**CONTROLLED DOCUMENT**

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Los Alamos

**National Laboratory**

**Environmental Programs Directorate**

**Waste and Environmental Services**

# Quality Assurance Project Plan

## for the

# BIOTA DOSE ASSESSMENT

**Signatures**

| | |
|---|---|
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# Table of Contents (A2)



**Appendix**

This plan has the following appendixes:

# Distribution List (A3)

**List of document recipients**

This document will be controlled under the organization's document control system to ensure that those performing work for the project will be notified of new revisions. Those who will be notified include:

- Group Leader
- Deputy Group Leader
- Team members
- Assistant Manager, Facility Operations, NNSA/DOE Los Alamos Site

# Introduction

**History of revision**

This table lists the revision history of this plan.

| Revision | Date | Description Of Changes |
|---|---|---|
| 0 | 06/16/05 | New document. |
| 1 | 03/10/09 | Clarified the use of RESRAD-Biota level-3, the RESRAD-Biota area factor, water data for terrestrial assessments, aquatic and riparian habitats, and the dose to representative individuals, as suggested in the DOE Assessment dated May 2008. |

**Purpose of this plan**

This document specifies the actions necessary to ensure the quality and accuracy of biota dose assessments in the Los Alamos environment. The environment is defined as the locations affected by DOE activities at Los Alamos National Lab and its predecessors (beginning with the Manhattan Project) that are not part of experimental facilities (for discussions of experimental facilities, see DOE-STD-1153-2002 pages M1-22 and M2-24).

This plan also demonstrates compliance with the DOE O414.1A requirements for a quality program.

# Project Organization (A4)

| | |
| --- | --- |
| **Project organization** | The Biota-Dose-Assessment project leader reports to the Group Leader. Members of the group work for the project leader as needed to provide dose assessment and data evaluation. |
| **Approval of products and deliverables** | Final products and deliverables will be approved by the project leader and reported to the Group Leader. |

# Problem Definition (A5)

**Background**

Los Alamos National Laboratory (LANL or the Laboratory) is a research and development institution operated by the Los Alamos National Security (LANS) for the U.S. Department of Energy (DOE).

Some of LANL's operations have emitted and continue to emit radionuclides. The impact on the biota is determined by calculating the dose rates in units of rad/day.

These doses are compared to standards developed by the International Commission on Radiation Protection (ICRP), the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the US Department of Energy (DOE). There is general consensus that standards of 0.1 to 1 rad/day are protective of biota.

**DOE Order 450.1**

DOE Order 450.1, "Environmental Protection Program", Attachment 2 Section 10, directs LANL to evaluate the potential impact to the biota in the vicinity of the DOE activity.

**DOE Order 5400.5**

DOE Order 5400.5 Chapter 2 Section 3a(5) states: "To protect native animal aquatic organisms, the absorbed dose to these organisms shall not exceed 1 rad per day from exposure to the radioactive material in liquid wastes discharged to natural waterways."

# **Problem Definition (A5)**, continued

**DOE-STD-1153-2002**

DOE-STD-1153-2002, "A graded approach of evaluating radiation doses to aquatic and terrestrial biota" (July 2002) page M1-1 [http://www.eh.doe.gov/techstds/standard/std1153/1153.htm] states that the absorbed dose should not exceed:

0.1 rad/day to terrestrial animals;
1 rad/day to terrestrial plants; and
1 rad/day to aquatic animals.

(Note: DOE-STD-1153-2002 uses "should" whereas DOE Order 5400.5 uses "shall".)

The DOE does not have a dose-rate standard for aquatic plants. According to DOE-STD-1153-2002 (page M1-21), aquatic plants are reasonably protected by the standard for aquatic animals.

**Problem definition**

LANL has emitted and continues to emit radionuclides that cause a radiological dose to biota. The problem is to determine if the biota doses are above the dose limits in DOE Order 5400.5 and DOE-STD-1153-2002.

**Decision makers**

The principal decision maker for the team is the Biota-Dose-Assessment project leader.

**Customer for results**

The results of the dose assessment will be sent to the Group Leader. Results will also be sent to any LANL operating group that requests them and will be published in the Laboratory's annual Environmental Surveillance Report. The results will ultimately be used by the LANL division leaders and the DOE to make decisions regarding mitigation.

# Project Description (A6)

**Purpose**

The purpose of biota dose assessment is to estimate the dose rates to biota in the environment near and on LANL property.

**Assessments**

The assessments performed annually and reported in the Environmental Surveillance Report (ESR) as part of this project are

- the dose rates to terrestrial animals, terrestrial plants, and aquatic animals for comparison with DOE Order 5400.5 and DOE-STD-1153-2002.

Other dose assessments may be performed as the needs arise.

**Quality assurance**

The group chose to write this plan in accordance with the EPA standard for quality plans (EPA QA/R-5, "EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations").

**Personnel**

Personnel with the following are required: experience or training in health physics, data evaluation and calculation, dose assessments, and quality assurance. Minimum training and education requirements are given in the section *Special Training and Certification (A8)*.

**Required records and reports**

Appropriate and sufficient records should be maintained so the final results can be verified or recalculated later. Such records should include the procedure used to determine the effective dose equivalent. See the section *Documentation and Records (A9)* for a list of the records to be preserved.

Biota dose assessments are calculated annually and published in the annual Environmental Surveillance Report (ESR) as specified in DOE Orders 231.1 and 450.1.

# Quality Objectives and Criteria for Measurement Data (A7)

**What are DQOs?**

The Data Quality Objectives, DQOs, for the Dose assessment team were developed in accordance with EPA QA/G-4, "Guidance for the Data Quality Objectives Process," September 1994. Data quality objectives (DQOs) are statements of the problem to be addressed, the decision to be made, and the scope of the data required for that decision.

Section A7 is organized into the following subsections:

7.1 Decision statement
7.2 Data types as input to the decision
7.3 Data boundaries
7.4 Data accuracy and precision
7.5 Completeness
7.6 Representativeness
7.7 Comparability

**7.1 Decision statement**

If any assessment indicates a biota dose with a potential to approach or exceed a limit specified in DOE-STD-1153-2002 or DOE Order 5400.5, the Biota-Dose-Assessment project leader will develop recommendations to management.

**7.1.1 Use of the BCGs**

The biota concentration guides, BCGs, are a general screening tool used to trigger further investigation. They should not be used to make management decisions. DOE-STD-1153-2002 (page M1-52) says: "An important point is that exceeding the BCGs should not force a mandatory decision regarding remediation of the evaluation area, but rather is an indication that further investigation is likely necessary."

# Quality Objectives and Criteria for Measurement Data (A7), continued

**7.2 Data types as input to the decision**

Inputs to the decision require measurements of radionuclide concentrations in environmental media as follows:

- soil
- sediment
- water
- biota

As noted in DOE-STD-1153-2002, the air pathway does not contribute significantly (pages M2-20 and M3-5).

Facilities such as LANSCE and DARHT are excluded (DOE-STD-1153-2002 pages M1-22 and M2-24) so direct radiation contributes only from the radionuclides in soil, sediment, and water.

Aquatic plants are assumed to be adequately protected by consideration of aquatic animals (page M1-21).

Each type of data is discussed in subsections 7.2.1-4.

**7.2.1 Soil**

Radionuclide concentrations in soil are measured; measurements near potential release sites (PRS) are especially important.

The measured soil concentrations will be compared with the general screening levels in Tables 6.3 and 6.4 of DOE-STD-1153-2002 by entering the maximum concentrations into RESRAD-BIOTA. Locations that fail the general screening (level 1) will be subjected to level-2 analysis. Locations that fail level-2 analysis will be subjected to level-3 analysis.

# Quality Objectives and Criteria for Measurement Data (A7), continued

**7.2.2 Sediment**

Radionuclide concentrations in sediment are measured, recorded in the ER database, and published in the annual environmental surveillance report.

The biota dose assessment may be completed without sediment data by taking the default distribution coefficients from Table 6.5 of Module 1 of DOE-STD-1153-2002. Nevertheless, the available data will be compared with the general screening levels in Tables 6.1 and 6.2 of DOE-STD-1153-2002 by entering the maximum concentrations into RESRAD-BIOTA. Locations that fail the general screening (level 1) will be subjected to level-2 analysis and locations that fail level-2 analysis will be subjected to level-3 analysis.

**7.2.3 Water**

Radionuclide concentrations in water are measured and published in the annual environmental surveillance report.

The measured concentrations will be compared with the general screening levels in Tables 6.1 through 6.4 of DOE-STD-1153-2002 by entering the maximum concentrations into RESRAD-BIOTA. Locations that fail the general screening (level 1) will be subjected to level-2 analysis and locations that fail level-2 analysis will be subjected to level-3 analysis.

Water data should be included in both aquatic and terrestrial assessments because terrestrial animals drink water.

Aquatic and riparian assessments should be performed only for perennial stream segements, as shown in Figure 6-3 of the Environmental Surveillance Report for 2007, LA-14369-ENV.

**7.2.4 Biota**

A biota dose assessment can be performed using soil and water data only. If so, the assessment is based on the default parameters in DOE-STD-1153-2002, which are conservative (DOE-STD-1153-2002 page M1-10). However, DOE-STD-1153-2002 encourages the use of biota data to obtain "more realistic site-representative" parameters.

