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Los Alamos
National Laboratory

Environment, Safety, Health Directorate

Environmental Protection Division – Environmental Stewardship Services Group

Technical Project Plan

for

Biota Dose Assessment

Signatures

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QAPP-05, R0	03/10/2009	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.
QAPP-05, R1	01/26/2014	Update for DOE Order 458.1
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1.0 INTRODUCTION

1.1 Purpose

This document specifies the actions necessary to ensure the quality and accuracy of biota dose assessments in the Los Alamos environment. The Los Alamos environment is defined as the locations affected by U.S. Department of Energy (DOE) activities at Los Alamos National Laboratory (LANL) and its predecessors (beginning with the Manhattan Project) that are not part of experimental facilities (for discussion of experimental facilities, see A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota [DOE 2002, DOE-STD-1153-2002] pp. M1-22 and M2-23–M2-25).

This plan also demonstrates compliance with requirements for a quality program in DOE Order 414.1D, Quality Assurance (DOE 2001).

This plan was prepared in accordance with the U.S. Environmental Protection Agency (EPA) standard for Technical Project Plan, (EPA 1994, EPA Requirements). Headings are followed by lettered and numeric designations (e.g., A3) taken from the EPA requirements.

2.0 DISTRIBUTION LIST (A3)

This document will be controlled under the Associate Directorate for Environment, Safety, and Health (ADESH) document control system to ensure that those performing work for the project will be notified of new revisions. Those who will be notified include the following:

- Group leader
- Deputy group leader
- Dose Assessment Team members

3.0 PROJECT ORGANIZATION (A4)

The principal decision maker for the team is the project leader for biota dose assessment (project leader). The 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.

The results of the dose assessment (final products and deliverables) will be approved by the project leader and reported to the group leader. Results will also be sent to any LANL operating group that requests them and will be published in LANL's annual site environmental report (ASER). The results will ultimately be used by LANL division leaders and DOE to make decisions regarding mitigation.

4.0 PROBLEM DEFINITION (A5)

4.1 Background

LANL is a research and development institution operated by Los Alamos National Security, LLC, for 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 with standards developed by the International Commission on Radiation Protection, the International Atomic Energy Agency, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and DOE. There is general consensus that standards of 0.1 to 1 rad/day are protective of biota.

4.2 DOE Order 458.1

DOE Order 458.1, Radiation Protection of the Public and the Environment (DOE 2011a) states that evaluations must be performed using DOE-STD-1153-2002 [Section 4.j.(2)(a)], an alternative approach [Section 4.j.(2)(b)], or an ecological risk assessment [Section 4.j.(2)(c)]. This procedure describes assessments using DOE-STD-1153-2002.

4.3 DOE-STD-1153-2002

DOE-STD-1153-2002, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota (July 2002) (http://energy.gov/ehss/downloads/doe-std-1153-2002), p. M1-1, 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.

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

5.0 PROJECT DESCRIPTION (A6)

5.1 Assessments

The assessments performed annually and reported in the ASER as part of this project are dose rates to terrestrial animals, terrestrial plants, and aquatic animals for comparison with DOE Order 458.1 and DOE-STD-1153-2002.

Other dose assessments may be performed as needed.

5.2 Personnel

Personnel are required to have the following: experience or training in health physics, data evaluation and calculation, dose assessments, and quality assurance.

5.3 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 Section 8.0 for a list of the records to be preserved.

Biota dose assessments are calculated annually and published in the ASER as specified in DOE Order 231.1B (DOE 2011b).

6.0 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA (A7)

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 (EPA 1994). DQOs are statements of the problem to be addressed, the decision to be made, and the scope of the data required for that decision.

This section is organized into the following subsections:

6.1, Decision Statement
6.2, Data Types as Input to the Decision
6.3, Data Boundaries
6.4, Data Accuracy and Precision
6.5, Completeness
6.6, Representativeness
6.7, Comparability

6.1 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 458.1, the project leader will develop recommendations to management.

6.1.1 Use of the Biota Concentration Guides

The biota concentration guides (BCGs) are a general screening tool used to trigger further investigation and should not be used to make management decisions. According to DOE-STD-1153-2002 (p. M1-52), "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."

6.2 Data Types as Input to the Decision

Inputs to the decision require measurements of radionuclide concentrations in environmental media, including

- soil,
- sediment,
- water, and
- biota.

As noted in DOE-STD-1153-2002, the air pathway does not contribute significantly (pp. M2-20 and M3-5), and aquatic plants are assumed to be adequately protected by consideration of aquatic animals (p. M1-21).

Facilities such as the Los Alamos Neutron Science Center (LANSCE) and the Dual-Axis Radiographic Hydrodynamic Test Facility are excluded (DOE-STD-1153-2002, pp. M1-22 and M2-24), so only radionuclides in soil, sediment, and water contribute to direct radiation.

Each type of data is discussed in the following subsections.

6.2.1 Soil

Radionuclide concentrations in soil are measured; measurements near solid waste management units (SWMUs) 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, and locations that fail level-2 analysis will be subjected to level-3 analysis.

