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Los Alamos NATIONAL LABORATORY EST.1943

Environment, Safety, Health Directorate

Environmental Protection Division – Environmental Stewardship Group

Technical Project Plan

Direct Penetrating Radiation Monitoring Network (DPRNET)

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History of Revisions

Document Number *[Include revision number, beginning with Revision 0]*	**Effective Date** *[Document Control Coordinator inserts effective date]*	**Description of Changes** *[List specific changes made since the previous revision]*
0	4/15/2002	New Document. RRES-MAQ-DPRNET, Quality Assurance Project Plan for Direct Penetrating Radiation.
0	07/2013	This document was previously RRES-MAQ-DPRNET, Quality Assurance Project Plan for Direct Penetrating Radiation. Updated to new format and to be consistent with DOE Order 458.1. New title and number assigned.

Table of Contents

1.0 PURPOSE

This document specifies all the actions necessary to ensure the quality and accuracy of direct penetrating radiation network (DPRNET) data for the Los Alamos environment. The environment is defined as the locations affected by DOE activities at Los Alamos National Laboratory and their predecessors (beginning with the Manhattan Project) that are not part of the workplace (occupational dose in the workplace is monitored and assessed by the Radiation Protection Division.)

This plan also demonstrates compliance with the DOE Order 414.1 (latest revision) requirements for a quality program.

2.0 SCOPE

Some LANL facilities, operations, and activities emit radiation that is subject to regulation by DOE (under Contractor Requirements Document [CRD] of Order 458.1, as promulgated in P 412). These regulations and requirements require routine annual reports and special reports of significant doses or potential doses. In addition, LANL policies mandate that doses be estimated in order to keep the doses ALARA (P 412 and PD 410).

Los Alamos National Laboratory (LANL or the Laboratory) is a research and development institution operated by Los Alamos National Security, LLC, (LANS) for the U.S. Department of Energy (DOE). The primary focus of Laboratory research activities is nuclear weapons, nuclear non-proliferation, energy technology, and basic sciences. As such, Laboratory operations include the use of radioactive and hazardous materials.

The Laboratory has operated monitoring networks for over 35 years to determine the impact of radiation on the environment. The Laboratory has followed the guidance in DOE/EH-0173T for the design and operation of the networks. The impact on the environment is determined by measuring doses to individuals in millirem (mrem).

These doses are compared to radiation protection standards and regulations developed by the National Council on Radiation Protection & Measurements (NCRP), by the International Commission on Radiological Protection (ICRP), by the DOE in Order 458.1 and promulgated in P412. Currently, the radiation protection dose standards for the public located off the Laboratory, on the Laboratory outside of RCAs, and to those exposed to residual radioactive material subsequent to release from controls are:

- 100 mrem/year whole body total effective dose (TED) from all pathways,
- 1500 mrem/year lens of eye (external) dose,
- 5000 mrem/year skin and extremities (internal + external) dose,
- 25 mrem/year whole body TED from radioactive waste management, storage, and disposal activities,
- 10 mrem/year effective dose equivalent (EDE) from the air pathway, and

- 4 mrem/year total body or organ dose for beta and photon emitters in the community water system (drinking water) pathway (maximum contaminant levels [MCLs] otherwise specified in 40 CFR 141.66).

3.0 PROJECT ORGANIZATION

3.1 Group Organization

The Environmental Stewardship Group (ENV-ES) of the Environmental Protection Division (ENV) supports the Los Alamos National Laboratory Quality Assurance Program (SD 330). ENV-ES is responsible for the direct penetrating radiation network (DPRNET) data required by DOE Order 458.1, as specified in Article 311 of P 412.

The ENV-ES group is organized by teams under the line management direction of the group leader. Teams are cross functional and focus on specific LANL environmental stewardship responsibilities, deliverables, or products. Teams are guided by team leaders who have the ultimate responsibility to assure the work is completed.

3.2 Task Organization

The Environmental Radiation Protection team leader manages the operation of the DPRNET task. The team leader reports to the ENV-ES Group Leader. A task leader, who reports to the team leader, provides day-to-day support to the task in the form of maintenance of a technical scope description, project management, and quality assurance. A division-level QA specialist is assigned to work for the team leader to provide quality assurance assistance, advice, and review. Members of the task work for the team leader to provide data. In addition, the following organizations provide support to the task: the AIRNET task within ENV-ES deploys and retrieves dosimeters.