Biota data have been used to develop Site-Representative Biota Concentration Guides (BCGs) for cesium-137 and strontium-90 in soil (McNaughton 2008a.)

The LANL limiting site-representative BCGs for soil are as follows:

- Cesium-137: 2,000 pCi/g
- Strontium-90: 300 pCi/g

and for water, they are as follows:

- Cesium-137: 20,000 pCi/L
- Strontium-90: 30,000 pCi/L

# Quality Objectives and Criteria for Measurement Data (A7), continued

**7.3.1 Data boundaries: spatial**

The following considerations constrain the spatial boundaries of the monitored region.

- Biota dose will not be assessed inside the boundaries of an experimental facility (DOE-STD-1153-2002 pages M1-22 and M2-24.)

For RESRAD-BIOTA level 1 (general screening) the maximum concentration is used. For level 2, the concentrations should be averaged over the intersection of the contaminated area and the habitat, as described in Module 2 Section 4 (pages M2-36 through M2-38) of DOE-STD-1153-2002. For level 3, the "Area Factor" should be used to correct for the receptor residence time within the contaminated area, as described in DOE-STD-1153-2002 Section 7.2.1.2 (page M1-48.)

The assessment described in McNaughton 2005 used three standard areas: 0.01 ha for an individual tree; 0.075 ha for an individual mouse; and 3 ha for a population of plants or animals. The first area, 0.01 ha, is the area chosen for LANL's soil monitoring program (Fresquez 1996). The second area, 0.075 ha, is approximately the home range of a deer mouse. And the third area, 3 ha, is 40 times the home range of a deer mouse, which is the population area described by Bowman et al. (Bowman 2002), by Ryti et al. (Ryti 2004), and in LA-UR-04-8246. Although this area is derived as the population area for deer mice, it is convenient to use it also as the standard population area for plants.

# Quality Objectives and Criteria for Measurement Data (A7), continued

**7.3.2 Data boundaries: temporal**

Dose evaluations will be conducted annually (DOE-STD-1153-2002 page M1-22).

Water conditions are not constant so water should be sampled several times per year if possible. There is no compelling reason to average the data over a time span shorter than a year (DOE-STD-1153-2002 page M2-28) so water data will be averaged over a year to coincide with the annual environmental surveillance report.

According to the DOE standard, sediment concentrations may be derived from water concentrations, so sediment sampling is not mandatory. Annual sediment sampling is not needed and sediment data should be used as available.

Soil conditions are relatively stable and there is no compelling reason for annual sampling. Soil data will be used as available.

If the soil conditions and the bioaccumulation factors are well known, concentrations in plants can be derived from soil and water concentrations and concentrations in animals can be derived from concentrations in plants. Therefore, at locations where soil data are well established and conditions are stable, it is not necessary to monitor the biota annually. However, at some locations, such as material disposal areas where the underground radioactive material is not well known and the biota dose is more than 10% of the standard, annual monitoring of biota would be valuable.

In summary, a biota dose assessment can be done with annual water data, historical soil data, and default assumptions from the DOE Standard. However, more frequent measurements improve the accuracy of the assessment.

# Quality Objectives and Criteria for Measurement Data (A7), continued

**7.4 Data Accuracy and Precision**

The dose limits in DOE-STD-1153-2002 are derived from data on many types of plants and animals; for example, see Figure 1.1 on page M1-8 of DOE-STD-1153-2002, which is the same as Figure VII of UNSCEAR 1996. This figure indicates the dose limit for mammals should be 1/3 of that for plants and aquatic animals. The DOE limits (0.1 rad/day for terrestrial animals and 1 rad/day for others) are broad generalizations. These considerations together with the extensive discussions in UNSCEAR 1996 indicate that the DOE dose limits are not accurate to better than a factor of three.

Furthermore, the dose to a representative individual is inversely proportional to the population area. The population area of 3 ha suggested in Section 7.3.1 is conservative; arguments could be made for much larger areas (see Section 7.3.1 of this QAPP and pages M2-35 to M2-38 of DOE-STD-1153-2002.). These considerations indicate that data with an accuracy of a factor of two is acceptable.

Using the graded approach of DOE-STD-1153-2002, a dose assessment can be completed with existing data. By including more data as they become available, the default assumptions are replaced by more realistic parameters. Therefore, whatever data are available, even with large uncertainties, are helpful.

The example on page M2-60 of DOE-STD-1153-2002 suggests an accuracy of about 50%, so we adopt a factor of two as the goal for the *absolute* accuracy. *Relative* accuracy (precision) should be better if possible to facilitate trending.

**7.5 Completeness**

The DOE Standard, DOE-STD-1153-2002, is designed so an assessment can be completed using only the existing measurements of soil and water concentrations, by taking the default distribution coefficients in Module 1 Table 6.5 and the default bioaccumulation factors in Module 3. As more data are obtained, the defaults are replaced by more realistic site-specific parameters. The DOE Standard recognizes that it is impossible to obtain measurements on every type of biota. Thus, in the graded approach, the data set is already minimally complete and will never become totally complete.

# Quality Objectives and Criteria for Measurement Data (A7), continued

**7.6 Representativeness**

Representativeness expresses the degree to which data represent the characteristics of a representative individual member of the population.

It is impossible to study every species of biota (DOE Standard page M1-53), so the types of species chosen for study should be representative of the types of species in the environment of LANL. For this purpose, the DOE Standard suggests representative receptors should be selected that are

- important to the structure and function of the community,
- indigenous,
- familiar to the general public and Native Americans,
- expected to receive a comparatively high degree of exposure,
- radio-sensitive.

Specifically, pages M2-5, 15-17, and 48 suggest monitoring:

- woody plants, especially of the pinaceae family; and
- animals with a small home range such as mice.

The ER publication "Screening Level Ecological Risk Assessment Methods," LA-UR-04-8246, lists 15 representative species in Table 3.6-1. These include a “generic plant” and deer mice.

In summary, the LANL site-representative biota dose assessment will be modeled primarily on the following representative plants and animals:

- trees of the pinaceae family (pine, spruce, douglas fir); and
- deer mice (peromyscus maniculatus).

**7.7 Comparability**

The measurements should be comparable, year-to-year and place-to-place. This is assured by using the same equipment, methods, and procedures.

# Special Training and Certification (A8)

**Personnel education**

Individuals performing dose assessments for the Dose Assessment Team must have education and/or experience as health physicists or an equivalent academic discipline. Documentation of education qualification is maintained by the LANL personnel division.

**Training of personnel**

All personnel performing work are required to obtain appropriate training prior to performing work governed by a procedure. Training will be performed and documented according to LANL procedures.

# Documentation and Records (A9)

**Records resulting from the project**

Dose assessments for the annual Environmental Surveillance Report and for compliance will be documented as required by the **AP-0002, R0 Service Delivery Model for Waste and Environmental Services Division (WES)**. The number, type, and detail of all records will provide sufficient information to allow an individual with equivalent education and training to verify or reconstruct the results. Implementing procedures specify the information to be kept as documentation of the performance of the procedure.

**Reporting of final results**

A dose assessment is calculated annually and published in the annual Environmental Surveillance Report (ESR) as specified in DOE Orders 231.1 and 450.1.

# Sampling Process Design (B1)

**Sampling process design**

Large amounts of data exist and continue to accumulate for the categories outlined in Section A7.2: soil, water, sediment, and biota. In this section, we consider what to do with these data and what additional data are needed.

Annually, a level-1 screening (as defined in RESRAD-BIOTA) will be performed using the data in the annual site environmental survey report. The level-1 screening may lead to more detailed level-2 and level-3 site-specific assessments of specific locations.

The existing measurements of terrestrial animals show the concentrations in the animals are several orders of magnitude below the concentrations of concern. For example, the concentrations of concern for $^{137}$Cs and $^{90}$Sr are >1,000 pCi/g (fresh), whereas existing data show the concentrations in animals are typically <1 pCi/g (fresh) and usually consistent with background. This is expected because the habitat ranges of animals are many orders of magnitude larger than the contaminated areas (see Table 4.2-5 of "Screening Level Ecological Risk Assessment Methods", LA-UR-04-8246) and for this reason, animals are not particularly sensitive tests of the study question.

In contrast to the large range of animals, a terrestrial plant has a fixed location, and those rooted in contaminated soil exhibit high concentrations of the specific radionuclides at these locations. Therefore, measurements are especially needed of terrestrial plants in the areas with highest soil and water concentrations.

# Sampling Methods and Sample Handling (B2 and B3)

**B2 Sampling methods**

In addition to using existing data, hand-held instruments may be used to make surveys and measurements of the concentrations of $^{137}$Cs and/or $^{90}$Sr in plants.

The advantages of a hand-held detector are:

- the measurements may be in-situ with no disturbance to biota or soil;
- a survey takes a few seconds per item;
- a measurement takes about a minute;
- the results are obtained immediately;
- it is cheaper than an analytical laboratory.

**B3 Sample handling**

We will avoid sample handling by making in-situ measurements, with essentially no disturbance to soil or biota.

The words on the "Soil Contamination Area" posting identify the requirements and potential hazards at the locations of interest:

- No digging without permission.
- Do not eat the vegetation.

