry*, D. Gedcke
- Canberra, *Basic Counting System Note* (Nov 2010)

6.2. Develop *In situ* Measurement Plan (Daily)

6.2.1 Quantity & Quality

Quantity

During RST daily planning, establish the number of *in situ* measurements to be performed:

- Review IT tasking for ROIs; work within Inspection Team Functionality processes;
- Establish which ROIs are to have *in situ* assays performed;
- Establish the intended survey pattern for each ROI, including the number of specific locations to receive *in situ* assays;
- Constrain the daily plan by the number of available RST members;
- Constrain by integrated timelines across locations incorporating all RST tasked functions at each site, such as *in situ* measurements, air sampling, and soil sampling
- Include timelines for departure from BOO, transit between locations, instrument setup, data acquisition, teardown, and return to BOO within the defined operating day.

Quality

During RST daily planning, establish the Data Quality Objectives (DQOs) for the individual *in situ* measurements to be performed. From IT tasking for each ROI, establish the relevant assay objectives within the following:

Objective 1 – Radionuclide Anomaly Detection

Objective 2 – OSI Relevant Radionuclide Detection

Objective 3 – OSI Relevant Radionuclide Quantification

Objective 4 – OSI Relevant Radionuclide Ratios

Determine matching Data Quality Objectives for each of the tasked objectives, drawn from companion OSI Radionuclide DQO references:

DQO 1 – Analyte Detection Limits (such as Bq/m^2 by OSI RR)

DQO 2 – Analyte Detection Confidence Level (% C.L. required for OSI RR detection)

DQO 3 – Assay Uncertainty (statistical and systematic, by individual OSI RR)

Present OSI Relevant Radionuclides include the following:

Particulates – Zr-95/Nb-95, Mo-99/Tc-99m, Ru-103, Ru-106/Rh-106, I-131, Te-132/I-132, Xe-133, Cs-134, Cs-137, Ba-140/La-140, Ce-141, Ce-144/Pr-144, Nd-147;
Noble Gases – Ar-37, Xe-131m, Xe-133m.

6.2.2 Instrument Selection

For daily operations, identify specific HPGe *in situ* instruments by serial number to be deployed to each tasked ROI, considering:

HPGe Relative Efficiency – Select the highest relative efficiency HPGe *in situ* detector appropriate to local gamma exposure rates of a specific ROI, to maximize data throughput. Given the fixed tripod geometry of *in situ* assay, and instrument-specific limits on accurate dead-time correction, certa*in situ*ations will dictate a lower relative efficiency detector be deployed.

HPGe Energy Resolution – Ensure that selected HPGe detectors meet the required energy resolution as determined by field check sources, given that detector resolution directly affects achieving OSI RR minimum detection limits (MDLs).

Collimation/Shielding – Determine whether collimation or shielding is required for the intended *in situ* assay locations, to shield against specific localized radiation sources, or reduce overall gamma exposure rates.

Spares – For each RST deploying to an ROI, select both primary and secondary *in situ* instruments to deploy with, to prepare for hardware failures in the field; such commercial instruments are not easily repaired under field conditions.

6.2.3 Site Selection

During daily operations planning before deployment, perform site selection for *in situ* assays as constrained overall by the IT survey grid for the ROI, previous radionuclide surveys & assays within the ROI, and then field conditions that dictate conditions for *in situ* assays:

- Perform local radiation surveys at the selected site (vehicle, backpack, or handheld) to determine gamma radiation profiles and homogeneity, identify potential hotspots.

- Perform *in situ* assays over as uniform a surface as practical; avoid areas with transitions between surfaces within 10 meters radial distance of the detector (pavement to vegetation, for instance); avoid tilled fields and similar settings.

- Level surfaces maximize the effective area being assayed. Surface roughness and diffusion into the surface result in attenuation and can impact achievable sensitivity. Surfaces subject to runoff by precipitation or other means should be considered carefully, with preference given to areas where runoff collects.

- While the standard tripod height for *in situ* assay is 1-meter above ground, consider whether a different height would improve assay conditions; for instance, a high deposition concentration may benefit from a measurement at greater than 1-meter above the surface to reduce detector exposure rate; deposition that shows large local gradients could benefit from measurement closer to the ground, to reduce the field inhomogeneities affecting data analysis. (Note that either of these options would require significantly different infinite-flat-plane efficiency corrections.)