6.2.2 Sediment

Radionuclide concentrations in sediment are measured, recorded in the Intellus database, and published in the ASER.

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 sediment 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.

6.2.3 Water

Radionuclide concentrations in water are measured and published in the ASER.

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 segments, as shown in Figure 6-3 of the ASER for 2007 (LANL 2007).

6.2.4 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 (p. 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 BCGs for cesium-137 and strontium-90 in soil (McNaughton et al. 2008).

The LANL site-representative BCGs for soil are

- Cesium-137, 2000 pCi/g, and
- Strontium-90, 300 pCi/g.

The BCGs for water are

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

6.3 Data Boundaries

6.3.1 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, pp. 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 DOE-STD-1153-2002, Module 2, Section 4 (pp. M2-36 through M2-38). 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 (p. M1-48).

The assessment described in McNaughton (2005) used three standard areas: 0.01 hectare (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 et al. 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. (2002), by Ryti et al. (2004), and in Screening-Level Ecological Risk Assessment Methods, Revision 3 (LANL 2012). Although this area is derived as the population area for deer mice, it is convenient to also use it as the standard population area for plants. These areas may be useful for comparison with previous assessments. However, they are not defined in the DOE standard and are not required.

6.3.2 Data Boundaries: Temporal

Dose evaluations should be conducted annually (DOE-STD-1153-2002, p. M1-22). The details of the evaluations should be guided by the availability of relevant data.

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, p. M2-28), so water data should be averaged over a year to coincide with the ASER.

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. New soil data will be obtained and used when there are significant changes to the soil concentrations.

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 (MDAs) 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 useful.

In summary, a biota dose assessment may 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.

6.4 Data Accuracy and Precision

The dose limits in DOE-STD-1153-2002 are derived from data from many types of plants and animals; for example, see Figure 1.1 on p. M1-8 of DOE-STD-1153-2002, which is the same as Figure VII of Effects of Radiation on the Environment (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 6.3.1 is conservative; arguments could be made for much larger areas (see Section 7.3.1 of this QAPP and pp. M2-35 to M2-38 of DOE-STD-1153-2002). These considerations indicate that data with an accuracy of a factor of two are acceptable.

Using the graded approach in 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 p. M2-60 of DOE-STD-1153-2002 suggests an accuracy of about 50%, so a factor of two is used as the goal for the *absolute* accuracy. *Relative* accuracy (precision) should be used if possible to facilitate trending.

6.5 Completeness

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 of every type of biota. Thus, in the graded approach, the data set is already minimally complete and will never become totally complete.

6.6 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-STD-1153-2002, p. M1-53), so the types of species chosen for study should be representative of the types of species in the environment at LANL. For this purpose, DOE-STD-1153-2002 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, and
- radiosensitive.

Specifically, pp. M2-5, M2-15–M2-17, and M2-48 suggest monitoring

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

The LANL publication, Screening Level Ecological Risk Assessment Methods (LANL 2012) 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*).

6.7 Comparability

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

7.0 SPECIAL TRAINING AND CERTIFICATION (A8)

7.1 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 human resources division.

7.2 Training

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

8.0 DOCUMENTATION AND RECORDS (A9)

Dose assessments will be published in the ASER as specified in DOE Order 231.1B. 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.

9.0 SAMPLING PROCESS DESIGN (B1)

Large amounts of data exist and continue to accumulate for the categories outlined in Section 6.2: soil, water, sediment, and biota. In this section, what to do with these data and what additional data are needed are considered.

Annually, a level-1 screening (as defined in RESRAD-BIOTA) will be performed using the data in the ASER. 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 cesium-137 and strontium-90 are >1000 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). For this reason, animals are not particularly sensitive tests of the study question.

In contrast to the large habitat ranges 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 of terrestrial plants are especially needed in areas with the highest soil and water concentrations of radionuclides.

10.0 SAMPLING METHODS AND SAMPLE HANDLING (B2 AND B3)

10.1 Sampling Methods (B2)

In addition to using existing data, hand-held instruments may be used to make surveys and measurements of the concentrations of cesium-137 and strontium-90 in plants.

The advantages of a hand-held detector include the following:

- 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, and
- using a hand-held detector is cheaper than an analytical laboratory.

10.2 Sample Handling (B3)

Sample handling will be avoided by making in-situ measurements, with essentially no disturbance to soil or biota.

A "Soil Contamination Area" posting identifies the requirements and potential hazards at the locations of interest:

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

Strontium-90 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-BIOTA. If the soil concentration is 1000 pCi/g, the external dose rate is 0.003 mrem/h. The internal dose to humans is 0.1 mrem/g of material ingested.

Similarly, RESRAD-BIOTA can be used to calculate the doses from other radionuclides. The effective dose from cesium-137 in the areas of interest is less than 0.1 mrem/h. The effective doses from plutonium-239, americium-241, and tritium 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.