$^{90}$Sr is a pure beta emitter and given the concentrations found in environmental media it is not an external hazard. The effective external dose to humans is calculated using RESRAD. If the soil concentration is 1,000 pCi/g, the external dose rate is 0.003 mrem/h. The internal dose to humans is 0.1 mrem per gram of material ingested.

Similarly, RESRAD can be used to calculate the doses from other radionuclides. The effective dose from $^{137}$Cs in the areas of interest is less than 0.1 mrem/h. The effective doses from Pu-239, Am-241, Pu-239, and H-3 are all much less than 0.1 mrem/h in any of the areas of interest for biota dose assessment.

In summary, the hazards of in-situ monitoring are minimal.

# Analytical Methods (B4)

**Calculations**

Sections B4.1 and B4.2 describe how to calculate the concentrations of radionuclides in biota using hand-held detectors.

Section B4.3 describes how to calculate the biota dose from the concentrations.

**B4.1 Calculating the $^{90}$Sr concentration**

Section B4.1 describes how to calculate the $^{90}$Sr concentration from measurements with a hand-held beta detector such as an Eberline E600 with SHP380AB.

According to MCNP, the effective thickness is 0.20 g/cm$^2$. For details of this calculation, see Appendix D.

The area of the SHP380AB is 100 cm$^2$, so the effective mass being sampled is (100 cm$^2$)*(0.20 g/cm$^2$) = 20 g.

For example, the count rate from some of the trees is about 200 kdpm, which corresponds to an activity concentration: (200 kdpm)/((2.22 kdpm/nCi)*20 g) = 4.5 nCi/g.

To take a different example, the "Work plan for Mortandad Canyon" (LA-UR-97-3291, page 3-54) reports measurements of the count rate of soil in Pratt Canyon with an ESP-1 with HP260 detector. As before, the count rate in the detector corresponds to an effective thickness of 0.2 g/cm$^2$. The area of the HP-260 probe is 15 cm$^2$, so the effective mass being sampled is 0.2*15 = 3 g. According to Figure 3.4.5-2 of the "Work Plan for Mortandad Canyon", LA-UR-97-3291, the maximum count rate is 8,500 cpm. The efficiency of the detector is 0.225 cpm/dpm (HSR-1 Radiation Detection Instrument Manual, HSR1-INS). Therefore, the soil concentration is:
(8500 cpm)/[(0.225 cpm/dpm)*(2.22 dpm/pCi)*(3 g)] = 5,672 pCi/g = 6 nCi/g.

In summary:

- the detector samples $^{90}$Sr to an effective depth of 0.2 g/cm$^2$; and
- the mass of the sample is (0.2 g/cm$^2$) multiplied by the area (cm$^2$).

# Analytical Methods (B4), continued

**B4.2 Calculating the $^{137}$Cs concentration**

The $^{137}$Cs concentration may be measured with an Exploranium gamma spectrometer or with a Bicron Micro-rem meter. A concentration of 20 pCi/g in a plane source such as the ground causes 20 counts per second in the 0.662-MeV gamma peak of the Exploranium detector. The same concentration causes a dose rate of 12 micro-rem/h in a Micro-rem meter. See Section B7.3 for the calibrations, Sections B7.4 and B7.5 for discussion of the distance of the detector from the source, and Appendix E for more details.

**B4.3 Calculating the biota dose**

*(continued on next page)*

The biota dose calculations will follow the methods specified in DOE-STD-1153-2002, which are conveniently set out in the RESRAD-BIOTA program, http://web.ead.anl.gov/resrad/home2/biota.cfm .

The initial screening will use Tables 6.1 through 6.4 of DOE-STD-1153-2002. All data in the environment (i.e., outside a facility, see DOE-STD-1153-2002 Section 3.3) that fail the screening will be subjected to further analysis as described in DOE-STD-1153-2002 Table 2.1, using levels 2 and 3 in RESRAD-BIOTA. If acceptable results are obtained using level 2, it is not necessary to use level 3.

There is more than an order of magnitude uncertainty in the bioaccumulation factors ($B_{iv}$ in RESRAD-BIOTA). To reduce this uncertainty, bioaccumulation factors should, if possible, be based on direct measurements of radionuclides in the biota. For example, see McNaughton 2008a and b.

As described in DOE-STD-1153-2002 and RESRAD-BIOTA, the analysis proceeds as follows, beginning with step 1, and continuing as far as needed, i.e., a minimal assessment could be performed using step 1 only, followed by a RESRAD-BIOTA run.

1. Enter soil and water data into RESRAD-BIOTA; include sediment data if available.
2. For level 1, use maximum concentrations and the sum-of-fractions method for a general screening.
3. For level-2, use time-weighted average concentrations.
4. For level-2, average the soil data over an appropriate area (e.g., 3 ha for biota populations).
5. For level 2, use site-specific bioaccumulation factors if available.
6. Measure concentrations in biota, deduce bioaccumulation factors, and substitute these for the default factors.
7. For level 3, use a realistic area factor, as described in Section A7.3.1.

# Analytical Methods (B4), continued

**B4.3 Calculating the biota dose,** *continued*

In some cases, internal dose contributes almost all the dose, so a measurement of the biota concentration multiplied by the internal dose conversion factors (Table 2.4, page M3-18, of DOE-STD-1153-2002) leads directly to the dose. If the soil or water concentrations are known, we can calculate a bioaccumulation factor, $B_{iv}$, from the ratio of the biota and the soil or water concentrations, replace the default value of $B_{iv}$ in RESRAD-BIOTA, and obtain the same result.

In some cases the effective soil concentrations are not known. Usually this is because the radioactive material is buried and it is not known how far plant roots have penetrated. In this case, calculate the biota dose using Table 2.4 (Module 3) of the DOE Standard. Also, use the best estimates of the bioaccumulation factors to back-calculate and estimate the effective soil concentrations. Compare these estimates to educated guesses of the actual soil concentrations at various depths.

# Quality Control (B5)

**Quality control**

For measurements with hand-held detectors, use the standard quality-control methods and procedures specified in DOE G 441.1-7:
http://www.directives.doe.gov/pdfs/doe/doetext/neword/441/g4411-7.pdf

In particular:

- Select instruments that are appropriate to the types and energies of the radiation.
- Calibrate the instruments (Section B7).
- Test the instruments before use; check the general condition, battery condition, calibration, response check, and background.

For more details, refer to DOE-HDBK-1122-99 Module 2.16 "Radiation Survey Instrumentation" and Module 2.17 "Contamination Monitoring Instrumentation".
http://www.eh.doe.gov/techstds/standard/hdbk1122/sg216.pdf
http://www.eh.doe.gov/techstds/standard/hdbk1122/sg217.pdf

The quality of the data are controlled most by care and attention to detail. The following details will be carefully addressed.

Data must address the questions:
Who?
When?
Where?
What?
How?

Who and when? Data logs and documents must be signed and dated.

Where? Record the location in a way that can be understood by others.
What was measured? Record the raw data and the units.

How? Record

- the type of instrument;
- the instrument's identification number;
- any adjustable settings of the instrument;
- the procedure being followed; and
- special conditions that may affect the data.

# Instrument and equipment Testing, Inspection and maintenance (B6)

**Instrument inspection, testing, and maintenance**

Instruments will be inspected before each use and tested by measuring and recording the response to a standard and the background rate. The standard may be a NIST-traceable source such as the Cs-137 sources purchased for procedure ESH-17-248, a depleted uranium check source, or a reproducible material such as potassium chloride, as discussed in Appendixes D and E. The responses will be documented and will be part of the record for each set of measurements.

For details on specific instruments, see the HSR-1 procedures:

http://hsr-1.lanl.gov/procedures.htm
HSR-1 Radiation Detection Instrument Manual, HSR1-INS
"Operating the Bicron Micro-rem Meter", ESH-1-07-49
"Operational Checks of Beta/Gamma Survey Instruments", ESH-1-07-85
"Operational Checks of Alpha/Beta Dual Use Probes", ESH-1-07-89
"Setting up the Eberline E-600 and Associated Detectors for Field Use", ESH-1-07-91
"Operating the Eberline E-600 and Associated Detectors", ESH-1-07-92

# Instrument Calibration and Frequency (B7)

**B7.1 Calibration**

The micro-rem meters and the E-600 detectors and probes will be calibrated annually according to the manufacturers' recommendations.

**B7.2 Response of a beta probe**

Depleted uranium (DU) may used to determine the response of the beta detectors. The $^{234m}$Pa in DU has a similar maximum beta energy as $^{90}$Y, so the effective depth is similar to wood. The effective depth is 0.2 g/cm$^2$ for $^{90}$Sr and $^{90}$Y in wood, and 0.16 g/cm$^2$ from $^{234m}$Pa in DU. For details, refer to Appendix D.

Alternatively, the $^{40}$K in potassium chloride may be used to determine the response, see Appendix D.

**B7.3 Calibration of gamma spectrometer**

The 662-keV gamma from $^{137}$Cs and its decay product $^{137m}$Ba provide a unique signature that is cleanly measured with a hand-held sodium-iodide gamma spectrometer such as the Exploranium. The Exploranium counts for a fixed time, (e.g., 1 minute), subtracts background, and reports the count in the 662-keV peak.

