LLNL-TM-678848

Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory Internal Dosimetry Program Manual

Revision 4

October 1, 2015

Prepared by LLNL under Contract DE-AC52-07NA27344.

Lawrence Livermore National Laboratory Internal Dosimetry Program Manual

Revision 4

W. G. Mansfield, A. R. Wood-Zika, M. L. Lobaugh, L. I. Tai

Approvals

Phil Worley
Radiological Control Manager

Lydia Tai
Principal Editor for Revision 4

Disclaimer

Table of Contents

Acronyms

ACRECC	Alameda County Regional Emergency Communication Center
ALARA	as low as reasonably achievable
ALI	annual limit on intake
AMAD	activity median aerodynamic diameter
ANSI	American National Standards Institute
ASI	Analytical Services and Instrumentation
BITS	Bioassay Investigation Tracking System (LLNL database)
BLAB	Bioassay Laboratory
BLIMS	Bioassay Laboratory Information Management System (LLNL database)
BS	bone surfaces
CAM	continuous air monitor
CEC	Commission of the European Communities
CED	committed effective dose
CFR	Code of Federal Regulations
CWT	chest wall thickness
DAC	derived air concentration
DAC-h	derived air concentration-hour
DCF	dose conversion factor
DIL	derived investigation level
DOE	Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
DPW	declared pregnant worker
DTPA	diethylenetriaminepentaacetate
ES&H	Environment, Safety, and Health
ET	extrathoracic airways
exIT	Institutional Terminations, Transfers, Leaves Program
FDA	Food and Drug Administration
FOIA	Freedom of Information Act
GA	gross alpha
H&S	Health and Safety
HEU	highly enriched uranium
HIPAA	Health Insurance Portability and Accountability Act
HP	health physicist
HP-DAP	Health Physics Discipline Action Plan
HP-FO	Health Physics Field Operations
HPS	Health Physics Society
HT	tritium gas
HTO	tritiated water

ICP-MS	inductively coupled plasma mass spectrometry
ICRP	International Commission on Radiological Protection
ICS	Information and Communication Services
ID	internal dosimetry
ID TBM	*LLNL Technical Basis Manual for Internal Dosimetry*
IEF	intake excretion fraction
IL	investigation level
IM	Information Management
IMBA	Integrated Modules for Bioassay Analysis (software)
IRF	intake retention fraction
ISQAP	Institutional Software Quality Assurance Program
IWS	Integration Work Sheet
LANL	Los Alamos National Laboratory
L_C	decision level
LEU	low-enriched uranium
LLNL	Lawrence Livermore National Laboratory
LLNS	Lawrence Livermore National Security, LLC
LSC	liquid scintillation counting
MDA	minimum detectable activity
MDC	minimum detectable concentration
MDD	minimum detectable dose
MI	Marshall Islands
MOU	memorandum of understanding
NALI	non-stochastic annual limit on intake
NCRP	National Council on Radiation Protection and Measurements
NDA	new drug application
NL	notification level
NUREG	Regulatory Guides (U.S. Nuclear Regulatory Commission)
ORPS	Occurrence Reporting and Processing System
OUO	Official Use Only
PAAA	Price-Anderson Amendment Act
PII	personally identifiable information
PLS	Physical and Life Sciences
PPE	personal protective equipment
QA	quality assurance
QC	quality control
RCA	radiologically controlled area
RCT	Radiological Control Technician

RCTP	Radiological Control Technical Position
REAC/TS	Radiation Emergency Assistance Center/Training Site
REMS	Radiation Exposure Monitoring System (LLNL database)
RHWM	Radioactive and Hazardous Waste Management
RML	Radiological Measurements Laboratory
RPFA	Radiation Protection Functional Area
RPP	Radiation Protection Program
RWP	Radiation Work Permit
SALI	stochastic annual limit on intake
SLAB	Spectroscopy Laboratory
SP	Safety Plan
STAR	Sample Tracking and Reporting (LLNL database)
STC	special tritium compound
Sv	Sievert
TED	total effective dose
TOED	total organ equivalent dose
TOD	total organ dose
TRU	transuranic
WBC	Whole Body Counter

1. INTRODUCTION

1.1 PURPOSE

The purpose of this Internal Dosimetry Program Manual (herein referred to as the "Manual") is to set forth the procedures and guidelines used by the Lawrence Livermore National Laboratory (LLNL) to monitor for and assess doses from intakes of radioactive materials. The primary function of this Manual, in conjunction with the *LLNL Technical Basis Manual for Internal Dosimetry* (ID TBM, LLNL 2009 or most current version), is to serve as a reference for the Environment, Safety, and Health (ES&H) Team Health Physicists (HPs) in designing and implementing the internal dose monitoring program for their facilities.