11.0 ANALYTICAL METHODS (B4)

Sections 11.1 and 11.2 describe how to calculate the concentrations of radionuclides in biota using hand-held detectors.

Section 11.3 describes how to calculate the biota dose from the concentrations.

11.1 Calculating the Strontium-90 Concentration

This section describes how to calculate the strontium-90 concentration from measurements with a hand-held beta detector such as an Eberline E600 with an SHP380AB probe.

According to the Monte Carlo N Particle (MCNP) computer program, the effective thickness is 0.2 g/cm^2. For details of this calculation, see Appendix D.

The area of the SHP380AB probe 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 k dpm, which corresponds to an activity concentration of (200 kdpm)/((2.22 kdpm/nCi)*20 g) = 4.5 nCi/g. (Note: k dpm is a unit that is displayed on the face of the Eberline E600 instrument; the letter k means thousand and dpm means disintegrations per minute.)

Another example is from the Work Plan for Mortandad Canyon (LANL 1997a, p. 3-54), which reports measurements of the count rate of soil in Pratt Canyon from an ESP-1 detector with HP260 probe. 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 (LANL 2007a), the maximum count rate is 8500 counts per minute (cpm). The efficiency of the detector is 0.225 cpm/disintegrations per minute (dpm). Therefore, the soil concentration is (8500 cpm)/[(0.225 cpm/dpm)*(2.22 dpm/pCi)*(3 g)] = 5672 pCi/g = 6 nCi/g.

In summary,

- the detector samples strontium-90 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).

11.2 Calculating the Cesium-137 Concentration

The cesium-137 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 (c/s) 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 14.3 for the calibrations, Sections 14.4 and 14.5 for discussion of the distance of the detector from the source, and Appendix E for more details.

11.3 Calculating the Biota Dose

The biota dose calculations will follow the methods specified in DOE-STD-1153-2002, which are conveniently set out in the RESRAD-BIOTA code, available at https://web.evs.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 Site-Representative Biota Concentration Guides at Los Alamos (McNaughton et al. 2008) and Notes on the Mortandad Canyon Biota Dose Assessment (McNaughton 2008).

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 6.3.1.

In some cases, internal dose contributes almost all the dose, so a measurement of the biota concentration multiplied by the internal dose conversion factors (DOE-STD-1153-2002, Table 2.4, p. M3-18) 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 DOE-STD-1153-2002. Also, use the best estimates of the bioaccumulation factors to back-calculate and estimate the effective soil concentrations. Compare these estimates with educated guesses of the actual soil concentrations at various depths.

12.0 QUALITY CONTROL (B5)

For measurements with hand-held detectors, perform the following:

- Select instruments that are appropriate to the types and energies of the radiation.
- Calibrate the instruments (see Section 14.0).
- Test the instruments before use; check the general condition, battery condition, calibration, response check, and background.

For more details, refer to the Radiological Control Technician Training Fundamental Academic Training Instructor's Guide Phase I (DOE 1999, DOE-HDBK-1122-99) Module 2.16, Radiation Survey Instrumentation, and Module 2.17, Contamination Monitoring Instrumentation.

http://energy.gov/sites/prod/files/2013/07/f2/hdbk-1122-04_lp216_0.pdf

http://energy.gov/sites/prod/files/2013/07/f2/hdbk-1122-04_lp217_0.pdf

The quality of the data is controlled mostly by care and attention to detail. The following questions must be carefully addressed.

- 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.

13.0 INSTRUMENT AND EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE (B6)

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 National Institute of Standards and Technology– (NIST-) traceable source such as a cesium-137 source, 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.

14.0 INSTRUMENT CALIBRATION AND FREQUENCY (B7)

14.1 Calibration

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

14.2 Response of a Beta Probe

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

Alternatively, the potassium-40 in potassium chloride may be used to determine the response; see Appendix D.

14.3 Calibration of Gamma Spectrometer

The 662-keV gamma from cesium-137 and its decay product barium-137m 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 cesium-137 source as described in Appendix E. The conclusion is the following:

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

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

14.4 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.

14.5 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 cesium-137 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 apply to photons.) This average may be calculated from the attenuation coefficient: $0.5/(0.08\ cm^2/g) = 6\ g/cm^2$. The value of $6\ g/cm^2$ is similar to the depth sampled by the Soil, Foodstuffs, and Biota (SFB) Team, which is 5 cm or $7.5\ g/cm^2$ (see LA-13149-MS).

Laterally, cesium-137 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 Team method (Fresquez et al. 1996) samples 5 spots: at the center and the 4 corners of a 10 m by 10 m square.

When measuring strontium-90 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, strontium-90 that is more than 0.5 in. 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 nonuniform, the detector should be placed close to the maximum.

15.0 INSPECTIONS, NONDIRECT MEASUREMENTS, AND DATA MANAGEMENT (B8–B10)

15.1 Consumables (B8)

No consumables are required for this project.

15.2 Nondirect Measurements (B9)

In addition to direct measurements, data may also be taken from an appropriate database and the ASERs and entered into RESRAD-BIOTA as appropriate.