3.3 Approval of Final Products and Deliverables

Final products and deliverables from the Dose Assessment task will be approved by the Environmental Radiation Protection team leader and reported to the ENV-ES group leader.

3.4 Decision Makers

The principal decision maker for the task is the Environmental Radiation Protection team leader.

3.5 Results

The results will be sent to the ENV-ES Radiation Protection team leader. Results will also be sent to any LANL operating group that requests them and will be published in the Laboratory's annual Environmental Report. The results will ultimately be used by LANL senior managers and the DOE/NNSA to make decisions regarding mitigation measures or

cessation/modification of operations that may impact the environment from a radiological standpoint.

4.0 TASK DESCRIPTION

4.1 Purpose

The purpose of DPRNET is to measure direct penetrating radiation from LANL at locations at and near LANL.

4.2 General Task Description

This activity works to ensure institutional compliance with DOE Order 458.1 (formerly 5400.5). This activity also supports the Emergency Operations Center (EOC) with data for accidents to ensure compliance with DOE Order 151.1. The staff measures environmental radiation at and near LANL in response to inquiries from agencies such as the New Mexico Environment Department, the Centers for Disease Control, and the public interest groups. This work contributes to the annual Environmental Report and New Project Review (PRID).

Subtasks include:

- Measure direct penetrating radiation in the environment at and near LANL,
- Support the EOC with data,
- Support the environmental ALARA program,
- Task management.

4.3 Subtasks

4.3.1 Measure direct penetrating radiation in the environment at and near LANL from current and legacy LANL environmental radiation

This activity includes the assessment of data from past and present sources of external radiation for members of the public who are either off site or on site.

4.3.2 Support the Emergency Operations Center with data for accidental releases of radioactive materials to the environment

This activity includes support to the LANL Emergency Operations Center (EOC) Emergency Technical Support Center (ETSC) during actual emergencies, exercises, and drills.

4.3.3 Support the environmental ALARA program for the Laboratory

It is the responsibility of the Laboratory to perform work in a manner that protects the health of the public and preserves the quality of the environment. In keeping

with this document, the Laboratory is committed to keeping external radiation fields in the environment As-Low-As-Reasonably Achievable (ALARA).

4.3.4 Task management

Task members work with DOE/NNSA personnel, other outside agencies, tribes, clients, and public interest groups to interpret regulatory/contractual changes and evaluate radiological impacts from Laboratory operations. Administrative functions critical to task performance are also included under this Subtask.

4.4 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*) and the format follows that documents structure.

4.5 Personnel

Personnel are required to have experience or training in health physics, data evaluation, and calculation. Minimum training and education requirements are given in section 6.0.

4.6 Required Records and Reports

Records will provide a trail, which can be audited, of the calculations and assumptions. Appropriate and sufficient records will be maintained for a minimum of five years (as specified in 40 CFR Part 61.95) so the final results can be verified or recalculated later. Such records will include, but are not limited to, the procedure used to determine the appropriate quantities. See section 7.1 for a description of the records to be preserved.

Radiation dose is calculated annually and published in the annual Environmental Report as specified in DOE Manual 231.1B.

5.0 QUALITY OBJECTIVES AND CRITERIA FOR MEASUREMENT DATA

5.1 What are DQOs?

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

5.2 Problem statement and requirements

The objective of this technical project plan is to assess the external radiation dose to the public as required by DOE Orders and to compare this dose with the limits and standards.

In the following sections, we review the orders, regulations, and guidance issued by the DOE and EPA.

5.2.1 Requirements in DOE Order 458.1

The CRD in DOE Order 458.1, and as promulgated in P 412, directs the subcontractor to:

- detect and characterize radiation from DOE activities;
- ensure that potential radiation exposures to members of the public are as low as is reasonably achievable;
- assess the radiation dose to members of the public;
- protect the environment from the effects of radiation;
- characterize the exposure to members of the public;
- characterize the exposures and doses to individuals and to the population; and
- evaluate the potential impact to the biota in the vicinity of the DOE activity (refer to QAPP-05, *Quality Assurance Project Plan for Biota Dose Assessment*).