LLNL program and facility management may also wish to use the information set forth in this Manual to review internal dose monitoring programs in areas for which they are responsible.

The objectives of the LLNL internal dose monitoring program are to:

- Meet regulatory requirements for monitoring for and managing internal doses,
- Assist ES&H and program or facility management in assuring that internal doses are kept As Low As Reasonably Achievable (ALARA), and
- Confirm the adequacy of engineered and administrative workplace controls.

These objectives are met by establishing and implementing LLNL policies regarding intakes of radioactive materials, establishing and maintaining individual and workplace monitoring programs to monitor for potential intakes, documenting the results of monitoring, assessing internal doses from significant intakes, and appropriately responding to suspected intakes.

The technical bases for information found in this Manual are presented in the ID TBM, with details of the biokinetic models and calculational methods used for specific radioactive materials commonly encountered at LLNL.

1.2 REQUIREMENTS

Title 10, Part 835 of the Code of Federal Regulations (10 CFR 835, also referred to as "the Rule") and LLNL's implementation of the Rule in Volume II of the ES&H Manual require workplaces to be designed and controlled to limit anticipated internal doses, and that the sum of actual internal doses and external doses received in any year be less than applicable limits. Internal dose monitoring is required by 10 CFR 835 if it is likely that the worker will receive intakes that could result in a committed effective dose[1] (CED) of 0.1 rem or more in one calendar year. In addition to the monitoring program required by 10 CFR 835, this Manual describes confirmatory and discretionary internal dose monitoring conducted at LLNL as a best management practice.

This Manual contains general guidelines and requirements for the LLNL internal dose monitoring program. Further technical and supporting information is found in the following documents:

- *Ionizing Radiation, Non-Ionizing Radiation* (ES&H Manual Volume II, Part 20)
- *LLNL Technical Basis Manual for Internal Dosimetry*
- Bioassay Laboratory Procedures (LLNL 2014a)
- Spectroscopy Laboratory Manual (LLNL 2013)
- Whole Body Counter Manual (LLNL 2011)

[1] Dose terms are defined in Appendix A of this Manual.

1.3 APPLICABILITY

In general, this Manual applies to all LLNL facilities and programs conducted or managed under the auspices of LLNL in which unencapsulated radioactive materials are used. Requirements for off-site activities involving LLNL personnel will be determined on a case-by-case basis by the ES&H Team HP with concurrence from Internal Dosimetry. Not all facilities will require internal dose (worker or workplace) monitoring programs, but such facilities and activities should be evaluated for the need for internal dose monitoring programs.

2. REGULATORY REQUIREMENTS AND GUIDANCE

2.1 REGULATORY REQUIREMENTS AND GUIDANCE

The primary regulatory requirements for radiation protection are set forth in 10 CFR 835. In accordance with 10 CFR 835.101, LLNL has established a single Radiation Protection Program (RPP) for the main site and Site 300 (Shingleton 2014, or most current version). The RPP addresses each requirement of the Rule and describes, where necessary for clarity, LLNL's implementation methodology. The RPP specifically states that LLNL documents used to implement the RPP remain under the revision authority of LLNL (i.e., implementing documents, including this Manual, are not part of the RPP).

The requirements of the Rule have been integrated into the ES&H Manual. In addition, applicable elements of DOE-STD-1098-2008, Change Notice 1, *Radiological Control* (the Radiological Control Standard, DOE 2009) are also incorporated into the ES&H Manual. As described in ES&H Manual Document 20.1, *Occupational Radiation Protection*, appropriate articles of the Radiological Control Standard have also been integrated into the ES&H Manual.