15.3 Data Management (B10)

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 (QMP) for software control will be followed.

16.0 ASSESSMENTS AND RESPONSE ACTIONS (C1)

Internal management assessments will be conducted in accordance with the QMP. Assessments are documented and filed as records.

LANL audit groups may be delegated responsibility for assessments under the LANL QMP.

The group leader may request assessments of any program or project. These assessments may also include assessment of organizations that supply information or services (e.g., analytical laboratories).

The group will document and track external and internal audit findings or other deviations from requirements found during an audit or assessment.

17.0 REPORTS TO MANAGEMENT (C2)

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 will include the group leader and team members, while other interested parties may be added to distribution as needed.

18.0 DATA REVIEW, VALIDATION, AND VERIFICATION (D1)

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, and
- acceptable analytical uncertainty.

Environmental data with negative values will be used in calculations in order to obtain the best estimate of the true value (DOE 2015, DOE-HDBK-1216-2015).

19.0 VALIDATION AND VERIFICATION (D2)

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 will not be used for dose assessment.

20.0 RECONCILIATION WITH DATA QUALITY OBJECTIVES (D3)

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.

21.0 ACRONYMS

See LANL Acronym Master List.

ADESH	Associate Directorate for Environment, Safety, and Health
ASER	annual site environmental report
BCG	biota concentration guide
c/s	counts per second
cpm	counts per minute
DOE	U.S. Department of Energy
dpm	disintegrations per minute
DQO	data quality objective
DU	depleted uranium
EPA	U.S. Environmental Protection Agency
ICRU	International Commission on Radiation Units and Measurements
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
MCNP	Monte Carlo N Particle (computer program)
MDA	material disposal area
NIST	National Institute of Standards and Technology
QAPP	quality assurance project plan
QMP	quality management plan
RaLa	Radioactive Lanthanum (project)
SFB	Soil, Foodstuffs, and Biota (Team)
SWMU	solid waste management unit
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation

22.0 APPENDICES

Appendix A: *References*
Appendix B: *Discussion of Radionuclides at LANL*
Appendix C: *Discussion of Locations at LANL*
Appendix D: *Measurements with a Hand-Held Beta Detector*
Appendix E: *Measurements with a Sodium-Iodide Gamma-Ray Spectrometer*

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APPENDIX B – DISCUSSION OF RADIONUCLIDES AT LANL

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This appendix explains why cesium-137 and strontium-90 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 1000 times the EPA limits. Therefore, the screening levels in DOE-STD-1153-2002 are expected to be greater than the concentrations tolerated in the environment at LANL. This is true for most radionuclides, but there are two exceptions: cesium-137 and strontium-90.

For example, the DOE-STD-1153-2002 screening level for plutonium-239 in soil is 6000 pCi/g; for uranium-238, it is 2000 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 cesium-137 and strontium-90, the screening levels in soil are both 20 pCi/g. Concentrations greater than this screening level have been measured at TA-05, -10, -21, -35, and -50.

Furthermore, for water, the DOE-STD-1153-2002 screening level for cesium-137 is 40 pCi/L, which is 1/3 of the EPA human drinking-water limit. If 40 pCi/L causes a dose of 1 mrem/year in humans, how can it cause a dose of 0.1 rad/day in terrestrial animals? The answer is that 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 1982, Volume 1, Chapter 5.III.B, p. 150). The cesium-to-potassium ratio tends to increase with trophic levels (Eisenbud and Gesell 1997, p. 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 Radiological Assessment: A Textbook on Environmental Dose Analysis (Till and Meyer 1983). In DOE-STD-1153-2002, Table 4.1, this factor is increased to 22,000 to include the 90% confidence level; in RESRAD-BIOTA, 22,000 is the value of B_{IV} for cesium-137 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, p. 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 TPP will be applied to all radionuclides, but only cesium-137 and strontium-90 are expected to fail the general screening, so this TPP focuses on these two radionuclides.

Note: 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 prohibit consumption of vegetation.

APPENDIX C – LOCATIONS AT LANL

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This appendix discusses the locations of concern at LANL. For further details, see Biota Dose Assessment at Los Alamos National Laboratory (McNaughton 2005a).

TA-01, the Original Technical Area

TA-01 is the original Manhattan Project technical area in the vicinity of the former Los Alamos Inn. Most of TA-01 has been decontaminated below human residential standards and is not a concern for biota. The remaining contaminated area at TA-01 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-01. The primary radionuclide is plutonium-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 located within TA-41, is fenced, and access is restricted by locked gates.

These hillsides are described in the RFI Work Plan for Operable Unit 1078 (LANL 1992a). This 1992 work plan refers to sampling data collected and reported in 1977 by Ahlquist et al. (Ahlquist et al. 1977). However, a remedial action (voluntary corrective action) in 1996 was reported in the Remedial Action Status Report for Potential Release Site 1-001(d) Hillside 138, dated January 1997 (LANL 1997b).

