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**Los Alamos
National Laboratory**

Environmental Stewardship Division

Meteorology and Air Quality Group
(MAQ)

**Quality
Assurance
Project
Plan**

for

**Biota
Dose
Assessment**

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Table of Contents (A2)

Topic	Page No.
Title and Approval Sheet (A1)	1
Table of Contents (A2)	2
Distribution List (A3)	3
Introduction	4
Project Organization (A4)	5
Problem Definition (A5)	6
Project Description (A6)	8
Quality Objectives and Criteria for Measurement Data (A7)	9
Special Training and Certification (A8)	18
Documentation and Records (A9)	19
Sampling Process Design (B1)	20
Sampling Methods and Sample Handling (B2 and B3)	21
Analytical Methods (B4)	22
Quality Control (B5)	25
Instrument and equipment Testing, Inspection and maintenance (B6)	26
Instrument Calibration and Frequency (B7)	27
Inspections, Non-direct measurements, and Data Management (B8 – B10)	29
Assessments and Response Actions (C1)	30
Reports to Management (C2)	31
Data Review, Validation, and Verification (D1)	32
Validation and Verification (D2)	32
Reconciliation with Data Quality Objectives (D3)	32

Appendix

This plan has the following appendixes:

Number	Appendix Title	No. of pages
A	References	4
B	Discussion of Radionuclides at LANL	2
C	Discussion of Locations at LANL	4
D	Measurements with a hand-held beta detector	5

Distribution List (A3)

**List of
document
recipients**

This document will be controlled under the organization's document control system (MAQ-030, "Document Distribution") to ensure that those performing work for the project will be notified of new revisions. Those who will be notified include:

- MAQ Group Leader
- MAQ Deputy Group Leader
- MAQ QA Officer
- MAQ Dose Assessment 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.

Purpose of this plan

This document specifies all 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 their 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.

Structure of the quality program

This Quality Assurance Project Plan is a second-tier document to the MAQ Quality Management Plan (MAQ-QMP). The following documents ensure that the Dose Assessment Team is operated in accordance with the above requirements:

- MAQ Quality Management Plan
 - QA Project Plan for Dose Assessment (this document)
 - implementing procedures
-

Revising this plan

This plan will be controlled through the MAQ document control program (MAQ-030, "Document Distribution").

The project leaders, at least one reviewer, and the group leader will approve all revisions to this plan.

Project Organization (A4)

Group organization

The Meteorology and Air Quality Group (MAQ) of the Environmental Stewardship (ENV) Division supports the Environmental Protection Program of the Environmental Stewardship division. MAQ is responsible for the biota dose assessments specified in DOE-STD-1153-2002 "A graded approach for evaluating radiation doses to aquatic and terrestrial biota."

See the MAQ Quality Management Plan (MAQ-QMP) for a description of the group organization and chain of authorities. The group is organized by teams under the line management direction of the group leader. Teams are cross functional and focus on specific LANL air quality responsibilities, deliverables, or products. Teams are guided by team leaders who have the ultimate responsibility to assure the work is completed.

Project organization

The MAQ Dose Assessment team leader manages the operation of the Dose Assessment Team. The team leader reports to the MAQ Group Leader. A group QA specialist is assigned to work for the team leader to provide quality assurance assistance, advice, and review. Members of the group work for the team leader as needed to provide dose assessment and data evaluation. The following groups provide data for the Dose Assessment Team: ECR and MAQ provide soil data, WQH provides sediment and water data, and MAQ provides biota data.

Approval of final products and deliverables

Final products and deliverables resulting from Dose Assessment will be approved by the Dose Assessment Team Leader and reported to the MAQ Group Leader.

Problem Definition (A5)

Background Los Alamos National Laboratory (LANL or the Laboratory) is a research and development institution operated by the University of California 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 about 0.1 to 1 rad/day are reasonably 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.

10 CFR 834 The draft of 10 CFR 834.7(A) contains similar words to DOE Order 450.1; 10 CFR 834 will be addressed specifically when it is final. DOE-STD-1153-2002 (page M1-2) includes among its purposes the development of methods and guidance with a view to codifying biota dose limits in 10 CFR 834.

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 Dose Assessment Project Leader.

Customer for results The results of the dose assessment will be sent to the MAQ 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 Records should provide a trail, which can be audited, of the calculations and assumptions made to calculate dose. Appropriate and sufficient records should be maintained so the final results can be verified or recalculated later. Such records should include, but are not limited to, 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, and the procedure MAQ-514.