DOE Order 458.1 also establishes the annual dose limits to "members of the public", who are defined in Attachment 2 of the order as "An individual who is not a general employee. An individual is not a member of the public during any period in which the individual receives an occupational dose". The dose limits to members of the public are specified in section 2.b. of the CRD of the order and are promulgated in Article 221 of P 412.

5.2.2 Requirements in DOE/EH-0173T

DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*, (January 1991) [http://www.orau.org/documents/ivhp/health-physics/eh0173t.pdf] discusses the appropriate monitoring for various dose rates; see Sections 2.1, 3.0, 3.3.2, 5.2.1, 5.8, 5.8.1, 5.10, 5.10.1.2, and 5.10.2; also see Tables 3-1, 5-1 and 5-2. According to Table 5-1:

- routine surveillance of all pathways should be performed if the total dose exceeds 5 mrem or 100 person-rem;
- annual surveillance should be considered if the dose is in the neighborhood of 1 mrem/year; and
- surveillance may be performed periodically at intervals ≤ 5 years if the projected dose is < 0.1 mrem/year.

DOE/EH-0173T recommends the use of thermoluminescent dosimeters (TLDs) and pressurized ion chambers (PICs). Continuous environmental gamma-ray monitoring is highly desirable but not mandated. An array of continuously

recording instruments should be considered if there is a potential for release of large inventories of gamma emitters.

Accuracy of 1 mrem/year or 10-20% are implied but not mandated.

5.3 Decision Statement

If any measurement indicates a source with a potential to approach or exceed a limit (100 mrem/year for all pathways), LANL will make appropriate decisions as follows:

- apply controls to maintain doses "as low as reasonably achievable," or ALARA;
- perform a quantitative ALARA review if the dose to a member of the public is 3 mrem/year or greater (PD 410 and SOP-5254);
- take corrective actions to reduce emissions;
- recommend cleanups;
- cease certain operations; and/or
- take the necessary actions to achieve compliance with regulations.

5.4 Data Types as Input into the Decision

Inputs to the decision require the following types of data:

- direct penetrating radiation doses from the DPRNET dosimeters.

Each type of data is discussed in the following subsections (5.4.1).

5.4.1 Data from DPRNET

Direct penetrating radiation (DPR) in the form of gamma photons and neutrons is monitored both close to the source and at receptor locations. The report, *Siting of Environmental Direct-Penetrating-Radiation Dosimeters*, LA-UR-00-1168 specifies the procedure to ensure all locations with a potential for 5 mrem/year or more are monitored for both gamma photons and neutrons.

5.5 Data Boundaries

The following considerations constrain the boundaries of the monitored region:

- Beyond a radius of 1 km from the source, direct radiation is too small to measure with DPRNET and contributes < 1 mrem/year.

5.6 Completeness Statement

The dose measurement described in this plan is complete because it includes complete assessment of the neutron and gamma pathways.

5.7 Data Accuracy

For the purpose of dose assessment, the desired accuracy of the input data is 1 mrem/year or 10%. This is appropriate because it is a small fraction of the limits and so it provides reasonable assurance that the limits are not exceeded. Accuracy is constrained by the limitations described below.

5.7.1 Accuracy Limitations

In practice, the following technical considerations limit the accuracy in some cases.

5.7.2 DPRNET Gamma Accuracy

As described in “Environmental Surveillance at Los Alamos during 2001", LA-13979-ENV, Chapter 4, Section C.1, natural gamma radiation varies from 100 to 200 mrem/year and is measured with a 1-standard-deviation accuracy of about 10 mrem/year. As a result, DPRNET measurements of the LANL contribution after background subtraction at a fixed location are limited to an accuracy of about 10 mrem/year. The accuracy of the public dose assessment is usually better than 10 mrem/year because of factors related to (a) distance, and (b) occupancy, as follows.

(a) Whenever possible, dosimeters are placed closer to the source than the publicly accessible locations, therefore an appropriate factor is applied to the measured doses [the inverse-square law predicts a factor of 1/9 in dose when the distance increases by a factor of 3; a more accurate factor may be calculated with the Monte Carlo N-Particle code MCNP (http://mcnp.lanl.gov) or a similar program].