The 1992 work plan (LANL 1992a, Table 4.5-1, p. 4-30) reports 36 pCi/g of plutonium-239 at Hillside 137, 68 pCi/g of uranium-235 at Hillside 140, and 797 pCi/g of plutonium-239 at Hillside 138. The 1996 remedial action was based on measurements taken with a FIDLER instrument. According to a memo from Paul Black to Valerie Rhodes, dated July 20, 1996 (Black 1996), the goals of the remedial action correspond to a plutonium-239 concentration of 300 pCi/g. According to the remedial action status report (LANL 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 BCG of 6000 pCi/g listed in Table 6.4 of DOE-STD-1153-2002. Therefore, TA-01 passes the level-1 screening.

TA-02, in LA Canyon

TA-02 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 strontium-90 and cesium-137 surface contamination was 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 (LANL 2004) shows that contamination was cleaned up to less than the BCGs in DOE-STD-1153-2002. Furthermore, the investigation report includes a detailed ecological investigation that concludes there are no hazards to the biota population. In conclusion, based on existing data, TA-02 passes the level-1 screening.

APPENDIX C – LOCATIONS AT LANL (CONT.)

TA-05, Mortandad Canyon

Mortandad Canyon continues to receive contamination from TA-50 and is described in the Work Plan for Mortandad Canyon, dated September 1997 (LANL 1997a). It is monitored regularly, and the results are reported in the ASER. Significant contamination extends from the TA-50 outfall to near well MCO-8.2. Cesium-137 has the highest ratio to the BCGs (see LANL 1997a, Section 3.4.4). Existing data show that Mortandad Canyon fails the level-1 screening. Further assessments are described in the biota dose assessments (McNaughton 2005 and 2008).

TA-10, Bayo Canyon

Bayo Canyon was the site of the original TA-10, which was contaminated during the Radioactive Lanthanum (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 Work Plan for the North Canyons, dated September 2001 (LANL 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 stronium-90 to the surface. A measurement of 90,500 pCi/g (ash) of strontium-90 in a chamisa plant is described in Strontium Concentrations in Chamisa (*Chrysothamnus nauseosus*) Shrub Plants Growing in a Former Liquid Waste Disposal Area in Bayo Canyon (Fresquez et al. 1995). An interim action is summarized on p. 3-51 of the North Canyons work plan (LANL 1997a), during which 199 pCi/g of strontium-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, also known as SWMU 15-004(f). 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 documented in several reports (Hanson and Miera 1976, 1977, and 1978; White et al. 1980), but the average over the home range of a mouse is less than the BCG.

The papers by Wayne C. Hanson and Felix Miera (1976, 1977, and 1978) include measurements in terrestrial plants and animals.

TA-18, Pajarito Site

A concentration of 28 pCi/g of strontium-90 was reported at SWMU 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 as a small underground area, is unlikely to be a concern. According to the Work Plan for Pajarito Canyon (LANL 1998), this contamination was removed in 1996, so TA-18 passes the initial screening.

APPENDIX C – LOCATIONS AT LANL (CONT.)
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TA-21, DP Canyon

DP Canyon, north of TA-21, is a tributary of Los Alamos Canyon. It was contaminated, primarily with cesium-137, by SWMU 21-011(k) (an outfall). The contaminated area is a channel of runoff north of MDA T and is described in the Task/Site Work Plan for Operable Unit 1049, Los Alamos Canyon and Pueblo Canyon (LANL 1995), in History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes (Areas A, B, C, D, E, F, G, and T) (Rogers 1977), and in Section 16.5 of the TA-21 Operable Unit RFI Work Plan for Environmental Restoration (LANL 1991). Cesium-137 concentrations are on the order of 50 pCi/g, which is greater than the BCG 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 (LANL 2004).

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 (LANL 1997a, Figure 3.4.3-1). Ten Site Canyon joins Mortandad Canyon upstream of the sediment traps and well MCO-7. Pratt Canyon is described in Sections 2.4.4.1, 3.4.3, and 3.4.5 of the Work Plan for Mortandad Canyon (LANL 1997a) and also in the RFI Work Plan for Operable Unit 1129 (LANL 1992b). It was contaminated in the 1950s, primarily with about 0.2 Ci of strontium-90 from TA-35-2 (see Jarmer and Lyman 1997, p. 6).

Section 3.4.5 and Figure 3.4.5-2 of the Work Plan for Mortandad Canyon (LANL 1997a) show strontium-90 contamination of about 5 nCi/g in a small area of the southwest headwall of Pratt Canyon. This is greater than the BCG of 20 pCi/g, so Pratt Canyon fails the level-1 screening.

TA-45 and Acid Canyon

Acid Canyon was contaminated from 1943 to 1951 by the outfall of the radioactive liquid waste line from TA-01, and until 1964 from the liquid-waste treatment plant at TA-45. The primary radionuclide is plutonium-239. Acid Canyon is described in the Task/Site Work Plan for Operable Unit 1049, Los Alamos Canyon and Pueblo Canyon (LANL 1995). More recently, the South Fork of Acid Canyon was remediated from September 12 through November 9, 2001, and the remediation goal of 280 pCi/g was surpassed (see LANL 2002). The 95% upper-confidence-level concentration of 206 pCi/g is far below the BCG of 6000 pCi/g, so Acid Canyon passes the level-1 screening.