The Exploranium Minispec detector is calibrated with a NIST-traceable standard $^{137}$Cs source as described in Appendix E. The conclusion is:

**1 count/s in the 662-keV peak implies 2 pCi/g in the ground.**

As discussed in Appendix E, this same result is accurate within a factor of 2 for a large tree with diameter greater than 1 foot. For a smaller tree with diameter between 3 inches and a foot, 1 count/s implies approximately 4 pCi/g.

**B7.4 Correction for solid angle**

The calibration described above applies to a large plane source with a solid angle of 2π ster-radians (i.e., half a sphere). A small plane source subtends a smaller solid angle, and when inside a hole in the ground, a larger solid angle is subtended. The count rate is proportional to the solid angle, so appropriate corrections should be made, as needed.

# Instrument Calibration and Frequency (B7), continued

**B7.5 Average and maximum concentration**

All measurements, using any method, measure an average concentration, and the average is always less than the maximum. It is important to be aware of what is being averaged, whether the average represents the quantity of interest, and whether the averages are comparable between various methods.

When measuring $^{137}$Cs with a handheld instrument in-situ, the average is over a depth of half the attenuation length. The factor of one half results from integrating over all angles as described in Appendix D. (Appendix D discusses beta particles; the same mathematics applies to photons.) This average may be calculated from the attenuation coefficient: $0.5/(0.08\ cm^2/g) = 6\ g/cm^2$. This value of 6 g/cm$^2$ is similar to the depth sampled by the Soil-Foodstuff-and-Biota (SFB) team, which is 5 cm or 7.5 g/cm$^2$ (see LA-13149-MS).

Laterally, $^{137}$Cs is averaged over a radius of about 2.5 times the distance of the detector from the ground or the tree. Thus, the effective area can be varied by placing the detector close to or far from the contamination. For comparison, the SFB method (LA-13149-MS) samples 5 spots: at the center and the 4 corners of a 10 m by 10 m square.

When measuring $^{90}$Sr in-situ, the hand-held instrument averages over 0.2 g/cm$^2$ nearest to the surface, whereas the SFB data average over 5 cm or 7.5 g/cm$^2$; so the results may differ, depending on the uniformity and depth of the contamination. For a tree, the most important parts are the actively growing parts and the reproductive structures, which are often near the surface. However, $^{90}$Sr that is more than 0.5-inch deep will not be measured.

For screening using the BCGs in DOE-STD-1153-2002, the maximum measured values should be used, so if the contamination is non-uniform, the detector should be placed close to the maximum.

# Inspections, Non-direct measurements, and Data Management (B8 – B10)

**B8 Consumables**

No consumables are required for this project.

**B9 Non-direct measure-ments**

In addition to direct measurements, data may also be taken from the ER database and the environmental surveillance reports, and entered into RESRAD-BIOTA as appropriate.

**B10 Data Management**

Data will be peer-reviewed by qualified technical staff members and then entered into a database before they are used for an official biota dose assessment.

In most cases, a spreadsheet will be used to store and manipulate the data. All requirements in the Quality Management Plan for software control will be followed.

# Assessments and Response Actions (C1)

| | |
|---|---|
| **Internal management assessments** | Internal management assessments will be conducted in accordance with the QMP. Assessments are documented and filed as records. |
| **LANL required audits** | LANL audit groups may be delegated responsibility for assessments under the LANL QMP. |
| **Requested audits** | The Group Leader may request assessments of any program or project. These assessments may also include assessment of organizations which supply information or services (e.g., analytical laboratories). |
| **Corrective actions** | The group will document and track external and internal audit findings, or other deviations from requirements found during an audit or assessment. |

# Reports to Management (C2)

**Dose reports**

The project leader will prepare reports on an annual or as-needed basis. These reports may be supplemented, as needed, to address problems or situations of a more immediate nature.

**Distribution of reports**

Distribution of reports will include:

- the Group Leader; and
- team members.

Other interested parties may be added to distribution as needed or desired.

# Data Review, Validation, and Verification (D1)

**Criteria used to accept, reject, or qualify data**

Data are evaluated for one of three outcomes: accept, qualify, or reject. Data evaluation criteria may include:

- data within expected range of values
- proper laboratory methods
- acceptable analytical uncertainty

**Use of negative values**

Environmental data with negative values will be used in calculations in order to obtain the best estimate of the true value (DOE/EH-0173T).

# Validation and Verification (D2)

**Professional evaluation of qualified data**

A professional evaluation will be performed to estimate or otherwise complete data labeled as "qualified." After this evaluation, the data will be either rejected or accepted for use in calculating dose.

**Rejected data**

Rejected data will not be used for dose assessment.

# Reconciliation with Data Quality Objectives (D3)

**Failure to meet specified DQOs**

When differences are identified between specified and measured values for precision and completeness, a deficiency report will be generated and the causes of the differences will be investigated, reported to management, and corrected where possible.

# *APPENDIX A: REFERENCES*

Requirements and guidance documents:

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"Setting up the Eberline E-600 and Associated Detectors for Field Use", ESH-1-07-91

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"Service Delivery Model for Waste and Environmental Services Division (WES)", AP-0002, R0

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Handbook of Health Physics and Radiological Health, (ed. B. Shleien, L. Slaback, and B.Birky) (ISBN 0-683-18334-6).

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Health Physics volume 85 pages 662 to 677, "In situ gamma-ray spectrometry intercomparison".

Health Physics volume 87 pages 664 to 669, "In situ depth profiling of 137Cs contamination in soils at INEEL".

ICRP, "International Commission on Radiological Protection", http://www.icrp.org/ "Protection of non-human species from ionizing radiation", ICRP reference 02/305/02, downloadable from http://homer.ornl.gov/oepa/public/bdac/ .

ICRU Report No. 37, "Stopping Powers for Electrons and Positrons" (1984).

ICRU Report No. 53. "Gamma-ray spectrometry in the environment", (1994).

Knoll, Glenn F., "Radiation Detection and Measurement" (2nd edition, 1989) ISBN 0-471-81504-7.

LA-13149-MS, "Radionuclides and Radioactivity in Soils within and Around LANL, 1974 through 1994", P.R. Fresquez et al. (April 1996).

LA-13206-MS "Human Dose Assessment for the Radionuclides $^{90}$Sr and 90Y at TA-35 SWMU 35-003(r] and Ten Site Canyon" (Daniel Jarmer and Jared Lyman, 1997).

LA-14091, "Tritium concentrations in vegetation as a function of distance from a low-level radioactive waste site at LANL", P.R. Fresquez et al., 2003.

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LA-14108-PR, "Radionuclide concentrations in soils and vegetation at low-level radioactive waste disposal Area G during the 2003 growing season", P.R. Fresquez et al., 2004.

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LA-UR-90-3400, "Solid Waste Management Units Report".

LA-UR-92-800 "RFI Work Plan for Operable Unit 1129", May 1992.

LA-UR-92-838, "RFI Work Plan for Operable Unit 1078", May 1992.

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LA-UR-97-3291, "Work Plan for Mortandad Canyon", September 1997.

LA-UR-98-2550, “Work Plan for Pajarito Canyon”, (1998).

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# Appendix B: Radionuclides at LANL

This section explains why $^{137}$Cs and $^{90}$Sr are the radionuclides at LANL that most often fail the general screening of DOE-STD-1153-2002.

The dose limit for terrestrial animals is 365 times the DOE all-pathway limit for the human public, and more than 1,000 times the EPA limits. Therefore, one would expect the screening levels in DOE-STD-1153-2002 to be greater than the concentrations tolerated in the environment of LANL. This is so for most radionuclides, but there are two exceptions: $^{137}$Cs and $^{90}$Sr.

For example, the DOE-STD-1153-2002 screening level for plutonium-239 in soil is 6,000 pCi/g; for uranium-238 it is 2,000 pCi/g; and for tritium it is 200,000 pCi/g; these are much greater than the concentrations in the environment near LANL.

However, for $^{137}$Cs and $^{90}$Sr, the screening levels in soil are both 20 pCi/g. Concentrations greater than this screening level have been measured at TA-5, -10, -21, -35, and -50.

Furthermore, for water, the DOE-STD-1153-2002 screening level for $^{137}$Cs is 40 pCi/L, which is 1/3 of the EPA human drinking-water limit. If 40 pCi/L causes 1 mrem/year in humans, how can it cause 0.1 rad/day in terrestrial animals? The answer is: DOE-STD-1153-2002 assumes a bioaccumulation factor of 54,000 for cesium in water. This worst-case assumption may be changed if there is justification, so the question is: how is this factor derived?

In biological systems, cesium behaves somewhat like potassium, though cesium is retained in the body longer than potassium so the concentration in the organism can be 1 to 4 times the concentration in its diet (Whicker and Schultz, volume 1, Chapter 5.III.B, page 150). The cesium-to-potassium ratio tends to increase with trophic level (Eisenbud and Gesell, page 104) so in a complex ecological system, the bioaccumulation factor can be about $3^n$ where $n$ is the number of links in the food chain.

Specifically, the bioaccumulation factor of 54,000 in DOE-STD-1153-2002 is derived as follows. A bioaccumulation factor of 11,000 for shrimp was reported in Table 5.41 of Till and Meyer. In DOE-STD-1153-2002 Table 4.1, this factor is increased to 22,000 to include the 90% confidence level; in RESRAD-BIOTA, this is the value of $B_{IV}$ for $^{137}$Cs in aquatic animals. An additional factor of 2.5 is included for terrestrial animals, assuming these contaminated aquatic animals make up 100% of the terrestrial animals' diet.