(b) In some cases, an occupancy factor is applied. Where other occupancy data are not available, the dose assessment team uses the occupancy factors on page 65 of NCRP Report No. 49. Specifically, we use an occupancy factor of 1 for residences and offices and a factor of 1/16 for publicly accessible roads or trails. Other occupancy factors may be used if justified in writing.

Where the distance factor is 1/9 or the occupancy factor is 1/16, the dosimeter accuracy of 10 mrem/year corresponds to a public-dose accuracy of about 1 mrem/year.

5.7.3 DPRNET Neutron Accuracy

The DPRNET neutron measurements are more accurate than the gamma measurements because the raw TLD data are multiplied by a neutron correction factor of 0.145 (refer to the memo ESH-17:00-322, *Environmental Neutron Monitoring*, June 13, 2000). Cosmic-ray-neutron background is about 10 mrem/year and limits the neutron accuracy to about 1 mrem/year. When a distance factor or an occupancy factor is applied, the accuracy is better than 1 mrem/year.

6.0 SPECIAL TRAINING AND CERTIFICATION

6.1 Personnel Education

Individuals performing work for the DPRNET task must understand the basics of radiation measurement and understand the general operation of the TLD system. Data interpretation personnel must have education and/or experience as health physicists or an equivalent academic discipline. Documentation of education qualification is maintained by the LANL human resources division in accordance with P701-6, *Personnel Records* (latest revision).

6.2 Training of Personnel

All personnel performing work are required to obtain appropriate training prior to performing work governed by a procedure. Training for ENV-ES personnel will be performed and documented according to the ENV-DO procedures for training (ENV-DO-QP-115, *Personnel Training* – latest revision) and new employee orientation (ENV-DO-QP-118, *New or Returning Employee Orientation* – latest revision). Training of personnel in other groups will be performed and documented according to each group's training procedure.

7.0 DOCUMENTATION AND RECORDS

7.1 Records Resulting from the Project

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.

7.2 Reporting of Final Results

Results are calculated annually and published in the annual Environmental Report as specified in DOE Manual 231.1B.

7.3 Records Final Disposition and Retention Period

All records will be maintained and be available for auditing in accordance with ENV-DO-QP-110, *Records Management*. Records will be archived in compliance with Laboratory and DOE requirements for records retention, storage, and management. These requirements specify the protection of records from damage due to fire, flood, or rodents; monitored access to the records; and maintenance of the records for at least 5 years (as specified in 40 CFR Part 61.95).

8.0 DATA GENERATION AND ACQUISITION

8.1 Data

For details see the procedure "Obtaining the environmental dose from the model 8823 dosimeter" RRES-MAQ-250.

Dosimeters are provided by LANL group RP-2, who provide quality assurance with the DOE Laboratory Accreditation Program, DOELAP. DPRNET data are kept on spreadsheets and are archived in the DPRNET folder of the AIRNET drive.

9.0 ASSESSMENTS AND RESPONSE ACTIONS

9.1 LANL Required Audits

LANL audit groups external to ENV-ES may be delegated responsibility for assessments under SD330, *Los Alamos National Laboratory Quality Assurance Program*, and P330-3, *Quality Audits*. These may apply to any program or project within ENV-ES.

9.2 ENV-ES Requested Audits

The ENV-ES group leader may request assessments of any program or project within ENV-ES. These assessments may also include assessment of organizations which supply information to ENV-ES or from which ENV-ES obtains services (e.g., analytical laboratories).

9.3 Performance Feedback and Actions within ENV-ES

ENV-ES will document, report, and track performance feedback and actions within the group. These activities will be handled in accordance with ENV-DO-QP-113, *Tracking Performance Feedback and Actions*.

9.4 Performance Feedback and Actions within other Participant Organizations

Performance feedback and actions will be initiated, tracked, corrected, and documented according to the organization's requirements and procedures for corrective action.

9.5 Trending of Deficiencies

Trending is intended to determine the existence of systematic design or implementation problems. The trending analysis results are documented in a memo or report, forwarded to the responsible managers (see section 10, "Reports to Management"), and copied to the records system for filing as a record.