Quality Objectives and Criteria for Measurement Data (A7)

What are DQOs? The 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 dose-assessment team will coordinate with the Ecology group, the Environmental characterization group, and/or the Water-quality and hydrology group (ECO, ECR, and/or WQH) to 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
- terrestrial animals
- terrestrial plants
- aquatic animals

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

Facilities such as LANSCE, DARHT, and LACEF 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 (1-6) is discussed in subsections 7.2.1-6.

7.2.1 Soil Radionuclide concentrations in soil are measured by MAQ and ECR; measurements near potential release sites (PRS) are especially important, and are recorded in the ER database <http://er17.lanl.gov/smart/>.

The measured soil concentrations will be compared with the general screening levels in Tables 6.3 and 6.4 of DOE-STD-1153-2002. Locations with concentrations above the general screening levels will be subjected to a site-specific analysis.

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

7.2.2 Sediment

Radionuclide concentrations in sediment are measured near potential release sites by ECR and recorded in the ER database <http://er17.lanl.gov/smart/>. Also, annual measurements are made by the water and hydrology group, WQH, 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. Locations with concentrations above the general screening levels will be subjected to a site-specific analysis.

7.2.3 Water

Radionuclide concentrations in water are measured by the ENV Water Quality and Hydrology group 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. Locations with concentrations above the screening levels will be subjected to a site-specific analysis.

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

7.2.4 Terrestrial animals

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. The following discussion provides examples to clarify what data are needed.

Terrestrial animals are the particular receptors that determine the screening levels in Tables 6.1 through 6.4 of DOE-STD-1153-2002. This is because they are subject to a lower dose limit than terrestrial plants and aquatic animals (Section A5), and also because they are near the top of the food chain and so may accumulate toxins and radionuclides.

For example, the default screening level for ^{137}Cs is determined by assuming the concentration in a terrestrial animal is 2.5 times the concentration in the aquatic animals it eats, and that the concentration in these aquatic animals is 22,000 times the concentration in the water, a conservative number from Table 5.41 of NUREG/CR-3332 (edited by Till and Meyer). In the limiting case, if the water concentration is 40 pCi/L (≈ 40 pCi/kg) the concentration in the terrestrial animal is assumed to be $54,000 \times 40$ pCi/kg = 2,160 pCi/g; (the factor is 54,000 in RESRAD-BIOTA and 50,000 on page M1-81 of DOE-STD-1153); 2,160 pCi/g causes a dose rate of 0.1 rad/day to the animal (Section 7.2.7).

Similarly:

- in the limiting case for ^{90}Sr , if the water concentration is 300 pCi/L, the concentration in the animal is assumed to be $6.2\text{E}3 \times 300$ pCi/kg = 1,860 pCi/g;
- in the limiting case for ^{137}Cs in soil, if the soil concentration is 20 pCi/g, the concentration in the animal is assumed to be $110 \times 20 = 2,200$ pCi/g;
- in the limiting case for ^{90}Sr in soil, if the soil concentration is 20 pCi/g, the concentration in the animal is assumed to be $80 \times 20 = 1,600$ pCi/g.

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

7.2.4 Terrestrial Animals Summary

The essential points are:

- the default assumptions are conservative;
- biota data can be used for a more realistic assessment.

As input to the analysis, site-specific data are needed to determine the ratios of the concentrations of ^{137}Cs and ^{90}Sr in biota to the concentrations in vegetation, soil and water. These ratios are variously called concentration ratios, transfer factors, or bioaccumulation factors, B_{iv} .

7.2.5 Terrestrial plants

Terrestrial plants will receive limiting dose rates (1 rad/day) if the concentrations of ^{137}Cs or ^{90}Sr in the plants are 20,000 pCi/g (see Section 7.2.7).

As input to the analysis, data are needed either for a direct measurement of the dose to the plant, or to determine the concentration ratios or bioaccumulation factors, B_{iv} .

7.2.6 Aquatic animals

Aquatic animals will receive limiting dose rates (1 rad/day) if the concentrations of ^{137}Cs or ^{90}Sr are approximately 20,000 pCi/g (see Section 7.2.7).

As input to the analysis, data are needed either for a direct measurement of the dose to the animals, or to determine the concentration ratios, a.k.a. bioaccumulation factors, B_{iv} for aquatic animals.