A similar discussion applies to other radionuclides at LANL. Strontium behaves like calcium in biological systems but has lower bioaccumulation factors than cesium. Actinides are not concentrated in terrestrial animals because uptake from the gut into the blood is small (see $f_1$ in Table 4.4 page M3-53 of DOE-STD-1153-2002). Tritium behaves like hydrogen but is not favored and does not bioaccumulate.

In summary, this biota dose assessment QAPP will be applied to all radionuclides, but only $^{137}$Cs and $^{90}$Sr are expected to fail the general screening, so the QAPP focuses on these two.

Note: as a side issue, be aware that bioaccumulation factors can potentially affect humans. If significant cases are identified, the area should be posted as a "Soil Contamination Area" to forbid eating.

# APPENDIX C: LOCATIONS AT LANL

This appendix discusses the locations of concern at LANL. Fpr further details, see McNaughton 2005a.

## TA-1, the original technical area

TA-1 is the original Manhattan-Project technical area in the vicinity of the LA Inn. Most of TA-1 has been decontaminated below human residential standards and is not a concern for biota. The remaining contaminated area at TA-1 is the hillside south of the Los Alamos Inn.

The hillside of Los Alamos Canyon south of the Los Alamos Inn was contaminated in the early 1940s by several outfalls from the original TA-1. The primary radionuclide is Pu-239. The highest levels are on Hillside 138, downhill from and 20 to 50 m southwest of 2101 Trinity Drive Suite U. The hillside is now within TA-41, is fenced, and access is restricted by locked gates.

These hillsides are described in the ER report: “RFI Work Plan for Operable Unit 1078”, LA-UR-92-838. This 1992 report refers to sampling data collected in 1977 by Ahlquist et al., reported in LA-6887. However, a remedial action (voluntary corrective action) in 1996 was reported in the ER report “Remedial Action Status Report for Potential Release Site 1-001(d) Hillside 138” dated January 1997.

The 1992 report (LA-UR-92-838, Table 4.5-1, page 4-30) reports 36 pCi/g of Pu-239 at Hillside 137, 68 pCi/g of U-235 at Hillside 140, and 797 pCi/g of Pu-239 at Hillside 138. The 1996 remedial action was based on measurements with a FIDLER instrument. According to the memo from Paul Black to Valerie Rhodes, dated 20 July 1996, subject “FIDLER cleanup level based on new 1996 data”, the goals of the remedial action correspond to a Pu-239 concentration of 300 pCi/g. According to the “Remedial Action Status Report” dated January 1997, the contamination was reduced by 60%, which also indicates the final average concentration was 300 pCi/g.

All these concentrations are well below the biota concentration guide (BCG) of 6,000 pCi/g listed in Table 6.4 of DOE-STD-1153-2002. Therefore, TA-1 passes the level-1 screening.

## TA-2, in LA Canyon

TA-2 was the site of numerous reactors, beginning with the "Water Boiler" in 1945 and ending with the "Omega West" reactor, which was decontaminated and decommissioned in the Spring of 2003. The ER database indicates Sr-90 and Cs-137 surface contamination of about 40 pCi/g east of the main buildings prior to the 2003 cleanup. However, the more recent "Los Alamos and Pueblo Canyons Investigation Report" LA-UR-04-2714 (2004) shows that contamination was cleaned up to less than the BCGs in DOE-STD-1153-2002. Furthermore, LA-UR-04-2714 includes a detailed ecological investigation that concludes there are no hazards to the biota population. In conclusion, based on existing data, TA-2 passes the level-1 screening.

## TA-5, Mortandad Canyon

Mortandad Canyon continues to receive contamination from TA-50. It is described in the ER report "Work Plan for Mortandad Canyon", LA-UR-97-3291, dated September 1997. It is monitored regularly and the results are reported in the annual report "Environmental Surveillance at Los Alamos". Significant contamination extends from the TA-50 outfall to about MCO-8.2. $^{137}$Cs has the highest ratio to the biota concentration guidelines (see Section 3.4.4 of LA-UR-97-3291). Gamma exposure rates in Mortandad Canyon are shown on the map designated "FIMAD plot ID 107934" dated July 22, 1999. Existing data show that Mortandad Canyon fails the level-1 screening. Further assessments are described in McNaughton 2005a and McNaughton 2008b.

## TA-10, Bayo Canyon

Bayo Canyon was the site of the original TA-10, which was contaminated during the RaLa project from the 1940s through 1963. TA-10 was decommissioned in 1963 and transferred to Los Alamos County in 1967. It is described in the ER report "Work Plan for the North Canyons", LA-UR-01-1316, dated September 2001. Most areas have been remediated to the standards for human health.

The most significant contamination is underground. Although the contamination is underground, plants are bringing Sr-90 to the surface. The report LA-13050-MS by P.R. Fresquez, T.R. Foxx, and L. Naranjo (1995) describes a measurement of 90,500 pCi/g (ash) of Sr-90 in a chamisa plant. An interim action is summarized on page 3-51 of LA-UR-01-1316, during which 199 pCi/g of Sr-90 was measured in vegetation.

## TA-15, Firing Sites

The firing sites are contaminated with uranium. The largest amount and the largest concentrations are at EF-Site, a.k.a. SWMU 15.004(f). According to the ER database, the maximum concentration is 1687 pCi/g, which is 84% of the uranium BCG of 2000 pCi/g. Individual measurements up to 5 times the BCG are reported in LA-6289, LA-6742, LA-7162, and LA-8221, but the average over the home range of a mouse is less than the BCG.

The papers by Wayne C. Hanson and Felix Miera, LA-6289, LA-6742, and LA-7162, include measurements in terrestrial plants and animals.

## TA-18, Pajarito Site

28 pCi/g $^{90}$Sr was reported at PRS 18-003(c), which is associated with an active septic tank dating to 1952 inside the fence of the SW Casa. This concentration is only 40% greater than the screening level of 20 pCi/g, and is a small underground area, so it is unlikely to be a concern. According to LA-UR-98-2550, this contamination was removed in 1996 so TA-18 passes the initial screening.

## TA-21, DP Canyon

DP Canyon, north of TA-21, is a tributary of Los Alamos Canyon. It was contaminated, primarily with Cs-137, by outfall PRS 21-011(k). The contaminated area is a channel of runoff north of MDA T, and is described in the ER report "Task/Site Work Plan for Operable Unit 1049, Los Alamos and Pueblo Canyon, LA-UR-95-2053 (November 1995), in LA-6848-MS, and in Section 16.5 of LA-UR-91-962. $^{137}$Cs concentrations are on the order of 50 pCi/g, which is greater than the biota concentration guide of 20 pCi/g, so the area fails the level-1 screening. It was subjected to a detailed ecological assessment in the "Los Alamos and Pueblo Canyons Investigation Report", LA-UR-04-2714.

## TA-35, Pratt Canyon

Pratt Canyon extends from the east end of the paved area of TA-35 for about 200 m parallel to and north of Ten-site Canyon, before it joins Ten-Site Canyon at the lagoons (Figure 3.4.3-1 of LA-UR-97-3291). Ten Site Canyon joins Mortandad Canyon upstream of the sediment traps and MCO-7. Pratt Canyon is described in Sections 2.4.4.1, 3.4.3, and 3.4.5 of the ER report "Work Plan for Mortandad Canyon", LA-UR-97-3291, dated September 1997, and also in the "RFI Work Plan for Operable Unit 1129", LA-UR-92-800. It was contaminated in the 1950s, primarily with about 0.2 Ci of Sr-90 from TA-35-2 (see page 6 of LA-13206-MS).

Section 3.4.5 and Figure 3.4.5-2 of LA-UR-97-3291 show $^{90}$Sr contamination of about 5 nCi/g in a small area of the southwest headwall of Pratt Canyon. This is greater than the biota concentration guide of 20 pCi/g, so Pratt Canyon fails the level-1 screening.

## TA-39, Ancho Canyon

In 1994, preliminary data indicated 34 pCi/g $^{137}$Cs at PRS 39-001(a), which is a 9 ft deep disposal pit under a paved volleyball court north of TA-39-69. These data have not been released and may not be used for a dose assessment at this time. Therefore, a dose assessment will not be performed for the environmental surveillance report until the data are verified. When a dose assessment is performed, the 9 ft depth will preclude external dose from Cs-137, and the site-specific bioaccumulation factor of 0.01 to 0.1 will preclude internal dose.

## TA-45 and Acid Canyon

Acid Canyon was contaminated during the years 1943 through 1951 from the outfall of the radioactive liquid waste line from TA-1, and until 1964 from the liquid-waste treatment plant at TA-45. The primary radionuclide is Pu-239. Acid Canyon is described in the ER report LA-UR-95-2053, "Task/Site Work Plan for Operable Unit 1049, Los Alamos Canyon and Pueblo Canyon" dated November 1995. More recently, the South Fork of Acid Canyon was remediated from September 12 through November 9, 2001 (LA-UR-02-5785, "Interim Action Completion Report for the South Fork of Acid Canyon"). The remediation goal, 280 pCi/g, was surpassed (see LA-UR-02-5785). The 95% upper-confidence-level concentration of 206 pCi/g is far below the biota concentration guide of 6,000 pCi/g, so Acid Canyon passes the level-1 screening.