- Consider local background and detector dead time. Note that increased dead times do not necessarily present a problem, depending on the instrument firmware. High-quality digitizers can remain linear in their dead time correction even to dead times approaching 95%, while other modern electronics start have been observed to show degradation above 70% dead time. HPGe electronics also have a maximum data throughput rate, often around 60% dead time for modern digital electronics.

- Conducting an assay at dead times significantly higher than the instrument's maximum throughput can result in unnecessarily longer measurements to achieve equivalent detection limits or assay uncertainties (even while the dead time correction algorithm may remain accurate). Among a suite of HPGe *in situ* detectors, higher and lower relative-efficiency detectors can be assigned according to the known or estimated exposure rates of planned field locations.

- If relevant, arrange the daily sequence of field *in situ* locations in order of lowest-to-highest contaminant risk, so as to minimize cross-contamination of gamma assays.

- As OSI operations progress, site selection will find it essential to have photographs, overhead images, or other documentation of field conditions. Documenting the same can be a significant aid to *in situ* data analysis and interpretation.

- During BOO planning, perform a thorough quality assurance review of site selection, to optimize sampling through improved planning, avoid non-representative sampling, and facilitate re-sampling.

6.2.4 Co-Located Radionuclide Methods

The RST is expected to conduct co-located radionuclide methods at a given selected site, as established in the daily plan for a given ROI. *In situ* operations in conjunction with physical sampling, air sampling, and others must be conducted such that no one approach interferes with the data quality objectives of another. It is essential for the Data Analysis function that field record keeping is sufficient that results of co-located assays are clearly and directly linked with one another for ongoing interpretation.

Cross-comparison of interpreted results among assay methods brings value, such as air samples determining the presence of air-shine for *in situ* assays, and corroborative comparison of deposition concentrations and radionuclide activity ratios.

6.3. Conduct *In situ* Field Assays (Daily)

6.3.1 Prepare

For each daily operational cycle, after the *In situ* Measurement Plan is established, the RST deployed team executing the plan for a specific ROI will have required preparations before deploying.

Daily Plan Review

The RST members assigned to perform *in situ* assays in a given ROI should review the *In situ* Measurement Plan developed for that day, for content and feasibility, in particular to confirm the requested Quantity and Quality are achievable.

Instrument Preparation

Work instructions for specific *in situ* instrument types are to include the following:

- Battery Charging (for electrically cooled detectors); field power sources for sustained operations.

- Cool Down; HPGe detectors must be allowed to reach operational temperature prior to using (whether mechanically-cooled or liquid-nitrogen cooled), which may be a significant amount of time depending on the starting state of the detector.

- Collimation; Detectors should generally be used uncollimated to see the maximum source area possible; if the specific site conditions warrant collimation or directional shielding, such materials must be prepared.

- Equipment Date/Time Settings – Ensure that the date and time are correctly set on each piece of equipment.

- Field Conditions Preparations – Steps should be taken to prevent equipment from becoming contaminated in the field. If tripods are used, bag the feet of the tripod with plastic; in environments with dispersible radioactivity or re-suspension hazard, also bag the instrument itself. For other equipment that may be set on the ground, bring a piece of plastic sheeting (or similar) to set the instrument on to avoid direct contact. Covers may be necessary to protect equipment from windblown dust and rain.

- Data storage; confirm by direct test that instruments to be fielded can properly store and transfer data according to their specifications.

Instrument Quality Control Checks

Work instructions for specific *in situ* instrument types are to include the following:

- Energy Calibration/Resolution Check – An energy calibration must be conducted based on manufacturer's instructions for the specific instrument being used, and either available radionuclide check sources or ambient background energy lines. Instruments undergoing active field use can suffer unexpected changes in energy calibration and energy resolution.

- Efficiency Calibration/Field Check; such efficiency calibration is properly performed before OSI deployment; daily check sources should be employed to confirm the detector efficiency is unchanged within tolerance.

- Background Data Acquisition; establish an *in situ "*baseline background location" in the vicinity of the BOO, with soil/vegetation conditions representative of the field ROIs; perform a daily background health check before deployment with the primary instrument; confirm background assay total count rate, NORM background peak intensities, and background continuum are consistent with the baseline record.

- Contamination Check; before departing for daily operations, in a reduced-background and source-free setting (such as a building interior), perform a brief contamination-control data acquisition with the primary and secondary instruments; confirm baseline records. Follow this by performing contamination checks of vehicles, equipment, and personnel; conduct the same at the end of the day.