7.2.7 Concentration to dose conversion factor

As described in Sections 7.2.4 through 7.2.6, the concentration to dose conversion factor for ^{90}Sr or ^{137}Cs in biota \approx 20,000 pCi/g per rad/day; this is the inverse of the conversion factors on page M3-18 of DOE-STD-1153-2002. More precisely, for ^{90}Sr it is $1/(5.8\text{E-}5) = 17,000$ pCi/g per rad/day, and for ^{137}Cs it is $1/(4.3\text{E-}5) = 23,000$ pCi/g.

This conversion assumes the radioactive material is evenly distributed throughout the organism, which is generally a good assumption for ^{137}Cs , and for ^{90}Sr in plants, but not for animals with a skeleton. Because strontium is like calcium, it accumulates in bone and other types of skeleton. If significant concentrations ($> 1,000$ pCi/g) of ^{90}Sr are found in animals, a more sophisticated model should be considered.

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

7.3.1 Data boundaries: spatial

According to the guidance of DOE-STD-1153-2002, begin with a general screening of all data, and where more data are needed focus on the areas of concern.

- All LANL potential release sites and all data in the ER database will be subjected to a general screening (DOE-STD-1153-2002 Table 2.1) to identify the areas of concern.

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.)
- Terrestrial animals should be measured near the most contaminated areas, taking into account the animals' home ranges.
- Terrestrial plants should be measured within the PRS of concern.
- Aquatic animals should be measured within the canyon reach of concern.

For the site-specific analysis, the concentrations are averaged over an appropriate area. DOE-STD-1153-2002 (page M2-35) suggests that averaging over 100 m² would, in most cases, be too small, and averaging over the entire site (100 million m²) would be too large.

The biota habitats at LANL are large: pinon-juniper covers 5,000 ha; ponderosa pine covers 3,000 ha; grassland covers 1,000 ha; etc. Rather than average over such large areas, we choose 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 Rytí et al. (Rytí 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. Furthermore, when the existing data are entered into RESRAD-BIOTA, they do not change the biota dose significantly. Therefore, annual 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 more frequently than every six years. 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 is valuable.

In summary, a minimal 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 population dose is inversely proportional to the population area, which is not accurate. The population area of 3 ha adopted 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 so as to facilitate trending; 2% is the expected change from the decay of ¹³⁷Cs or ⁹⁰Sr in one year. So, when it is reasonably achievable, data should be obtained in a reproducible manner with a goal of a factor of two absolute accuracy, and in some cases a relative precision of 2%.

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 Represent- ativeness

Representativeness expresses the degree to which data represent the characteristics of a population. In this case, the population of interest is: all biota. This diverse population is represented by samples from a small subset of species.

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 Compar- ability

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 and in accordance with the MAQ Quality Management Plan (MAQ-QMP).

Training of personnel

All personnel performing work are required to obtain appropriate training prior to performing work governed by a procedure. Training for MAQ personnel will be performed and documented according to the MAQ procedures for training (MAQ-024) and new employee orientation (MAQ-032). Training of personnel in other groups will be performed and documented according to each group's training procedure.

Documentation and Records (A9)

Records resulting from the project

Dose assessments for the annual Environmental Surveillance Report and for compliance will be peer-reviewed and fully documented as required by the Environmental Protection Program Integrated Management Plan (EPP-IMP). 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.

Records to be kept in the MAQ records system (MAQ-025, "Records Management") include the dose assessments, assumptions, and references to the data sets used in the calculations.

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, and in the ENV Division Integrated Management Plan (ENV-IMP).

Records final disposition

All records will be maintained and available for auditing in the records center at the MAQ group office (MAQ-025, "Records Management"). Records will be archived in compliance with Laboratory and DOE requirements for records retention, storage, and management.

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, terrestrial animals and plants, and aquatic animals. 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 existing soil data in the ER database and the existing water data in the annual site environmental survey report, and whatever sediment data are available. The level-1 screening will lead to more detailed level-2 and/or 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, we will use hand-held instruments to make surveys and measurements of the concentrations of ^{137}Cs and/or ^{90}Sr in plants. We will also attempt to use the Violinist instrument to measure Am-241 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 4.3 describes how to calculate the biota dose from the concentrations.

**B4.1
Calculating
the ⁹⁰Sr
concentration** Section 4.1 describes how to calculate the ⁹⁰Sr 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/cm². For details of this calculation, see Appendix D.