**TA-50**

PRS 50-006(a) is the remnants of a 1974 spill that spread to the east of TA-50-1 (see LA-UR-96-1283 Appendix I). The ER database shows a small area with residual concentration of about 50 pCi/g, which is greater than the biota concentration guideline.

**TA-53, LANSCE**

The ER database lists concentrations in the lagoons east of the LANSCE accelerator that were greater than the biota concentration guidelines prior to their remediation. The data are marked "Excav: Y", which means the contamination has been excavated and removed.

**TA-54, Area G**

Area G includes locations with concentrations greater than the biota concentration guidelines, for example PRS 54-013(b)-99. Area G is monitored by the SFB team (LA-14091, LA-14095-PR, LA-14108-PR).

**TA-60, impoundment on Sigma Mesa**

PRS 60-005(a) is a 0.1-ha fenced surface impoundment with dry sludge containing $^{137}Cs$. It is next to the RLW line from TA-21 to TA-50, 0.4 mi E of TA-60-35. It was a solar evaporative pond used in the 1970s for a study with 25,000 gallons of effluent from TA-50. According to preliminary data, the concentration in a single sample was 35 pCi/g in 1995. However, this datum has not been released and may not be used for a biota dose assessment in the environmental surveillance report. If the data are averaged over the 0.1 ha area, the concentration is 2 pCi/g, which results in a dose rate <0.1 mrad/day.

**Material Disposal Areas, MDAs**

The concentration can be estimated by dividing the total estimated inventory by the total estimated volume, in which case the following fail the initial screening: MDA A, B, AB, C, G, H, T, and W. These are Nuclear Environmental Sites, NES. Therefore, we should do a biota dose assessment for these MDAs. In some cases, it is sufficient to note that the radioactive material is isolated from the biota so the biota dose is zero.

# *APPENDIX D: MEASUREMENTS WITH A HAND-HELD BETA DETECTOR*

## Abstract

This appendix describes how to use and calibrate hand-held beta detectors to measure contamination in pCi/g instead of the usual dpm/(100 $cm^2$). As a check on the method, measurements of the concentration of $^{234m}Pa$ in depleted uranium and $^{40}K$ in potassium chloride yielded the expected result.

## Introduction

Hand-held beta detectors are normally used to measure surface contamination in units of activity per nominal surface area, for example dpm/(100 $cm^2$). In some applications, however, it is necessary to measure activity per unit mass, for example pCi/g or Bq/kg. One such application is the measurement of strontium-90 in trees in Pratt Canyon at Los Alamos National Laboratory (LANL) as part of the biota dose assessment called for by DOE-STD-1153-2002.

Pratt Canyon was contaminated with 0.2 Ci of $^{90}Sr$ during operations at TA-35 from 1951 to 1963. The $^{90}Sr$ was a byproduct of the Radioactive Lanthanum (RaLa) project, which used $^{140}La$ and $^{140}Ba$. Ba is chemically similar to Sr, so $^{90}Sr$ accompanied $^{140}Ba$ and remains in the canyon although the short-lived $^{140}Ba$ and $^{140}La$ have decayed. In some places, the $^{90}Sr$ concentration in the soil and vegetation is on the order of 3 nCi/g.

The usual method of measuring activity per unit mass (pCi/g) is to send samples to an analytical laboratory. This method is slower and more expensive than using a hand-held detector. A measurement with a hand-held detector takes about a minute and costs little more than the time and effort of the person making the measurement. Furthermore, it can be made in-situ without disturbing the soil or vegetation. Thus, hand-held instruments are quicker, cheaper, and simpler.

## Analytical estimate of effective depth

A beta detector measures the activity (dpm or pCi) over the area of the detector, so it is straightforward to report the activity per unit area (pCi/$cm^2$). To convert to activity per unit mass, we need the effective depth in g/$cm^2$; the quotient (pCi/$cm^2$)/(g/$cm^2$) is the desired result in pCi/g.

The effective depth may be estimated analytically using average beta energies and ranges. $^{90}Sr$ emits a beta with maximum energy 0.55 MeV and average energy 0.20 MeV, and its decay product, $^{90}Y$, emits a beta with maximum energy 2.28 MeV and average energy 0.93 MeV. According to the ESTAR program (described in ICRU Report No. 37 and accessible from NIST by a Google search "site:nist.gov estar") the range in wood or water is 0.04 g/$cm^2$ for a 0.2-MeV beta and 0.4 g/$cm^2$ for a 0.93-MeV beta. (These estimates are calculated using the continuous-slowing-down-approximation, CSDA.)

The effective depth would equal the range, $r$, only if all paths were perpendicular to the surface. If the direction is random, the effective depth is $r/2$. (If $\theta$ is the angle of the path with the surface, the effective depth is calculated by weighting the depth, $r\sin\theta$, with the available solid angle, which is proportional to $\cos\theta$, i.e., the average depth is the integral from 0 to $\pi/2$ of $r\sin\theta\cos\theta d\theta$.)

Therefore, if every decay results in two betas, one from $^{90}$Sr with average range 0.04 g/cm$^2$ and the other from $^{90}$Y with 0.4 g/cm$^2$, and if the betas travel in a perfect straight line, the count rate in the detector would correspond to the activity in an effective thickness of 0.5*(0.04+0.4) = 0.22 g/cm$^2$.

Notice that 90% of the counts are from $^{90}$Y. This fact is confirmed by detailed Monte Carlo calculations. In the following discussions, it is conceptually simpler to consider the $^{90}$Y and adjust for the small contribution from $^{90}$Sr as a separate step.

**Monte Carlo calculation of effective depth**

For the Monte Carlo calculation, rather than use an average energy we calculated the beta spectrum with the Fermi-Kurie equation:

$$n = [\sqrt{(T^2+2mT)}](T+m)(T_{max}-T)^2$$

where $n$ is the relative number of betas in each energy bin, $T$ is the kinetic energy in keV, and $m$ is energy equivalent of the electron mass, 511 keV.

The Monte Carlo calculation includes the multiple scattering of the electrons that causes the actual paths to deviate from a perfect straight line. The calculation is performed with the "Monte Carlo N particle" computer program, MCNP, as follows.

Define an MCNP cell with large surface area and with thickness larger than the maximum beta range. This cell corresponds to the ground, a tree trunk, or a mat of vegetation. Populate it uniformly with a source that has the appropriate beta spectrum, and tally the net number of electrons that leave through the large surface. (The net number is obtained by subtracting the electrons that scatter back into the original cell from those that leave it.) Multiply this tally by 2 and by the thickness of the cell to obtain the effective thickness sampled by the beta detector. The factor of 2 is required because the MCNP calculation considers electrons leaving one surface and therefore it corresponds to a $2\pi$ solid angle, whereas the LANL detectors are calibrated for a $4\pi$ solid angle.

According to MCNP, the effective thickness for $^{90}$Y together with $^{90}$Sr in wood or water is 0.20 g/cm$^2$, close to that predicted by the simple model. The area of the SHP380AB beta detector is 100 cm$^2$, so the effective mass being sampled is:
(100 cm$^2$)*(0.20 g/cm$^2$) = 20 g.

A sample MCNP input file for $^{90}$Y follows. The contribution from $^{90}$Sr is 10% of that from $^{90}$Y. The two contributions are calculated separately and added.

```
Title: MCNP input file for 90Y, 1/8 inch CH2, and SHP380AB detector
c
c Cells
1  1  -1.0        1  -2  -101    imp:e=1  $ sample
2  2  -0.91       2  -3  -101    imp:e=1  $ CH2 (optional)
3  3  -1.         3  -4  -101    imp:e=1  $ Mylar
4  4  -3.         4  -5  -101    imp:e=1  $ ZnS
5  5  -1.         5  -6  -101    imp:e=1  $ scintillator
100 0             -1 :6  :101    imp:e=0  $ void

c Surfaces
1   px   -1.0            $ to void
2   px    0.             $ upper surface of sample
3   px    0.3175         $ detector face
4   px    0.3275         $ back of Mylar
5   px    0.3375         $ back of ZnS
6   px    0.3625         $ back of scintillator and begin void
*101 cx   100.           $ reflecting rim

c Source
mode e
sdef par 3 pos -.5 0 0 axs 1 0 0 rad d1 ext d2 cel 1 erg d3
si1 100.
si2 0.5
si3   .0 .125 .25 .375 .5 .625 .75 .875
      1. 1.125 1.25 1.375 1.5 1.625 1.75 1.875 2. 2.125 2.25 2.375
sp3   .0 .015 .038 .053 .067 .078 .086 .090 .092
      .090 .086 .078 .068 .056 .043 .031 .019 .009 .002 .0    $ 90Sr spectrum
cut:e  100000 0.01 0 0 0   $ low-energy cutoff at 0.01 MeV
c
c Materials
m1 1001 0.571 6000 0.143 8016 0.286  $ wood = C + 2H2O = CH4O2
m2 6012  0.3333  1001  0.6667          $ CH2
m3 1001 8. 6000 10. 8016 4.           $ Mylar C10H8O4
m4 30000 1. 16000 1.                  $ ZnS
m5 1001 1. 6000 1.                    $ scintillator (polystyrene)
c
c Tally
e0    .0 .125 .25 .375 .5 .625 .75 .875
      1. 1.125 1.25 1.375 1.5 1.625 1.75 1.875 2. 2.125 2.25 2.375
f21:e   2 3 4 5 6  $ particles through surfaces 2,3,4,5,6
c21 0. 1.          $ cosine bins
c
ctme  720
```

## Corrections to the measurement

There are several other small corrections to consider before calculating the concentration.