With respect to internal dose monitoring programs, 10 CFR 835 specifies requirements for:

- Limits for occupational exposure to radiation,
- Individual monitoring,
- Area monitoring,
- Design of facilities,
- Control of operations,
- Records management, and
- Internal audits.

Additional Department of Energy (DOE) guidance for implementation of internal dose monitoring requirements is found in:

- DOE G 441.1-1C, *Radiation Protection Programs Guide for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection* (the RPP Guide, DOE 2011), and
- DOE-STD-1121-2008, *Internal Dosimetry* (the Internal Dosimetry Standard, DOE 2008).

2.1.1 Regulatory Requirements for Individual Monitoring

10 CFR 835.402(c) states:

> For the purpose of monitoring individual exposures to internal radiation, internal dosimetry programs (including routine bioassay programs) shall be conducted for:
> (1) **Radiological workers** who, under typical conditions, are likely to receive a committed effective dose of 0.1 rem (0.001 Sv) or more from all occupational radionuclide intakes in a year;
> (2) **Declared pregnant workers** likely to receive an intake or intakes resulting in an equivalent dose to the embryo/fetus in excess of 10 percent of the limit stated at § 835.206(a);
> (3) **Occupationally exposed minors** who are likely to receive a dose in excess of 50 percent of the applicable limit stated at § 835.207 from all radionuclide intakes in a year; or
> (4) **Members of the public** entering a controlled area likely to receive a dose in excess of 50 percent of the limit stated at § 835.208 from all radionuclide intakes in a year.

10 CFR 835.402(d) states:

> Internal dose monitoring programs implemented to demonstrate compliance with § 835.402(c) shall be adequate to demonstrate compliance with the dose limits established in Subpart C of this part and shall be:
> (1) Accredited, or excepted from accreditation, in accordance with the DOE Laboratory Accreditation Program for Radiobioassay; or,
> (2) Determined by the Secretarial Officer responsible for environment, safety and health matters to have performance substantially equivalent to that of programs accredited under the DOE Laboratory Accreditation Program for Radiobioassy.

The primary mandates of 10 CFR 835 with respect to internal dose monitoring may be summarized as:

- Facilities shall be designed and operated in such a manner as to maintain radiation exposures to levels that are ALARA,
- Occupational doses shall be controlled so that annual dose limits are not exceeded,
- Internal doses shall be appropriately combined with external doses for determination of compliance with dose limits,
- Monitoring programs shall be adequate to demonstrate compliance with dose limits,
- Workers shall be monitored if they are likely to receive greater than 0.1 rem in a year,
- Area monitoring shall be performed under specified conditions,
- Sufficient records shall be maintained to document compliance with requirements, and
- Dose reports shall be provided to individuals as specified.

2.1.2 Additional DOE Guidance

With regard to individual monitoring, for internal exposure, the RPP Guide states:

> Situations may arise where a decision is made to monitor radiological workers who are not likely to receive intakes that exceed 0.1 rem (0.001 Sv) committed effective dose in a year. Such monitoring may be useful for demonstrating compliance with 10 CFR 835.401(a) or established for other purposes. The internal dosimetry program documentation should clearly identify those individuals or groups of individuals being monitored for such purposes.

The Internal Dosimetry Standard states:

> Most radiation protection programs should be capable of preventing intakes through rigorous application of engineering and administrative controls. Under such controls, a good argument can be made that no one is likely to have an intake resulting in a E_{50} [CED] of 100 mrem. This may reduce the need for participation in a routine bioassay program (meaning scheduled periodic measurements) but does not eliminate the need for confirmatory or special bioassay monitoring. Likewise, the need for an internal dosimetry program is linked more to the potential for intake than the likelihood of intake. If sufficient quantities of radionuclides are present or handled at a facility that accidental intakes resulting in 100 mrems E_{50} cannot be ruled out, an internal dosimetry program must be available.