TA-50

SWMU 50-006(a) consists of the remnants of a 1974 spill that spread to the east of TA-50-1 (see Emelity 1996, Appendix I). There is a small area with residual concentration of about 50 pCi/g, which is greater than the BCG.

APPENDIX C – LOCATIONS AT LANL (CONT.)

TA-53, LANSCE

The concentrations in the lagoons east of the LANSCE accelerator were greater than the BCGs prior to remediation of the lagoons. The data are marked "Excav: Y," meaning the contamination has been excavated and removed.

TA-54, Area G

Area G includes locations with concentrations greater than the BCGs, for example, SWMU 54-013(b)-99. Area G is monitored by the SFB Team (Fresquez et al. 2003, Nyhan et al. 2004, and Fresquez et al. 2004).

Material Disposal Areas

For the MDAs, concentrations can be estimated by dividing the total estimated inventory by the total estimated volume, resulting in the following MDAs failing the initial screening: A, B, AB, C, G, H, T, and W. Because these MDAs are nuclear environmental sites, a biota dose assessment should be performed. 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 of the method, measurements of the concentrations of protactinium-234m in depleted uranium and potassium-40 in potassium chloride were taken and yielded the expected results.

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 LANL as part of the biota dose assessment per DOE-STD-1153-2002.

Pratt Canyon was contaminated with 0.2 Ci of strontium-90 during operations at TA-35 from 1951 to 1963. The strontium-90 was a byproduct of the RaLa project, which used lanthanum-140 and barium-140. Barium is chemically similar to strontium, so strontium-90 accompanied barium-140 and remains in the canyon, although the short-lived barium-140 and lanthanum-140 have decayed. In some places, the strontium-90 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 instrument measurements 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, the effective depth must be 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. Strontium-90 emits a beta with maximum energy of 0.55 MeV and average energy of 0.20 MeV, and its decay product, yttrium-90, emits a beta with maximum energy of 2.28 MeV and average energy of 0.93 MeV. According to the ESTAR program (described in the International Commission on Radiation Units and Measurements [ICRU] Report No. 37 [1984] and accessible from NIST by searching "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 θ 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 $r\sin\theta\cos\theta d\theta$.)

APPENDIX D – MEASUREMENTS WITH A HAND-HELD BETA DETECTOR (CONT.)

Therefore, if every decay results in two betas, one from strontium-90 with an average range of 0.04 g/cm^2 and the other from yttrium-90 with 0.4 g/cm^2, and if the betas travel in a perfectly 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.

Note that 90% of the counts are from yttrium-90. This fact is confirmed by detailed Monte Carlo calculations. In the following discussions, it is conceptually simpler to consider the yttrium-90 and adjust for the small contribution from strontium-90 as a separate step.

Monte Carlo Calculation of Effective Depth

For the Monte Carlo calculation, rather than using an average energy, the beta spectrum was calculated 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 an 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 perfectly straight line. The calculation is performed with the MCNP as follows.

1. Define an MCNP cell with a large surface area and with a thickness larger than the maximum beta range. This cell corresponds to the ground, a tree trunk, or a mat of vegetation.
2. Populate the cell 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.)
3. 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 corresponds to a 2π solid angle, whereas the LANL detectors are calibrated for a 4π solid angle.

According to MCNP, the effective thickness for yttrium-90 together with strontium-90 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 yttrium-90 is on the next page. The contribution from strontium-90 is 10% of that from yttrium-90. The two contributions are calculated separately and added.

APPENDIX D – MEASUREMENTS WITH A HAND-HELD BETA DETECTOR (CONT.)


```
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
```

APPENDIX D – MEASUREMENTS WITH A HAND-HELD BETA DETECTOR (CONT.)

Corrections to the Measurement

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

At LANL, the SHP380AB detector is calibrated with chlorine-36 betas, and the count rate (cpm) is divided by an effective 4π efficiency of 0.16 ± 0.02 cpm/dpm so the detector reads in dpm. The average beta energy from yttrium-90 is 0.93 MeV, whereas the average from chlorine-36 is 0.25 MeV, so the efficiency for yttrium-90 is higher at 0.22 cpm/dpm. The chlorine-36 source is thin, whereas the wood is thick, so the betas from yttrium-90 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 detector 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% higher and so must be multiplied by 2/3.

For example, the count rate from some of the trees is 200,000 dpm, which corresponds to an activity concentration of (2/3)(2E5 dpm)/((2220 dpm/nCi)*20 g) = 3 nCi/g.

Checking the Method with Protactinium-234m in Uranium-238

These calculations can be checked using the betas from protactinium-234m, which is a decay product of uranium-238. The maximum beta energy from protactinium-234m is 2.28 MeV, almost the same as yttrium-90.