The area of the SHP380AB is 100 cm², so the effective mass being sampled is (100 cm²)*(0.20 g/cm²) = 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/cm². The area of the HP-260 probe is 15 cm², 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 ⁹⁰Sr to an effective depth of 0.2 g/cm²; and
- the mass of the sample is (0.2 g/cm²) multiplied by the area (cm²).

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 Bicon 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; (e.g., using levels 2 and/or 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.

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.
2. Include sediment data if available.
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. Use site-specific bioaccumulation factors if available.
6. Measure concentrations in biota, deduce bioaccumulation factors, and substitute these for the default factors.

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 annually (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. GPS locations are helpful but are usually only accurate to 10 meters.

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. Instruments will be calibrated annually.

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 be 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. The expected beta response is approximately 500 k dpm, in good agreement with the actual measured rate. 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 steradians (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: $0.5/(0.08 \text{ cm}^2/\text{g}) = 6 \text{ g/cm}^2$. This value of 6 g/cm^2 is similar to the depth sampled by the Soil-Foodstuff-and-Biota (SFB) team of MAQ, 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 will 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 MAQ Quality Management Plan for software control will be followed. These include methods for version identification, verification of proper operation by an independent technically qualified person, regular backups, and documentation of operations and calculations performed by the software.

Assessments and Response Actions (C1)

Internal management assessments

Internal management assessments will be conducted in accordance with the MAQ QMP and procedure MAQ-029, "Management Assessments." This procedure requires periodic assessments by the group leader of the effectiveness of programs or teams. These assessments are documented and filed as records.

LANL required audits

LANL audit groups external to MAQ may be delegated responsibility for assessments under the LANL QMP. These may apply to any program or project within MAQ.

MAQ requested audits

The MAQ Group Leader may request assessments of any program or project within MAQ. These assessments may also include assessment of organizations which supply information to MAQ or from which MAQ obtains services (e.g., analytical laboratories).

Corrective actions within MAQ

The group has adopted the word "deficiency" to replace other commonly used terms such as finding, condition adverse to quality, and nonconformance. The group QMP defines a deficiency as a malfunction of a process that negatively impacts the quality specifications of MAQ products.

MAQ will document and track external and internal audit findings, or other deviations from requirements found during an audit or assessment as deficiencies. The deficiency, corrective actions, and any resulting root cause analyses, follow-ons, and closures, will be handled in accordance with MAQ-026, "Deficiency Reporting and Correcting."

Reports to Management (C2)

Dose reports The Dose Assessment team 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:

- MAQ Group Leader; and
- Dose-assessment 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 will include:

- 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 (MAQ-026), and the causes of the differences will be investigated, reported to management, and corrected where possible.

[Click here to record “self-study” training to this procedure.](#)

APPENDIX A: REFERENCES

Requirements and guidance documents:

DOE Order 231.1, "Environmental Safety and Health Reporting".

DOE Order 414.1A, "Quality Assurance," issued September 29, 1999, changed July 12, 2001.

DOE Order 450.1 "Environmental Radiation Protection".

DOE Order 5400.5, "Radiation Protection of the Public and the Environment," changed January 7, 1993.

DOE-STD-1153-2002, "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota", July 2002.

DOE/EH-0173T, "Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance," January 1991
<http://tis.eh.doe.gov/oepa/guidance/aea/effluent/eh0173t.pdf> .

10 CFR 834, "Radiation Protection of the Public and the Environment", Proposed Rule, Federal Register Volume 58 No. 56, March 25, 1993.

EPA QA/R-5, "EPA Requirements for Quality Assurance Project Plans for Environmental Data Operations," EPA/240/B-01/003, March 2001.

EPA QA/G-4, "Guidance for the Data Quality Objectives Process," September 1994.

ENV-IMP, "Integrated Management Plan for the Environmental Stewardship Division", ENV Division, LANL.