At LANL, the SHP380AB detector is calibrated with $^{36}$Cl betas and the count rate (cpm) is divided by an effective 4π efficiency of 0.16 ± 0.02 cpm/dpm so it reads in dpm. The average beta energy from $^{90}$Y is 0.93 MeV, whereas the average from $^{36}$Cl is 0.25 MeV, so the efficiency for $^{90}$Y is higher: 0.22 cpm/dpm. The $^{36}$Cl source is thin whereas the wood is thick, so the betas from $^{90}$Y in wood have an average energy of 0.7 MeV, a median energy of 0.6 MeV, and an effective efficiency of 0.20, 20% higher than the calibration. Furthermore, the SHP380AB is calibrated 3 cm from the toe, where the efficiency is 30% lower than the average. As a result, the detector reading will be 50% high and so must be multiplied by 2/3.

For example, the count rate from some of the trees is 2E5 dpm, which corresponds to an activity concentration: (2/3)(2E5 dpm)/((2220 dpm/nCi)*20 g) = 3 nCi/g.

## Checking the method with $^{234m}$Pa in $^{238}$U

We can check these calculations using the betas from $^{234m}$Pa, which is a decay product of $^{238}$U. The maximum beta energy from $^{234m}$Pa is 2.28 MeV, almost the same as $^{90}$Y.

The CSDA range is greater in uranium than in water or wood, but the multiple scattering is also greater. According to MCNP, the straight-line distance from the point of decay to the point at which the electron emerges from the surface is 20% less in uranium than wood, which leads to an effective depth of 0.16 g/cm$^2$ for betas from $^{234m}$Pa in uranium.

We placed a 4-cm$^2$ uranium disk near the calibration point of the SHP380AB detectors, so the 30% correction for the spatial variation in efficiency is not applicable. The efficiency for $^{234m}$Pa (0.20) was higher than the calibrated efficiency for $^{36}$Cl (0.16), and the solid angle was lower than for a large source because the small disk was placed 3/8 inch from the face of the detector. These two correction factors are each about 25% but in opposite directions and cancel within about 10%. Also, $^{234m}$Pa emits a beta in only 99% of its decays, and $^{234}$Th emits a beta with 50 keV average energy; these small corrections cancel within about 1%.

The count rate (the average from four detectors) was 4.9E5 dpm (± 10%), and background was negligible, so the measured specific activity was

(4.9E5 dpm)/[(2.22E6 dpm/micro-Ci)(0.16 g/cm$^2$)(4 cm$^2$)] = 0.34 micro-Ci/g.

When secular equilibrium is established, the specific activities of $^{234m}$Pa and $^{238}$U are almost the same. The surface of the uranium is oxidized but we don't know how deep so the expected result is between that for uranium metal, 0.34 micro-Ci/g, and uranium dioxide, 0.30 micro-Ci/g. We conclude the expected and measured results agree within about 10%.

## Checking the method with $^{40}$K in potassium chloride

We also checked the method using the betas from $^{40}$K in potassium chloride, which is available as a salt substitute in grocery stores. 280 grams (ten ounces) of potassium chloride was placed on a sheet of polyethylene (to control background) and spread into a layer more than 1 cm thick. The average reading on the potassium chloride was 16.9 k dpm and the background was 1.7 k dpm so the net reading was 15.2 k dpm. (The counting uncertainties were about 1% and much smaller than the systematic uncertainties.)

The area was larger than the detector, so the reading was multiplied by 0.7 for the spatial variation in efficiency, and by 16/18 to correct for the efficiency for $^{40}$K (0.18) relative to the calibrated efficiency for $^{36}$Cl (0.16). Also, the activity was divided by 0.89 because $^{40}$K emits a beta in only 89% of its decays. Background (10%) was subtracted. With these corrections, the measured activity was 10600 dpm. According to MCNP, the effective depth is 0.10 g/cm$^2$, so the activity concentration is:

$$(10600 \text{ dpm})/[(2.22\text{E}3 \text{ dpm/nCi})(0.10 \text{ g/cm}^2)(100 \text{ cm}^2)] = 0.48 \text{ nCi/g}.$$

This result is within 10% of the expected concentration: 0.44 nCi/g.

We can also estimate the effective depth from the CSDA range calculated by ESTAR. The maximum beta energy from $^{40}$K is 1.32 MeV, the average is 0.51 MeV, and the CSDA range is 0.23 g/cm$^2$. As stated previously, the effective depth would equal the range, *r*, only if all paths were perpendicular to the surface. If the direction is random, the effective depth is *r*/2. Therefore, according to this method, the effective depth is 0.12 g/cm2, in acceptable agreement with the MCNP calculation.

## Nuclide identification

A potential advantage of an analytical laboratory is positive identification of the radionuclides. However, when $^{90}$Sr is measured with a hand-held detector, it can be uniquely identified by the following three properties. The combination of $^{90}$Sr and $^{90}$Y

- emits no alphas and no gammas, and also
- emits betas that penetrate 1/8 inch of polyethylene, and also
- persists in the environment with a half life longer than 14 days.

No other contamination source has this combination of properties.

If the $^{90}$Sr concentration is uniform, the count rate with 1/8 inch of polyethylene placed between the sample and the detector is 20% of the count rate without the polyethylene.

## Average concentration

Every method measures some sort of average. For example, if a sample is sent to an analytical laboratory, the result is the average over the sample.

When $^{90}$Sr is measured in-situ with a hand-held instrument, the concentration is averaged near the surface. In the case of vegetation, this is acceptable because the important parts are the actively

growing parts, which are near the surface. If other parts are to be sampled, it is necessary to disturb the object being investigated.

**Summary**

Hand-held beta detectors can be used to measure the activity concentration (pCi/g) of 90Sr in vegetation, and possibly for other applications. The method is cheap, quick, and simple.

**Reference**

Michael W. McNaughton, "Measurement of the Activity Per Unit Mass with Hand-Held Alpha and Beta Detectors," Operation Radiation Safety, 2009.

# APPENDIX E: MEASUREMENTS WITH A SODIUM-IODIDE GAMMA-RAY SPECTROMETER

## Abstract

This appendix describes how to use and calibrate hand-held sodium-iodide gamma-ray spectrometers to measure 137Cs in the ground and in trees.

## Introduction

It is standard practice to use gamma-ray spectrometers to quantify gamma-emitting radionuclides. The principles are described in ICRU Report No. 53 (ISBN 0-913394-52-1.)

## Methods

$^{137}$Cs can be uniquely identified and measured using a sodium-iodide gamma spectrometer such as the Exploranium "GR-130 Minispec" as follows.

A concentration of 20 pCi/g of $^{137}$Cs in a plane source causes a count rate of 10 counts per second (c/s) in the 662-keV peak; this can be measured in 30 s.

A mouse can be approximated as a point-source. (For example, if the mouse is 12 cm long (ignoring the tail), is oriented in the y direction, and is placed 6 cm from the detector in the x direction, measured center to center, the true rate is 80% of the rate estimated with the inverse-square-law.) A concentration of 2,000 pCi/g in a 20-gram mouse at a distance of 6 cm results in a count rate of about 10 c/s, which can be measured in 30 s. A 1-gram snail with 2,000 pCi/g placed at 4 cm would produce 1 c/s and can be measured in 300 s.

A tree is essentially a line source. A typical tree with a concentration of 20 pCi/g produces a count rate of 5 c/s close to the tree. This can be measured in 60 s.

The calculations and calibrations used to derive these numbers are described in Section B7 and in the following section. The techniques are also discussed in ICRU Report No. 53 and in Health Physics volume 85 pages 662 to 677.

A tree containing $^{137}$Cs will normally sit on ground containing $^{137}$Cs. In this case, the detector will detect 662-keV gammas from both the ground and the tree. These two sources can be distinguished by their dependence on distance. In theory, the count rate from an infinite plane source is essentially constant, the count rate from an infinite line source is inversely proportional to distance, and the count rate from a point source is inversely proportional to distance squared. Therefore, in the case of a contaminated tree on contaminated ground, the count rate $C$ as a function of distance $r$ follows the functional form:
$C = A/r + B$.
Where $A$ is related to the $^{137}$Cs in the tree, and $B$ is a constant background related to the $^{137}$Cs in the ground.

The theories are good approximations until the distance becomes comparable with either (a) the mean-free path (tens of meters of air) or (b) the dimensions of the source. When the distance is larger than the largest dimension of the source, the source may be treated as a point source.

A general survey for $^{137}$Cs may be rapidly performed using a gamma dose rate meter such as the Exploranium in Survey mode or a Bicron Micro-rem meter. A plane source with a concentration of 20 pCi/g (the screening level in DOE-STD-1153-2002) results in a dose rate of 12 micro-rem/h, which is easily detected with a Micro-rem meter.

In summary, $^{137}$Cs can be identified unambiguously and the concentrations of interest can be quantified in less than a minute.