In addition, DOE Standard 1128, *Good Practices for Occupational Radiological Protection in Plutonium Facilities* (DOE 2013), provides the following guidance:

> . . . no typical plutonium worker is <u>likely</u> to have intakes of 100-mrem CED or more. However, this should not be used as an excuse to exclude workers from routine bioassay. Although no one should be considered likely to have intakes resulting in 100-mrem CED, some workers are at significantly higher risk for incurring an intake than others and should be on routine bioassay.

> The workers at highest risk of incurring an intake are the ones in closest contact with the material. Typically, these are the operators, maintenance, and health physics personnel handling plutonium or plutonium-contaminated objects in the course of routine glove-box, maintenance, or decommissioning operations. In the event of containment system failure, or failure [of] respiratory protection devices, it is these workers who will most likely incur exposure and subsequent intake. These workers should be on a routine bioassay program designed to meet the requirements of 10 CFR 835 . . . as a kind of safety net to identify intakes which might have gone undetected by workplace monitoring.

Consistent with the above collective requirements and guidance, LLNL internal dose monitoring programs for individuals are categorized as *required* (in order to meet 10 CFR 835), *confirmatory* (recommended by this Manual in accord with DOE guidance), or *discretionary* (a best management practice). Criteria for selecting the appropriate monitoring categories are presented in detail in Section 6.3 of this Manual.

2.2 RADIATION DOSE LIMITS

The radiation dose limits of 10 CFR 835 with respect to internal dose are summarized below:

Table 2.1 Summary of 10 CFR 835 radiation dose limits

Category	Limit (rem)	Type of Dose
General employee	5	Total effective dose[1]
	50	Sum of equivalent dose and committed equivalent dose to an organ or tissue
Embryo/fetus of a Declared Pregnant Worker	0.5	Equivalent dose from the period of conception to birth
Occupationally exposed minor	0.1	Total effective dose
Member of the public	0.1	Total effective dose

2.3 GENERAL REQUIREMENTS FOR MONITORING

10 CFR 835 requires that monitoring of individuals and work areas be performed to:

- Demonstrate compliance with 10 CFR 835,
- Document radiological conditions,
- Detect changes in radiological conditions,
- Detect the gradual buildup of radioactive material,
- Verify the effectiveness of engineered and administrative controls for containing radioactive materials and reducing radiation exposure, and
- Identify and control potential sources of individual exposure to radiation and/or radioactive materials.

Radiological monitoring for internal dosimetry will typically consist of individual monitoring (e.g., a bioassay program) and/or workplace monitoring (e.g., air sampling, surface contamination monitoring).

[1] Dose terms are defined in Appendix A of this Manual.

2.4 REQUIREMENTS FOR PARTICIPATION IN INTERNAL DOSE MONITORING PROGRAMS

LLNL has established three categories of monitoring in order to distinguish between monitoring that is required by regulation and monitoring which is confirmatory or discretionary. In general, individual monitoring may be:

- Required by 10 CFR 835,
- Confirmatory, as recommended by this Manual, or
- Discretionary.

The procedure for selecting the appropriate monitoring category for individuals is detailed in Section 6.3 of this Manual.

2.5 PROGRAM DOCUMENTATION

10 CFR 835.104 states:

> Written procedures shall be developed and implemented as necessary to ensure compliance with this part, commensurate with the radiological hazards created by the activity and consistent with the education, training, and skills of the individuals exposed to those hazards.

Additionally, with regard to program documentation, the RPP Guide specifies:

> An acceptable internal dosimetry program includes the following features:
>
> - internal dosimetry technical basis documentation providing scientific information and other rationale explaining essential elements of the internal dosimetry program to support dose evaluation methods;
> - written policies and procedures covering essential steps in the activities used to determine worker internal dose;

and that "Essential elements of the internal dosimetry program should be addressed in written procedures." This Manual and the ID TBM are intended to provide the documentation recommended by the RPP Guide.

The details of the routine internal dose monitoring program for each area or facility should be documented in appropriate work planning or authorization documents (for example, in the Health Physics Discipline Action Plan (HP-DAP) for the facility or the Integration Work Sheet (IWS) for the work activity).