9.6 Emergency Response Actions

ENV-ES may be asked by the Laboratory's Emergency Response Organization (ERO) to respond to a suspected release of radioactive materials. In such cases, dose may be calculated if necessary.

10.0 REPORTS TO MANAGEMENT

10.1 Annual Report

The Environmental Radiation Protection team leader will direct the preparation of the appropriate sections of the environmental report on an annual basis. This report may be supplemented, as needed, to address problems or situations of a more immediate nature.

10.2 Distribution of Reports

Distribution of reports will include, at a minimum:

- ENV-ES Group Leader

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

11.0 DATA REVIEW, VALIDATION, AND VERIFICATION

11.1 Criteria Used to Accept, Reject, or Qualify Data

All data will be 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

11.2 Use of Negative Values

Environmental data with negative or "less than" values will be used in calculations in order to obtain the best estimate of the true value (DOE/EH-0173T). The true value, which is always unknown for a continuous variable, cannot be negative but is estimated by the average of many measurements, some of which may be negative (especially when the true value is very close to zero). Thus, arbitrarily discarding negative values will improperly bias the estimate of the true value. For a full explanation of this statistical principle, see memo ESH-17:95-384.

11.3 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.

11.4 Rejected Data

Rejected data will not be used.

12.0 RECONCILIATION WITH DATA QUALITY OBJECTIVES

12.1 Failure to Meet Specified DQOs

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

13.0 INDEPENDENT PEER REVIEW AND RESEARCH AND DEVELOPMENT (R&D) EXPECTATIONS

13.1 DOE Order 458.1 Required Data Peer Review

All data used to demonstrate compliance with DOE Order 458.1, as implemented through P412, must be independently peer reviewed. Items to be reviewed should include the data used, data reduction techniques, assumptions, site-specific or generic exposure parameters used, actual calculations performed, and the interpretation of results. The peer reviews described in SOP-5203 and ENV-ES-QP-501 are sufficient to meet the intent of this section.

13.2 Non-Regulatory Required Data Peer Review

These types of data would include those performed for internal customers and for internal and external publication, but not related to compliance with DOE environmental radiation regulations and requirements. To the extent possible, using a graded approach, an independent peer review equivalent to that described in Section 13.1 should be performed.

13.3 R&D Expectations

When data are included in any work product that would be considered R&D, the expectations of SD601, *Conduct of Research and Development*, should be reviewed and followed, using a graded approach. This is particularly important for data that will be included in scientific journals.

APPENDIX A

REFERENCES

External Requirements and guidance documents:

Title 40 Code of Federal Regulations Part 61, Subpart H, *National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities*, December 15, 1989.

Title 40 Code of Federal Regulations Part 58, *Ambient Air Quality Surveillance,* Appendix E.

Title 40 Code of Federal Regulations Part 141, *National Primary Drinking Water Regulations"*

Title 40 Code of Federal Regulations Part 142, "*National Primary Drinking Water Regulations Implementation*

DOE Order 151.1C, *Comprehensive Emergency Management System*

DOE Manual 231.1B, *Environment, Safety, and Health Reporting Manual*

DOE Order 414.1D, *Quality Assurance*

DOE Order 458.1, *Radiation Protection of the Public and the Environment*

DOE Order 5400.5, *Radiation Protection of the Public and the Environment*

DOE/EH-0173T, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance,* January 1991

EPA 400R92001, *Manual of Protective Action Guides and Protective Actions for Nuclear Incidents,* (1992)

EPA 402R93081, Federal Guidance Report No. 12, *External Exposure to Radionuclides in Air, Water, and Soil,*

EPA 402-R-99-001, Federal Guidance Report No.13, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides,* (1999)

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.

NCRP Report No. 49, *Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies up to 10 MeV*

NCRP Report No. 93, *Ionizing Radiation Exposure of the Population of the United States* (1987).

NCRP Report No. 129, *Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site-specific Studies,* (1999).

ANSI/HPS N13.12-1999, *American National Standard – Surface and Volume Radioactivity Standards for Clearance,* American National Standards Institute, Inc., August 31, 1999.