MAQ Group documents:

MAQ-QMP, "Quality Management Plan for the Air Quality Group"

MAQ-022, "Preparation, Review and Approval of Procedures"

MAQ-024, "Personnel Training"

MAQ-025, "Records Management"

MAQ-026, "Deficiency Reporting and Correcting"

MAQ-029, "Management Assessments"

MAQ-030, "Document Distribution"

MAQ-032, "New Employee Orientation"

MAQ-514, "Calculating dose to non-human biota"

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

Other references:

Bowman 2002, JA Bowman et al., "Dispersal distance of mammals is proportional to home range size", Ecology volume 83, pages 2049-2055 (2002)

DOE G 441.1-7, "Portable Monitoring Instrument Calibration Guide,"
<http://www.directives.doe.gov/pdfs/doe/doetext/neword/441/g4411-7.pdf>

DOE-HDBK-1122-99 Module 2.16 "Radiation Survey Instrumentation" and Module 2.17
"Contamination Monitoring Instrumentation".

M. Eisenbud and T. Gesell, "Environmental Radioactivity, Academic Press (1997), ISBN 0-12-235154-1.

Federal Guidance Report No. 12, EPA-402-R-93-081.

Fresquez 1996, PR Fresquez et al., "Radionuclides and radioactivity in soils within and around Los Alamos National Laboratory, 1974 through 1994, trends and dose comparisons." LA-13149-MS (1996)

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

Health Physics volume 78 pages 295 to 302, "Monte Carlo Calculations of Dose Rate Conversion Factors for External Exposure to Photon Emitters in Soil" (A. Clouvas et al.)

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 ⁹⁰Sr 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.

LA-14095-PR, "Radionuclide concentrations in soils and vegetation at low-level radioactive waste disposal Area G during the 2002 growing season, with a summary of radionuclide concentrations in soil and vegetation since 1980", J.W. Nyhan, P.R. Fresquez, et al., 2004.

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.

LA report (to be published), "Radionuclide contaminant analysis of small mammals at Area G, TA-54, 2001-3, with a cumulative summary for 1994-2003", Lars Sohlt, P.R. Fresquez, Ed Lopez, 2004 or 2005.

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.
- LA-UR-95-2053, "Task/Site Work Plan for Operable Unit 1049, Los Alamos Canyon and Pueblo Canyon", November 1995.
- LA-UR-96-1283 "A History of Radioactive Liquid Waste Management at Los Alamos, L.A. Emelity.
- LA-UR-96-1605, "RFI Report for Potential Release Sites 35-003 ..." June 1996.
- LA-UR-97-3291, "Work Plan for Mortandad Canyon", September 1997.
- LA-UR-98-2550, "Work Plan for Pajarito Canyon", (1998).
- LA-UR-99-1405 (to be updated in 2004) "Screening level ecological risk assessment methods".
- LA-UR-00-502, "Environmental Radioactivity", M.W. McNaughton,
<http://www.lanl.gov/orgs/rres/maq/CommunityMonitoring/pdf/Envir-Rad-expanded.pdf>.
- LA-UR-01-1316, "Work Plan for the North Canyons".
- LA-UR-02-5785, "Interim Action Completion Report for the South Fork of Acid Canyon", ER2002-0544, Steve Reneau, Tom Benson, and Randall Ryti.
- LA-UR-04-2714 "Los Alamos and Pueblo Canyons Investigation Report".
- LA-UR-04-8246, "Screening-Level Ecological Risk Assessment Methods, Revision 2," ER2004-0519 (2004).
- NCRP, "National Council on Radiation Protection", <http://www.ncrp.com/> "Effects of Ionizing Radiation on Aquatic Organisms," Report No. 109 (1991).
- RESRAD, <http://web.ead.anl.gov/resrad/home2/>
- Ryti 2004: Randall T. Ryti, James Markwiese, Richard Mirenda, Lars Soholt, "Preliminary Remediation Goals for Terrestrial Wildlife", Human and Ecological Risk Assessment, 10: 437-450, (2004).
- J.E. Till and H.R. Meyer (editors), "Radiological Assessment", NUREG/CR-3332 and ORNL-5968, 1983.
- J.E. Turner, "Atoms, Radiation, and Radiation Protection", McGraw Hill (1992) (ISBN 0-07-105320-4).

UNSCEAR, "United Nations Scientific Committee on the Effects of Atomic Radiation",
<http://www.unscear.org/>, "Effects of radiation on the Environment", ISBN 92-1-142219-1 (1996)

F.W. Whicker and V. Schultz, "Radioecology: nuclear energy and the environment"
published by CRC Press, 1982, ISBN 0-8493-5353-X

APPENDIX B: DISCUSSION OF 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. Are they more hazardous than plutonium? And if they are not hazardous to humans, why are they hazardous to biota?