- Dead Time/Throughput Detector Characterization Records; such characterization is properly performed before OSI deployment to the IA; the RST deployed team should ensure these performance characteristics are immediately on-hand for each instrument serial number deploying for operational use.

Ensure RST field team *in situ* instruments have documentation of acceptable operating ranges for dead time and throughput, by serial number.

Additional Equipment/Materials

In addition to the detector, other equipment and materials that should be prepared or replenished ahead of daily operations should include:

- Field Computer – for detector setup (if necessary) and data transfer.
- Instrument File Download – necessary data cables, electronic media, or host software for file download.
- Communications Equipment – for maintaining BOO and RSTGL oversight and real-time status reporting during operations; for transmitting data and records as required.

- Check Sources – for detector calibration and quality control.
- Instrument heating/cooling materials, for high & low temperature environments (consider manufacturer specifications for instrument operating temperatures).
- Camera – for documenting field conditions throughout *in situ* operations.
- Tape measure or a fixed-length guide – for measuring source to detector distance or fixing it to a specific distance.
- Health physics instruments – Micro-R meter, ion chambers (for higher level dose areas), and beta/gamma friskers for assessing personnel safety when in the field and detecting contamination.
- GPS – for marking sample locations.
- Personal protective equipment – gloves, booties, coveralls, etc. for preventing personnel contamination.
- Dosimetry – for assessing dose to field personnel; personnel and self-reading dosimeters should be provided if potentially high radiation areas are present.
- Miscellaneous supplies – Ziploc bags, plastic and tape for preventing contamination to equipment.
- Batteries – spare batteries should be carried for all equipment in the field.
- Liquid nitrogen – for LN cooled detectors, if any; the logistics for obtaining LN may be difficult in remote areas.

6.3.2 Conduct

On arrival at an identified assay location within an ROI, apply detailed site selection criteria, implement WINS for *in situ* instrument setup and data acquisition, and perform sufficient recordkeeping associated with the *in situ* assay.

<u>Detailed Site Selection</u>

Once at a general location, it is necessary to choose a specific site to obtain the *in situ* spectrum. If only a qualitative analysis is to be done, locating areas of elevated radioactivity is the goal. Handheld exposure rate instruments should be used to survey the local area to find areas of potential interest. In semi-arid regions, fallout may clump around vegetation from wind-blown soil. Disturbed areas such as tilled fields and pavement should be avoided because these effectively reduce the field of view of the detector, and distort quantitative accuracy. (See Figures 2 and 3.)

Where quantitative analyses are in the daily objectives, it is desirable to choose a site similar to the infinite-plane calibration geometry. The site should be a flat, open area with no obstructions such as boulders, trees or man-made structures within at least a 10 meter radius, and preferably a 50-100 meter radius. This will allow for averaging over the maximum possible area while limiting attenuation of the gamma rays by intervening materials.

When choosing a site, it is important to characterize and record the surrounding conditions. This process includes the measurement of the ambient dose rate and surface contamination levels, and non-radiological hazards. Areas that would be subject to runoff, such as paved surfaces, could lead to reduced sensitivities and possibly non-representative samples of the average deposition and nuclide composition in those areas. When optimum sites are not available and data is critical from that location, processes need to be developed for analysis of such data to address the objectives of the OSI.

Note that only daytime operations allow thorough site selection and documentation nighttime operations are note recommended, for these reasons and for general health & safety and other inherent human factors in field operations in a radiological environment.

Figure 2. Proper placement of *in situ* assay instruments, focusing on level and undisturbed areas.

Figure 3. Examples of less-than-ideal *in situ* site selection – inhomogeneous surfaces and those prone to runoff complicate radionuclide assay, whether for detection limits, nuclide deposition concentrations, or activity ratios.

Data Acquisition

Perform data acquisition sufficient to meet the established DQOs:

- Before spectrum acquisition, perform field data quality checks according to the WINS.
- Ensure instrument dead time and throughput are within acceptable limits as determined in advance for each specific instrument by serial number.
- Specify duration by desired number of total counts/counts in a peak, a pre-determined elapsed live time/real time, or a minimum detection limit achieved.
- During data acquisition, confirm no unanticipated radiological sources are present.
- Download and transmit gamma spectrum file for Data Analysis.
- Perform field handheld radionuclide identification for OSI RRs.
- Communicate findings for each location to the RST group leader, and consider whether the daily plan deserves amendment.