LANL requirements documents:

SD 330, *Los Alamos National Laboratory Quality Assurance Program*

P 330-3, *Quality Audits*

P 412, *Environmental Radiation Protection*

PD 410, *Los Alamos National Laboratory Environmental ALARA Program*

SD601, *Conduct of Research and Development*

P 701-6, *Personnel Records*

ENV Division and ENV-ES Group documents:

ENV-DO-QP-110, *Records Management*

ENV-DO-QP-113, *Tracking Performance Feedback and Actions*

ENV-DO-QP-115, *Personnel Training*

ENV-DO-QP-118, *New or Returning Employee Orientation*

ENV-ES-RN-QAPP, *Quality Assurance Project Plan for the Rad-NESHAP Compliance Project*

SOP-5140, *Quality Assurance Project Plan for Radiological Air Sampling Network*

ENV-ES-QP-ERPP, *Environmental Radiation Protection Plan under DOE Order 458.1*

SOP-5242, *Air Emissions from Environmental Fires*

LA-UR-00-1168, *Siting of Environmental Direct-Penetrating Radiation Dosimeters*

LA-13979-ENV, *Environmental Surveillance at Los Alamos during 2001*

ESH-17:95-384, *"Statistical Analysis of Environmental Data With Negative Values,"* Craig Eberhart to Distribution, May 19, 1995.

ESH-17:00-322, *Environmental Neutron Monitoring,* June 13, 2000.

Memorandum

ESH-17:00-322
June 13, 2000
To: Robert Devine, ESH-4, G761
From: Mike McNaughton
Thru: Doug Stavert, ESH-17 Group Leader
Thru: Joe Graf, Radiological Protection Program Manager

Environmental Neutron Monitoring

Summary

ESH-17 will standardize on the following method for monitoring environmental neutrons at Los Alamos National Lab. (LANL) and calculating the public dose.

- Use the LANL-standard 8823 albedo dosimeter, mounted on a 4-inch-thick slab of lucite, calibrated with the DOELAP-standard D2O-moderated Cf-252 source.
- Use the occupancy factors recommended in Table 4 (page 65) of NCRP Report No. 49: 1/16 for Pajarito Road and the TA-18 parking lot; 1 for all residences and work areas.

Discussion

At present, environmental neutrons are monitored at TA-3, -18, and -53 by ESH-1, -4, and -17. These measurements use LANL 8823 albedo dosimeters mounted on hydrogenous material. The dose equivalent is derived using a neutron correction factor, NCF, which corrects for the biological response of the human body relative to the physical response of the dosimeter.

The 8823 dosimeter is calibrated using DOELAP standard neutron sources consisting of a Cf-252 source, either bare or inside CH_2 or D_2O moderators up to a radius of 6 inches. The resulting NCF ranges from 1.08 for the bare source to 0.145 for the source inside a 5-inch-radius D_2O moderator. The hydrogen-moderated spectra have been used for personnel dosimetry and for environmental neutrons at TA-53, whereas a special NCF value of 0.07 has been used for environmental neutrons at TA-18. For environmental monitoring, we propose to standardize on the D_2O-moderated spectrum, for which the NCF = 0.145.

This estimate of the NCF is conservative, based on a combination of calculations and measurements, as follows.

Calculations

In an attempt to understand the NCF, I calculated the environmental neutron spectrum for a variety of conditions using the computer program MCNP. These calculations show that environmental neutrons differ significantly from the hydrogen-moderated neutrons used to calibrate personnel dosimeters.

Hydrogen-moderated spectra consist of three regions:

a) a fast-neutron peak, near 2 MeV;

b) a continuum of intermediate-energy neutrons; and

c) a thermal-neutron peak near 0.025 eV.

The fast neutrons are unscattered. Once a neutron scatters from hydrogen it changes direction and loses energy thus increasing its chances of scattering again. The intermediate-energy neutrons have scattered typically between 1 and 20 times and are in the process of being thermalized. The thermal neutrons have typically scattered more than 20 times.

In contrast to hydrogen-moderated neutrons, environmental neutrons are moderated by higher-Z materials such as nitrogen (in air) and silicon (in the earth). The mean-free path in air is 100 m, so there are very few unscattered (fast) neutrons in the publicly-accessible environment near LANL facilities.