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 much 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 BIV 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.

Concentrations > 40 pCi/L have been measured in Mortandad Canyon (at GS-1), so LANL fails the initial screening. As applied to LANL, the next questions are as follows.

- Do aquatic animals in Mortandad Canyon have a concentration of $22,000 \times 40$ pCi/L?
- Are there terrestrial animals that eat these aquatic animals?
- If so, what fraction are they of the terrestrial animals' diet?

- Do terrestrial animals at LANL have a ^{137}Cs concentration of $2.5 \times 22,000 \times 40$ pCi/L?
- Can we deduce that the cesium bioaccumulation factor differs from 54,000?

A similar discussion applies to the 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 will be posted as a "Soil Contamination Area" to forbid eating. At present, Bayo Canyon, Mortandad Canyon, and Pratt Canyon, are so posted.

APPENDIX C: DISCUSSION OF LOCATIONS AT LANL

This appendix discusses the locations of concern at LANL.

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 and does not require further investigation.

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 and does not need further biota dose assessments.

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. ¹³⁷Cs 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, so it will be the subject of further biota dose assessment.

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 exception is the combined area of PRS 10-003 and 10-007 (a.k.a. decision set 10-002(a)-99) which is fenced and posted as a Soil Contamination Area.

The significant contamination is underground and includes 1,395 pCi/g of Am-241 and 41,887 pCi/g of Sr-90 at a depth of 5 m. 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.

In summary, existing soil data show that Bayo Canyon fails the level-1 screening and should be investigated further.

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 ⁹⁰Sr is 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. Therefore, TA-18 passes the initial screening and does not need further biota dose assessment.

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. ¹³⁷Cs 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 ⁹⁰Sr 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 and will be investigated further.

TA-39, Ancho Canyon

In 1994, preliminary data indicated 34 pCi/g ¹³⁷Cs 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, so the biota dose will be zero.

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 and does not need to be investigated further.

TA-50, Effluent Canyon

TA-50 is the Radioactive Liquid Waste Treatment Facility. PRS 50-006(d) is Effluent Canyon. Peak ¹³⁷Cs concentrations have sometimes been greater than the biota concentration guide (BCG) of 40 pCi/L. Therefore, this PRS fails the level-1 and will be subjected to a site-specific assessment.

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, so this will be investigated further.

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. So TA-53 does not need to be investigated further.

TA-54, MDA G

MDA G includes locations with concentrations greater than the biota concentration guidelines, for example PRS 54-013(b)-99. MDA G is monitored by the SFB team of group MAQ (LA-14091, LA-14095-PR, LA-14108-PR). We will assess these data annually.

TA-60, impoundment on Sigma Mesa

PRS 60-005(a) is a 0.1-ha fenced surface impoundment with dry sludge containing ¹³⁷Cs. 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, which is essentially zero.

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 cm²). As a check on the method, measurements of the concentration of ^{234m}Pa in depleted uranium and ⁴⁰K 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 cm²). 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 ⁹⁰Sr during operations at TA-35 from 1951 to 1963. The ⁹⁰Sr was a byproduct of the Radioactive Lanthanum (RaLa) project, which used ¹⁴⁰La and ¹⁴⁰Ba. Ba is chemically similar to Sr, so ⁹⁰Sr accompanied ¹⁴⁰Ba and remains in the canyon although the short-lived ¹⁴⁰Ba and ¹⁴⁰La have decayed. In some places, the ⁹⁰Sr 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/cm²). To convert to activity per unit mass, we need the effective depth in g/cm²; the quotient (pCi/cm²)/(g/cm²) is the desired result in pCi/g.

The effective depth may be estimated analytically using average beta energies and ranges. ⁹⁰Sr emits a beta with maximum energy 0.55 MeV and average energy 0.20 MeV, and its decay product, ⁹⁰Y, 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/cm² for a 0.2-MeV beta and 0.4 g/cm² 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 $r\sin\theta\cos\theta d\theta$.)

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 $0.5*(0.04+0.4) = 0.22 \text{ g/cm}^2$.

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 2π solid angle, whereas the LANL detectors are calibrated for a 4π 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:
 $(100 \text{ cm}^2)*(0.20 \text{ g/cm}^2) = 20 \text{ g}$.

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 $2\text{E}5$ dpm, which corresponds to an activity concentration: $(2/3)(2\text{E}5 \text{ dpm}) / ((2220 \text{ dpm/nCi}) * 20 \text{ g}) = 3 \text{ nCi/g}$.