Record Keeping

Record keeping is to be conducted in line with Inspection Team record keeping, electronic media, data security, data transfer, and chain of custody guidelines; to include at a minimum:

- Inspector and team indicator (if applicable)
- The instrument serial number and calibration date
- Details of collimation and shielding, in any; whether intentional or inadvertent
- Records of field quality control checks (Energy, FWHM, Peak Shape)
- Data acquisition start date/time, live time, real time
- Records confirming dead time & throughput are within acceptable operating ranges
- Location of the spectrum, including GPS coordinates
- Source to detector distance (height above ground)
- Details of the surface type and environmental conditions
- Thorough photographs of the actual detector setup, immediate local measurement environment, and the four cardinal directions of the wider environment

6.3.3 Recover

On return to the BOO, perform equipment and materials recovery necessary to prepare for next day operations. This is to include instrument quality control field checks, and contamination checks of instruments, equipment, vehicles, and staff.

6.4. Report to Data Analysis (Daily)

Either by field transmission or on return to the BOO, the RST deployed team will transmit to the BOO Data Analysis team the collected *in situ* gamma spectrum files, all required additional information regarding the field assay (as described in record keeping above), and confirmation of field data acquisition quality control checks.

The Data Analysis team will perform data analysis and interpretation of *in* situ gamma measurements, to meet the daily objectives and DQOs (and see Section 6.1.1). Over the course of data analysis and interpretation, RST deployed team members should anticipate queries from the Data Analysis team on aspects of the data collection and reporting.

Data Analysis will use the CTBTO NDC-in-a-Box package and Open Spectra GUI Software. The process will require *in situ* spectrum files, detector calibration parameters, and records.

7. QUALITY ASSURANCE CONSIDERATIONS (DAILY)

Main quality assurance considerations for *in situ* gamma assays include:

- Ongoing review of measurement plans and outcomes for site selection criteria; necessary full record keeping and reporting for the same
- *In situ* instruments operating within appropriate dead time and throughput ranges
- Necessary quality control checks being performed on energy calibration, resolution, peak shapes, and efficiency
- Overall review of whether the Data Quality Objectives are being achieved for ongoing *in situ* gamma assays, including identifying corrective actions for the same

GLOSSARY [TO BE EXPANDED]

Base of operations (BOO): A fixed or temporary facility located inside, or in the vicinity of, the inspection area from which the IT coordinates and/or conducts its inspection activities. It is the equivalent of the term "basing point" as the latter appears in Part II of the Protocol.

Global Positioning System (GPS): An accurate worldwide navigational and surveying network based on the reception of signals from an array of satellites.

APPENDIX: *IN SITU* OPERATIONAL PROCEDURE CHECKLIST

Performed by: Date ______________________

______________________ ______________________
Name of IT Member Signature

Operational Process Activity	YES	NO	Remarks
6.2. Develop In situ Measurement Plan (Daily)			
6.2.1 Quantity & Quality			
- Determine Quantity by ROI			
- Determine Objectives and DQOs by ROI			
6.2.2 Instrument Selection			
- Identify Primary & Secondary Instruments, by Serial No.			
- Ensure documentation of acceptable operating ranges			
6.2.3 Site Selection (By ROI and Team)			
6.2.4 Co-Located Radionuclide Methods (Identify)			
6.3. Conduct In situ Field Assays (Daily)			
6.3.1 Prepare			
- Review the Daily Plan (content and feasibility)			
- Instrument Preparation (follow the WIN)			
- Perform Instrument Quality Control Checks			
- Prepare Additional Equipment/Materials			
6.3.2 Conduct			
- Detailed Location Selection			
- Data Acquisition (Meet Objectives and DQOs)			
- Download and transmit spectrum files for Data Analysis			
- Perform field handheld radionuclide ID for OSI RRs			
- Communicate findings by location to the RSTGL			
- Perform Record Keeping			
6.3.3 Recover			
- Perform equipment and materials recovery for next day			
- Instrument quality control field checks			
- Contamination checks of equipment, vehicles, and staff			
6.4. Report to Data Analysis (Daily)			
- Transmit spectrum files to Data Analysis			
- Transmit all associated record keeping, incl. field QC checks			
- Respond to Data Analysis queries on field operations			
7. Quality Assurance (Daily)			
- Review plans and outcomes for site selection criteria			
- Confirm in situ instruments operating within ranges			
- Ensure necessary quality control checks being performed			
- Review Daily Objectives and DQOs are being achieved			
- Identify corrective actions			