The energy lost during each scatter from high-Z materials is small so the progress from high energy to thermal requires hundreds of scatters. Therefore, a typical environmental spectrum consists of a peak of intermediate-energy neutrons that decreases in energy as the distance from the source increases. In this respect, it is comparable to a D_2O-moderated spectrum. The similarity would be closer if the D_2O were replaced by a material with higher Z, and if the D_2O were thicker than 6 inches so as to provide a larger number of mean-free paths.

However, the DOELAP-standard D_2O-moderated spectrum is a better approximation to environmental neutrons than the CH2-moderated spectra.

Bonner-sphere measurements

William Casson reported measurements using Bonner spheres of the environmental neutron spectra from Godiva and SHEBA; see the memos: ESH-4-MTS-98:021 (March 17, 1998); and NIS6:99-172 (June 24, 1999). The results are consistent with the calculations discussed in the last section. These memos recommended the value of 0.07 for the NCF that has been used since 1997.

Other measurements, however, suggest a larger value of the NCF, as follows.

Measurements of the neutron dose equivalent from SHEBA

Tom Buhl reported measurements of neutrons from SHEBA in the memo HSE8-85-1424-1 (March 15, 1985). The largest reported dose rates at Pajarito Road were obtained near the water tanks at the entrance to TA-54: 37 mrem/h was measured with a RASCAL-BF3 detector, and 26 mrem/h was measured with a TLD-600; both of these were inside 9-inch-diameter-CH2 spheres. These dose rates were obtained while SHEBA was operating at 1 kW; according to NIS6-SHEBA-OA-6, 1 kW corresponds to 1.3E-5 A on the RAP2 ion-chamber detector. From these numbers, the number of Amp-seconds on the RAP2 can be converted to the dose equivalent at Pajarito Road:

- Using a RASCAL, the conversion factor = 1.3E-3 A.s/mrem
- Using a TLD-600, the conversion factor = 1.8E-3 A.s/mrem

A similar number is derived from the memo ESH-4-MTS-97:053 from William Casson (June 20, 1997): 3.5 mrem/h was measured with a PNR-4 while SHEBA was operating at 1.5E-6 A, which yields the result:

- Using a PNR-4, the conversion factor = 1.5E-3 A.s/mrem.

Tom Buhl et al. measured the dose equivalent from SHEBA using two WENDI detectors on December 13, 1999, near the water tanks at the entrance from Pajarito Road to TA-54. The detectors registered 1.8 mrem while the RAP registered 1.73E-3 A.s, so

- Using WENDIs, the conversion factor = 1.0E-3 A.s/mrem.

With these data, we can use the environmental albedo-dosimeter data to estimate the NCF. In the table below, the "Dosimeter" column is the 137Cs-equivalent value of element 8 minus element 7 of the 8823 dosimeter at the entrance to TA-54, corrected for background. The "Dose equivalent" is calculated from the "SHEBA emission" (A.s) using the average conversion factor: 1.4E-3 A.s/mrem. The NCF is the dose equivalent divided by the 137Cs-equivalent value.

year and quarter	SHEBA emission (A.s)	Dose equivalent (mrem)	Dosimeter E8-E7 (137Cs-equiv.)	NCF
99Q1	1.3E-3	0.9	4.3	0.21
99Q2	.86E-3	0.6	4.3	0.14
99Q3	2.2E-3	1.6	13	0.12
99Q4	1.7E-3	1.2	6.9	0.17
total	6.1E-3	4.4	28.5	0.15

MCNP calculations indicate that the neutron detectors mentioned above all overestimate the dose equivalent from intermediate energy neutrons, so the above estimates of the NCF are conservative. The average, NCF=0.15, is consistent with the value obtained from the D_2O moderated source, NCF=0.145.

Other useful information derived from the SHEBA measurements are:

- the gamma dose is 5% of the neutron dose equivalent; and
- the dose at the entrance to TA-18 is half that at the entrance to TA-54.

Measurements from Godiva

Tom Buhl reported measurements from Godiva in the memo HSE8-88-170 (March 15, 1988) and concluded that DeltaT = 120 degrees C results in 1 mrem at location #3, which is the closest location to Godiva, in the parking lot 115 m from Godiva.