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 protactinium-234m in uranium.

A 4-cm^2 uranium disk was placed near the calibration point of the SHP380AB detectors, so the 30% correction for the spatial variation in efficiency is not applicable. The efficiency for protactinium-234m (0.20) was higher than the calibrated efficiency for chlorine-36 (0.16), and the solid angle was lower than for a large source because the small disk was placed 3/8 in. from the face of the detector. These two correction factors are each about 25% but in opposite directions and cancel within about 10%. Also, protactinium-234m emits a beta in only 99% of its decays, and thorium-234 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

$$(4.9E5 \text{ dpm})/[(2.22E6 \text{ dpm}/\mu\text{Ci})(0.16 \text{ g/cm}^2)(4 \text{ cm}^2)] = 0.34 \ \mu\text{Ci/g}.$$

When secular equilibrium is established, the specific activities of protactinium-234m and uranium-238 are almost the same. The surface of the uranium is oxidized, but the depth is unknown, so the expected result is between that for uranium metal, 0.34 µCi/g, and uranium dioxide, 0.30 µCi/g. It is concluded that the expected and measured results agree within about 10%.

APPENDIX D – MEASUREMENTS WITH A HAND-HELD BETA DETECTOR (CONT.)

Checking the Method with Potassium-40 in Potassium Chloride

The method was also checked using the betas from potassium-40 in potassium chloride, which is available as a salt substitute in grocery stores. Potassium chloride (280 g [10 oz]) was placed on a sheet of polyethylene (to control background) and spread into a layer more than 1 cm thick. The average reading of 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 potassium-40 (0.18) relative to the calibrated efficiency for chlorine-36 (0.16). Also, the activity was divided by 0.89 because potassium-40 emits a beta in only 89% of its decays. Background (10%) was subtracted. With these corrections, the measured activity was 10,600 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 of 0.44 nCi/g.

The effective depth can also be estimated from the CSDA range calculated by ESTAR. The maximum beta energy from potassium-40 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/cm^2, in acceptable agreement with the MCNP calculation.

Nuclide Identification

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

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

No other contamination source has this combination of properties.

If the strontium-90 concentration is uniform, the count rate with 1/8 in. of polyethylene placed between the sample and the detector is 20% of the count rate without the polyethylene.

APPENDIX D – MEASUREMENTS WITH A HAND-HELD BETA DETECTOR (CONT.)

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 strontium-90 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 strontium-90 in vegetation and possibly used 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," Operational Radiation Safety, 96(5): S46-S49 (2009).

APPENDIX E – MEASUREMENTS WITH A SODIUM-IODIDE GAMMA-RAY SPECTROMETER

Page 1 of 5

Abstract

This appendix describes how to use and calibrate hand-held sodium-iodide gamma-ray spectrometers to measure cesium-137 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 (ICRU 1994).

Methods

Cesium-137 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 cesium-137 in a plane source causes a count rate of 10 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 2000 pCi/g in a 20-g 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-g snail with 2000 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 14 and in the following section. The techniques are also discussed in ICRU Report No. 53 (ICRU 1994) and in An In Situ Gamma-Ray Spectrometry Intercomparison (Shebell et al. 2003).

A tree containing cesium-137 will normally be in ground containing cesium-137. 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 cesium-137 in the tree, and B is a constant background related to the cesium-137 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.

APPENDIX E – MEASUREMENTS WITH A SODIUM-IODIDE GAMMA-RAY SPECTROMETER (CONT.)
Page 2 of 5

A general survey for cesium-137 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, cesium-137 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, Isotope Products Laboratories source No. 812-44-1 (18.3 μCi 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 μCi 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 oz of potassium chloride, placed on either side of the detector at an average distance of 7.5 cm from the center line was 1.0 c/s.

In November 2004, the original 18.3-μCi cesium-137 source had decayed to 17.0 μCi. At a distance of 1 ft, the 17.0-μCi source caused a dead time of 5% and a count rate in the peak of 160 c/s; after correcting for dead time, the count rate was 168 c/s.

The dose rate is calculated from first principles; refer to Atoms, Radiation, and Radiation Protection (Turner 1992), p. 208. The dose rate in rad/h is

$$(C\ \text{Ci})(E\ \text{MeV})(\mu_{en}/\rho\ \text{cm}^2/\text{g})(3.7\text{E}10\ \text{s}^{-1}\text{Ci}^{-1})(1.6\text{E}{-}13\ \text{J/MeV})(1\text{E}3\ \text{g/kg})(100\ \text{rad kg/J})$$
$$(3600\ \text{s/h})*(1\text{E}{-}4\ \text{m}^2/\text{cm}^2)\ /\ (4*\text{pi}*r^2\ \text{m}^2)$$

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 1 ft) = $6CE$ (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, where E is the average energy per particle and n is the number of particles.)

There is a small uncertainty about what value of μ_{en}/ρ to use (see the Handbook of Health Physics and Radiological Health [Shleien et al. 1992], pp. 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.