2.6 GENERAL GUIDANCE DOCUMENTS

General guidance for conducting internal dose monitoring programs may be found in:

- ANSI/HPS N13.30-2011, *Performance Criteria for Radiobioassay*,
- ANSI/HPS N13.39-2001, *Design of Internal Dosimetry Programs*,
- ICRP Publication 78, *Individual Monitoring for Internal Exposure of Workers*, and
- NCRP Report No. 87, *Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition*.

The primary regulatory and guidance documents considered in development of this Manual are the Rule, the Radiological Control Standard, the RPP Guide, and the Internal Dosimetry Standard. Guidance from other documents may be applied as determined necessary by the Internal Dosimetry Team.

3. THE LAWRENCE LIVERMORE NATIONAL LABORATORY POLICY

This Chapter reflects LLNL ES&H policy as presented in the ES&H Manual. If inconsistencies exist between the policies stated in the current ES&H Manual and this document, the ES&H Manual prevails.

3.1 ALARA POLICY

It is the policy of LLNL to plan and conduct its radiological activities in a manner that protects the health and safety of all its employees, contractors, the general public, and the environment. In achieving this policy, LLNL shall ensure that efforts are taken to reduce radiological exposures and releases to as low as reasonably achievable (ALARA), taking into account social, technical, economic, practical, and public policy considerations. The Laboratory is committed to implementing a high-quality radiological control program that reflects this policy.

3.2 DESIGN OF FACILITIES

The design objectives for controlling airborne radioactive material must be, under normal conditions, to avoid releases to the workplace atmosphere and, in any situation, to control the inhalation of such material by workers to levels that are ALARA. Engineered controls (e.g., confinement, ventilation, remote handling, shielding) shall be the primary methods used. Administrative controls and protective clothing shall be employed only as supplemental means to limit intakes.

3.3 CONTROL OF OPERATIONS

During routine operations, a combination of engineered controls, workplace monitoring, administrative controls, and personal protective equipment (PPE) are implemented to ensure that anticipated occupational dose is kept ALARA below the maximum allowable dose limits. Engineered controls (e.g., confinement, ventilation, remote handling, shielding) shall be the primary method of reducing exposures in radiologically controlled areas (RCAs) to ALARA. For specific activities where use of engineered controls is demonstrated to be impractical, administrative controls shall be used to maintain radiation doses ALARA. Administrative controls shall be employed only as supplemental methods to control radiation exposure. PPE provides a third tier of radiological control.

3.4 MONITORING OF WORKERS AND THE WORKPLACE

As presented in ES&H Manual Document 20.2, *LLNL Radiological Safety Program for Radioactive Materials*, LLNL conducts worker and workplace monitoring as required by 10 CFR 835. In addition, confirmatory monitoring is recommended and discussed in detail in Chapter 6 of this Manual. Confirmatory monitoring provides verification that radiological controls (e.g., engineered, administrative, and personal protective equipment) are adequate and workplace practices are effective.

3.5 INTERNAL DOSE RECORDS

Records that are generated as a result of the Rule's requirements shall be retained until DOE authorizes their disposition. Appendix F of ES&H Manual Document 20.1 identifies the individuals and organizations responsible for maintaining and storing various records. It also provides guidance for the long-term retention of these records as required by DOE. Table F-1 in Appendix F lists the types of records that should be retained and the individual or organization responsible for storage.