William Casson reported Bonner-sphere measurements from Godiva in the memo ESH-4-MTS-97:053 (June 20, 1997) and concluded that DeltaT = 110 degrees C corresponded to 1 mrem at location #6, half way up the hill along Pajarito Road. From this result we estimate the conversion factors at location #3

both by using the inverse-square law and using the data obtained during the Godiva burst of October 29, 1997. Either method yields a conversion factor for Godiva at location #3: 45 C/mrem.

In the following table, the conversion factor 45 C/mrem is used to obtain an estimate of the NCF from Godiva. The dose equivalent is obtained by dividing DeltaT by the conversion factor: 45 C/mrem. The 137Cs-equivalent dosimeter value is element 8 minus element 7 of the 8823 dosimeter closest to Godiva, corrected for background. The NCF is the ratio of the dose equivalent to the 137Cs-equivalent value.

Year and quarter	Godiva DeltaT	Dose equiv. (mrem)	Dosimeter 137Cs-eq.	NCF
99Q1	525 C	11.7	83	0.14
99Q2	65 C	1.4	10	0.14
99Q3	491 C	10.9	94	0.12
99Q4	105 C	2.3	19	0.12
total	1186 C	26.4	206	0.13

These estimates are conservative. The average NCF = 0.13, is consistent with the value obtained from the D_2O-moderated neutron source: NCF = 0.145.

Implications for SHEBA

According to the TA-18 ALARA-implementation plan, NIS6:98-257, and the SHEBA operator aid, NIS6-SHEBA-OA-6 dated 5/3/2000, the following conversion factor are used for planning SHEBA operations:

- 3E-2 A.s/mrem at the railroad gate when SHEBA is in the pit;
- 4E-4 A.s/mrem at the railroad gate when SHEBA is out of the pit;
- 8.6E-4 A.s/mrem at Pajarito Road.

These conversion factors are more conservative than the conversion factors listed above, and therefore allow a margin of safety.

Implications for Godiva

The policy described in the NIS6 ALARA plans, NIS6-AP-1, R03 (July 17, 1998) and NIS6:98-257 (July 16, 1998) requires approval of the NIS6 group leader for Godiva bursts if DeltaT > 140 degrees C, and closing Pajarito Road if DeltaT > 350 degrees C. This policy is consistent with the data discussed here.

However, a Godiva burst with DeltaT = 200 degrees C will register 5 mrem in the dosimeter at location #3 (closest to Godiva, in the parking lot). Therefore, a conservative policy would be to close the parking lot during a burst with DeltaT >200 degrees C.

Public Occupancy Factor

We propose to use an occupancy factor of 1/16 when calculating the public dose on Pajarito Road and the parking lot at the entrance to TA-18. This factor corresponds to the value in Table 4 (page 65) of NCRP Report No. 49, and is appropriate for "outside areas used only for pedestrians or vehicular traffic." An occupancy factor of 1 will continue to be used for work areas such as East Gate north of TA-53.

When planning an operation, we recommend planning to keep the dose on all dosimeters below 100 mrem/yr without applying an occupancy factor.

Most Exposed Individual

The following method will be used to calculate the dose to the most-exposed individual (MEI) member of the public for the Environmental Surveillance Report:

a. select the largest dose recorded by the dosimeters in publicly-accessible areas and multiply by the appropriate occupancy factor;
b. select the largest dose resulting from a single operation of one hour or less;
c. the dose to the MEI is the larger of a or b.

Conclusions

1. Estimates of the NCF for the 8823 albedo dosimeters range from about 0.05 to 0.15. ESH-17 will use the most conservative value, NCF = 0.145, which results from calibrating the dosimeters with the D_2O-moderated neutron spectrum.

2. In reporting the dose at Pajarito Road, Potrillo Road, or the parking lot at the entrance to TA-18, ESH-17 will use an occupancy factor of 1/16. However, when planning TA-18 operations, we recommend keeping the accumulated dosimeter readings below 100 mrem/yr without applying an occupancy factor.

3. Consideration should be given to closing the parking lot at the entrance to TA-18 when the Godiva DeltaT is expected to exceed 200 degrees C.

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