## Calibration

The Exploranium Minispec detector was calibrated with a NIST-traceable radioactive point source of known activity, the cesium-137 type-D IPL sources, No. 812-44-1 (18.3 micro-curies on August 15, 2001.) The calibration can be checked using the cesium-137 source supplied with the Exploranium Minispec detector, which had an activity of 1.5 micro-curies in November 2004.

The calibration for potassium-40 can be obtained using a known quantity of potassium chloride. The background-subtracted count rate from 2 bottles, each containing 5 ounces of potassium chloride, placed either side of the detector at an average distance of 7.5 cm from the center line was 1.0 counts per second.

In November 2004, the original 18.3 micro-curie cesium-137 source had decayed to 17.0 micro-curies. At a distance of 1 foot, the 17.0 micro-curie source causes a dead time of 5% and a count rate in the peak of 160 Counts per second; after correcting for dead time, the count rate is 168 Counts per second.

The dose rate is calculated from first principles; refer to "Atoms, Radiation, and Radiation Protection" by James Turner, McGraw Hill, 1992, ISBN 0-07-105320-4, page 208. The dose rate in rad/h is
($C$ Ci)($E$ MeV)($\mu_{en}/\rho$ cm$^2$/g)(3.7E10 s$^{-1}$Ci$^{-1}$)(1.6E-13 J/MeV)(1E3 g/kg)(100 rad kg/J)(3600 s/h)*(1E-4 m$^2$/cm$^2$) / (4*pi*$r^2$ m$^2$)

For example, if $r$ = 0.3048 m, and $\mu_{en}/\rho$ = 0.033 cm$^2$/g, then the result is the familiar rule of thumb: dose rate (rad/h at one foot) = 6$CE$ (Note: this formula may be given in units of R/h: for water or tissue, 1 R = 0.97 rad. Also, the total energy emitted in each disintegration, $E$, is sometimes written as $En$, in which case $E$ is the average energy per particle and $n$ is the number of particles.)

There is a small uncertainty about what value of $\mu_{en}/\rho$ to use (see Handbook of Health Physics pages 5-2 to 5-35; use the right hand column.)

$\mu_{en}/\rho$ = 0.033 cm$^2$/g for water,
$\mu_{en}/\rho$ = 0.032 cm$^2$/g for tissue,
$\mu_{en}/\rho$ = 0.031 cm$^2$/g for sodium-iodide, or
$\mu_{en}/\rho$ = 0.029 cm$^2$/g for air or silicon-dioxide
We accept an uncertainty of 10% and use: dose rate = 6*CE* (rad/h).

For $^{137}$Cs, *E* = 0.85*0.662 MeV, and if *C*=17 micro-curies, the dose rate at 1 foot = 57 micro-rad/h. This causes a count rate of 168 Counts per second in the Exploranium peak, therefore, 1 micro-rad/h causes 168/57 ≈ 3 counts per second. The concentration in the ground can now be deduced by 3 different methods, which are compared as follows.

Method 1

Consider the dose rate caused by 1 pCi/g of $^{137}$Cs in the ground. Results have been published by Clouvas et al. (Health Physics volume 78 page 301) and on page 173 of Federal Guidance Report No. 12. It can also be calculated using RESRAD. With 20% accuracy: 1 pCi/g of $^{137}$Cs in the ground causes 0.4 micro-rad/h.

But only 30% of the photons have the full energy of 662 keV, and they carry 50% of the energy. So in this case the 662-keV photons cause 0.2 micro-rad/h and 0.6 counts per second (c/s).

Method 2

The count rate depends on the detector area, *A*, and the thickness; (to first order, the count rate depends on the volume, so it is not significantly affected by the orientation of the detector relative to the source.) At a distance *r*, the solid angle is $A/4\pi r^2$, and if a source with activity *B* Bq causes a count rate *S* c/s the effective efficiency is $4\pi r^2 S/AB$.

A concentration of 1 pCi/g to a depth of 8 g/cm$^2$ = (0.037 Bq/pCi)(8 g/cm$^2$)(1 pCi/g) = 0.3 Bq/cm$^2$, which causes a count rate of $0.3A(4\pi r^2 S/AB) = 1.2\pi r^2 S/B$. The calibration with the 17 micro-curie source showed that *S* = 168 c/s at *r* = 30.48 cm for a source *B* = (3700 Bq/μCi)*(17 μCi), so the count rate from 1 pCi/g = $1.2\pi(30.48)^2(168)/(3700*17)$ = 1 c/s. Half of these are in the 662-keV peak, so the count rate is 0.5 c/s, in satisfactory agreement with method 1. The effective efficiency is also in satisfactory agreement with Figure 10-25 of the text "Radiation Detection and Measurement" by Glenn Knoll.

Method 3

Consider the method described in ICRU Report No. 53. Interpolating for 662-keV photons in Table 3.3, and using the same notation as in this table, the "primary photon fluence per source photon per unit area" for a "relaxation mass per unit area" β = 8 g/cm$^2$ is (3*.589+2*.386)/5 = 0.5. Therefore, the expected flux for 1 pCi/g is

$$\phi_1 = 0.5*(8\ \text{g/cm}^2)*(1\ \text{pCi/g})*(0.037\ \text{Bq/pCi}) = 0.15\ \text{s}^{-1}\text{cm}^{-2}.$$

The measured flux from the 17 micro-curie source at a distance of 30.48 cm is

$$\phi_2 = (17\ \text{micro-curie})*(37000\ \text{Bq/micro-curie})/(4\pi 30.48^2\ \text{cm}^2) = 54\ \text{s}^{-1}\text{cm}^{-2}$$

and this flux causes $S_2$ = 168 c/s in the detector. So the count rate from 1 pCi/g in soil is

$$S_1 = S_2\phi_1/\phi_2 = 168*0.15/54 = 0.5 \text{ c/s}.$$

**Conclusion: 1 c/s in the 662-keV peak implies 2 pCi/g in the ground.**

The calibrations described above apply to a large plane source with a solid angle of 2π ster-radians. A small plane source subtends a smaller solid angle, and a hole in the ground subtends a larger solid angle. The count rate is proportional to the solid angle, so appropriate corrections for solid angle must be made, as needed.

**Measurement of cesium-137 in a tree**

Before considering a tree, consider the equation for a point source.
At a fixed distance, r = 30.48 cm, the dose rate (rad/h) = 6*EC*
(*C* is the activity in Ci, *E* is the energy per emission in MeV)
so at a distance *r* (cm) from the detector:
dose rate (rad/h) = $6EC(30.48/r)^2 = 5600EC/r^2$ (equation 1)

Now, consider a tree along the x axis; the tree has cross-section area *A*, density ρ, and concentration *c* Ci/g. The detector is at a distance *y* from the *x* axis.
Consider a small segment d*x* at a distance $r = \text{sqrt}(x^2+y^2)$.
Replace *C* in equation 1 with cρ*A*d*x*:
dose rate (rad/h) = $5600Ec\rho A dx/(x^2+y^2)$ (equation 2)
(*c* is the concentration in Ci/g, ρ is the density in g/cm$^3$, *A*d*x* is the volume in cm$^3$)

Assume the tree is infinitely long in the *x* direction and integrate with respect to *x* (*y* is constant) from $x = -\infty$ to $x = +\infty$.
[Integral $dx/(x^2+y^2) = y^{-1}\arctan(x/y)$ ]
$\therefore$ dose rate (rad/h) = $5600Ec\rho A\pi/y$ (equation 3)

Compare equation 3 with equation 4 for a point source, activity *C*, that causes the same dose rate at a distance *y*:
dose rate (rad/h) = $5600EC/y^2$ (equation 4)
Therefore, $C = c\rho A\pi y$ (equation 5)

(Roughly speaking, equation 5 implies the effective length of the tree = π*y*.)

A $^{137}$Cs point source with *C* = 17E-6 Ci at a distance of 30.48 cm produces a count rate of 168 c/s in the Exploranium. So if we measure a rate *S* c/s at a distance *y*, the concentration, *c*, is
$c = (17E\text{-}6)(S/168)(y/30.48)^2/(\rho A\pi y)$ Ci/g (equation 6)
If the tree's radius, *r* is 8 cm, about half the photons experience Compton scattering and their energy is less than 0.662 MeV, so if *S* is the count rate of the 0.662-MeV peak:
$c \approx 2^{(r/8)}(17E\text{-}6)(S/168)(y/30.48)^2/(\rho A\pi y)$ Ci/g (equation 7)

For example, if $S$ = 1 c/s, $\rho$ = 0.9 g/cm$^3$, $r$ = 9 cm, $A = \pi r^2$ = 250 cm$^2$, and $y \approx r$+3 cm = 11 cm, then $c$ = 4 pCi/g.

Equation 7 can be approximated within a factor of two for trees with $r$ > 4 cm:

$$c \approx 4S$$

($c$ pCi/g; $S$ counts per second.)
For $r$ > 15 cm, $2^{(r/8)}$ is inaccurate, so use the equation for a plane, 1 c/s is 2 pCi/g, or

$$c \approx 2S$$

Conclusion: for a large tree, r > 15 cm, 1 count/s implies about 2 pCi/g. For a smaller tree with radius between 4 cm and 15 cm, 1 count/s implies 4 pCi/g, within a factor of 2.