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

We can check these calculations using the betas from $^{234\text{m}}\text{Pa}$, which is a decay product of ^{238}U . The maximum beta energy from $^{234\text{m}}\text{Pa}$ 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 $^{234\text{m}}\text{Pa}$ 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 $^{234\text{m}}\text{Pa}$ (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, $^{234\text{m}}\text{Pa}$ 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 $4.9\text{E}5$ dpm ($\pm 10\%$), and background was negligible, so the measured specific activity was

$$(4.9\text{E}5 \text{ dpm}) / [(2.22\text{E}6 \text{ dpm/micro-Ci})(0.16 \text{ g/cm}^2)(4 \text{ cm}^2)] = 0.34 \text{ micro-Ci/g.}$$

When secular equilibrium is established, the specific activities of $^{234\text{m}}\text{Pa}$ 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/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 ^{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 ^{90}Sr in vegetation, and possibly for other applications. The method is cheap, quick, and simple.

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 ^{137}Cs 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 owned by ENV-MAQ, 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

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

For example, if $r = 0.3048 \text{ m}$, and $\mu_{en}/\rho = 0.033 \text{ cm}^2/\text{g}$, then the result is the familiar rule of thumb: dose rate (rad/h at one foot) = $6CE$ (Note: this formula may be given in units of R/h: for water or tissue, $1 \text{ R} = 0.97 \text{ rad}$. 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 μ_{en}/ρ to use (see Handbook of Health Physics pages 5-2 to 5-35; use the right hand column.)

$\mu_{en}/\rho = 0.033 \text{ cm}^2/\text{g}$ for water,
 $\mu_{en}/\rho = 0.032 \text{ cm}^2/\text{g}$ for tissue,
 $\mu_{en}/\rho = 0.031 \text{ cm}^2/\text{g}$ for sodium-iodide, or
 $\mu_{en}/\rho = 0.029 \text{ cm}^2/\text{g}$ for air or silicon-dioxide

We accept an uncertainty of 10% and use: dose rate = $6CE$ (rad/h).

For ^{137}Cs , $E = 0.85 \cdot 0.662 \text{ MeV}$, 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 $168/57 \approx 3$ 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 $8 \text{ g/cm}^2 = (0.037 \text{ Bq/pCi})(8 \text{ g/cm}^2)(1 \text{ pCi/g}) = 0.3 \text{ Bq/cm}^2$, 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 $S = 168 \text{ c/s}$ at $r = 30.48 \text{ cm}$ for a source $B = (3700 \text{ Bq}/\mu\text{Ci}) \cdot (17 \mu\text{Ci})$, so the count rate from 1 pCi/g = $1.2\pi(30.48)^2(168)/(3700 \cdot 17) = 1 \text{ c/s}$. 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" $\beta = 8 \text{ g/cm}^2$ is $(3 \cdot .589 + 2 \cdot .386)/5 = 0.5$. Therefore, the expected flux for 1 pCi/g is

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

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

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

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 steradians. 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) = $6EC$

(C is the activity in Ci, E is the energy per emission in MeV)

so at a distance r (cm) from the detector:

$$\text{dose rate (rad/h)} = 6EC(30.48/r)^2 = 5600EC/r^2 \quad (\text{equation 1})$$

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 a distance $r = \sqrt{x^2 + y^2}$.

Replace C in equation 1 with $c\rho A dx$:

$$\text{dose rate (rad/h)} = 5600Ec\rho A dx / (x^2 + y^2) \quad (\text{equation 2})$$

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

$$\therefore \text{dose rate (rad/h)} = 5600Ec\rho A\pi / y \quad (\text{equation 3})$$

Compare equation 3 with equation 4 for a point source, activity C , that causes the same dose rate at a distance y :

$$\text{dose rate (rad/h)} = 5600EC / y^2 \quad (\text{equation 4})$$

$$\text{Therefore, } C = c\rho A\pi y \quad (\text{equation 5})$$

(Roughly speaking, equation 5 implies the effective length of the tree = πy .)

A ^{137}Cs point source with $C = 17\text{E-}6$ 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

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

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:

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

For example, if $S = 1$ c/s, $\rho = 0.9$ g/cm³, $r = 9$ cm, $A = \pi r^2 = 250$ cm², 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.