An uncertainty of 10% is acceptable. Use a dose rate = $6CE$ (rad/h).

APPENDIX E – MEASUREMENTS WITH A SODIUM-IODIDE GAMMA-RAY SPECTROMETER (CONT.)
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For cesium-137, E = 0.85*0.662 MeV, and if C=17 μCi, the dose rate at 1 ft = 57 micro-rad/h. This causes a count rate of 168 c/s in the Exploranium peak; therefore, 1 micro-rad/h causes 168/57 ≈ 3 c/s. The concentration in the ground can now be deduced by three different methods, which are compared as follows.

Method 1

Consider the dose rate caused by 1 pCi/g of cesium-137 in the ground. Results have been published by Clouvas et al. (2000, p. 301) and EPA (1993, p. 173), and can also be calculated using RESRAD. With 20% accuracy, 1 pCi/g of cesium-137 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 c/s.

Method 2

The count rate depends on the detector area, A, and the thickness. (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 an activity of B Bq causes a count rate of 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-μCi 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 Radiation Detection and Measurement by Glenn Knoll (1999).

Method 3

Consider the method described in ICRU Report No. 53 (ICRU 1994). Interpolating for 662-keV photons in Table 3.3, and using the same notation as in Table 3.3, 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-μCi source at a distance of 30.48 cm is

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

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.

APPENDIX E – MEASUREMENTS WITH A SODIUM-IODIDE GAMMA-RAY SPECTROMETER (CONT.)

The calibrations previously described 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 a 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, and the dose rate (rad/h) = $6EC$, where C is the activity in Ci, and 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, dx, at distance $r = \text{sqrt}(x^2+y^2)$. Replace C in Equation 1 with $c\rho A\text{d}x$:

dose rate (rad/h) = $5600Ec\rho A\text{d}x/(x^2+y^2)$ **Equation 2**

Where c is the concentration in Ci/g, ρ is the density in g/cm^3, and Adx 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 $\text{d}x/(x^2+y^2) = y^{-1}\arctan(x/y)$]

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 = πy.)

A cesium-137 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 a rate S c/s is measured at a distance y, the concentration, c, is

$c = (17\text{E-}6)(S/168)(y/30.48)^2/(\rho A\pi y)$ Ci/g **Equation 6**

APPENDIX E – MEASUREMENTS WITH A SODIUM-IODIDE GAMMA-RAY SPECTROMETER (CONT.)
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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, then

$$c \approx 2^{(r/8)}(17E\text{-}6)(S/168)(y/30.48)^2/(\rho A \pi y)\ \text{Ci/g} \qquad \textbf{Equation 7}$$

For example, if S = 1 c/s, ρ = 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:

$$c \approx 4S$$

Where c is in pCi/g, and S is in 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, and 1 c/s implies about 2 pCi/g. For a smaller tree with a radius between 4 cm and 15 cm, 1 c/s implies 4 pCi/g, within a factor of 2.

Los Alamos
NATIONAL LABORATORY
EST. 1943

Environment, Safety and Health

Electronic Public Reading Room - Posting of Controlled Procedures

Operations Integration Office Management Approval:

Print Name	Signature	Date
Ellena Martinez	Ellena Martinez	3/4/16

Derivative Classifier:

☐ OUO ☐ UCNI ☒ Unclassified ☐ Classified

Print Name	Signature	Date
Larry W. Maassen	Larry Maassen	3/4/16

List of Controlled Documents:

Procedure No.	Title/Description
Air Monitoring (ENV)	
ENV-ES-TPP-003	Technical Project Plan for the Neighborhood Environmental Watch Network (NEWNET)
ENV-ES-TPP-007	Technical Project Plan for the Direct Penetrating Radiation Monitoring Network (DPRNET)
Data Validation (ADESH)	
OIO-TP-5161	Routine Validation of Volatile Organic Compound Analytical Data
OIO-TP-5162	Routine Validation of Semivolatile Organic Compound Analytical Data
OIO-TP-5163	Routine Validation of Organochlorine Pesticide and Polychlorinated Biphenyl Analytical Data
OIO-TP-5165	Routine Validation of Metals Analytical Data
General Field Work	
OIO-TP-222	Shipping/Receiving of Environmental Samples by the Sample Management Office (SMO)
OIO-QP-219	Sample Control and Field Documentation
Soil, Foodstuffs, and Biota Sampling (ENV)	
ENV-ES-TPP-002	Technical Project Plan for Biota Dose Assessment
ENV-ES-TP-003	Collection of Soil and Vegetation Samples for the Environmental Surveillance Program
ENV-ES-TP-004	Produce Sampling
ENV-ES-TP-007	Game Animal Sampling
ENV-ES-TP-006	Sampling Soil and Vegetation at Facility Sites
SOP-5247	Collection of Benthic Macroinvertebrates in the Rio Grande
ENV-ES-TP-008	Collection of Crawfish in the Rio Grande
Well Drilling, Construction, Development, Maintenance, and Abandonment	
ENV-RCRA-QP-010	Land Application of Groundwater