3.6 EMPLOYEE INFORMATION

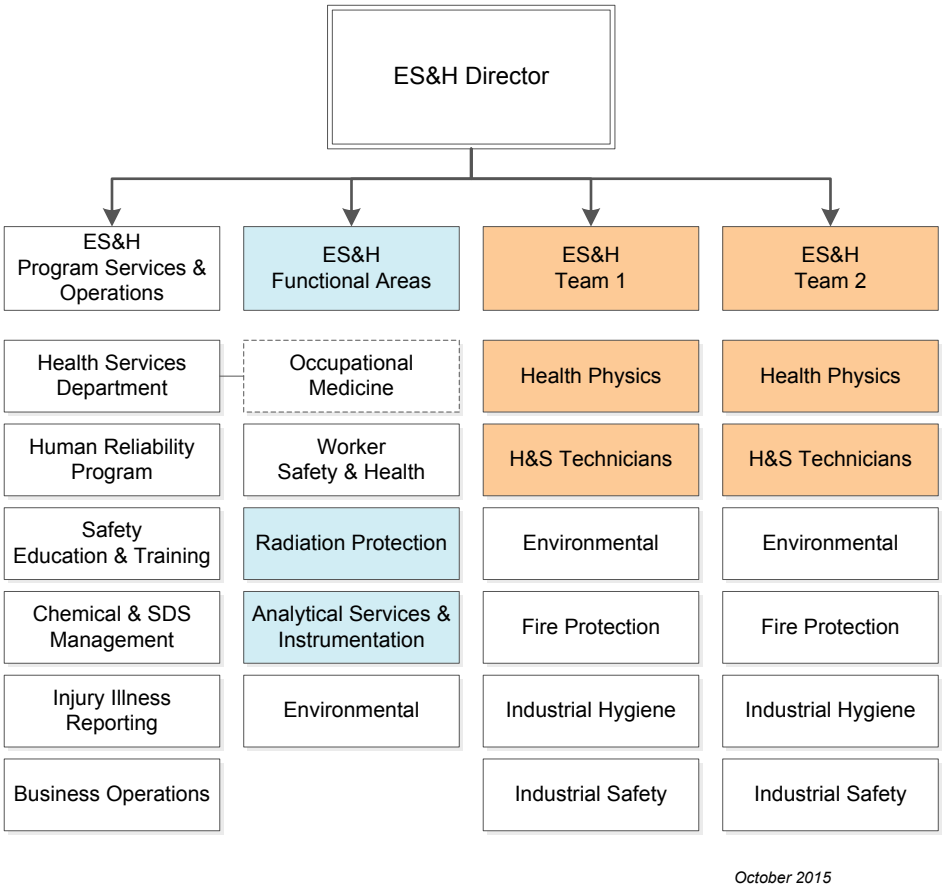
Dosimetry records, including detailed information, that are identified with a specific individual shall be readily available to that individual and to others (e.g., the individual's supervisor, management, and safety personnel) on a need-to-know basis, consistent with the Privacy Act. Individuals who are monitored in accordance with 10 CFR 835 shall be provided an annual dose report. Upon request, an individual shall be provided detailed information concerning his or her dose.

4. ORGANIZATION AND RESPONSIBILITIES

4.1 GENERAL ORGANIZATION AND STAFFING

The general structure of the LLNL Environment, Safety, and Health (ES&H) Organization is illustrated in Figure 4.1. The Internal Dosimetry Program is implemented and supported by several organizations, both internal and external to ES&H, as illustrated in Figure 4.2 on the following page. Key communication and functional support activities are noted by arrows between the organizations.

Figure 4.1 General structure of the LLNL ES&H organization



Each LLNL facility or programmatic area is supported by an ES&H Team. The ES&H Team HP, in conjunction with program or facility management, has the primary responsibility for the design and implementation of the internal dose monitoring program for his or her area.

The Radiation Protection Functional Area (RPFA) provides general health physics guidance and technical support, including dosimetry, to the ES&H Team HPs. The Analytical Services and Instrumentation Division (ASI) provides the bioassay, radiological measurements, in vivo measurements, and radiation instrumentation services that support workplace and worker monitoring programs. The RPFA Functional Area Manager and the ASI Division Manager both report to the ES&H Functional Area Manager, as illustrated in Figure 4.3.

The RPFA Internal Dosimetry Team provides the technical expertise and administrative support necessary to perform internal dosimetry-related functions for LLNL. The Internal Dosimetry Team has the responsibility for evaluating intakes and assessing doses from any confirmed occupational intakes.

The Internal Dosimetry (ID) Team Lead is responsible for establishing policies and guidelines for the LLNL internal dose monitoring program. These policies and guidelines are maintained in this Manual and in the ID TBM. Key members of the Internal Dosimetry staff and other ASI teams meet on a regular basis to address and resolve issues related to bioassay and internal dose monitoring programs. Members of the ASI teams are also available to provide technical assistance and review for dose evaluations as necessary.

Figure 4.2 Functional components of the LLNL Internal Dosimetry Program

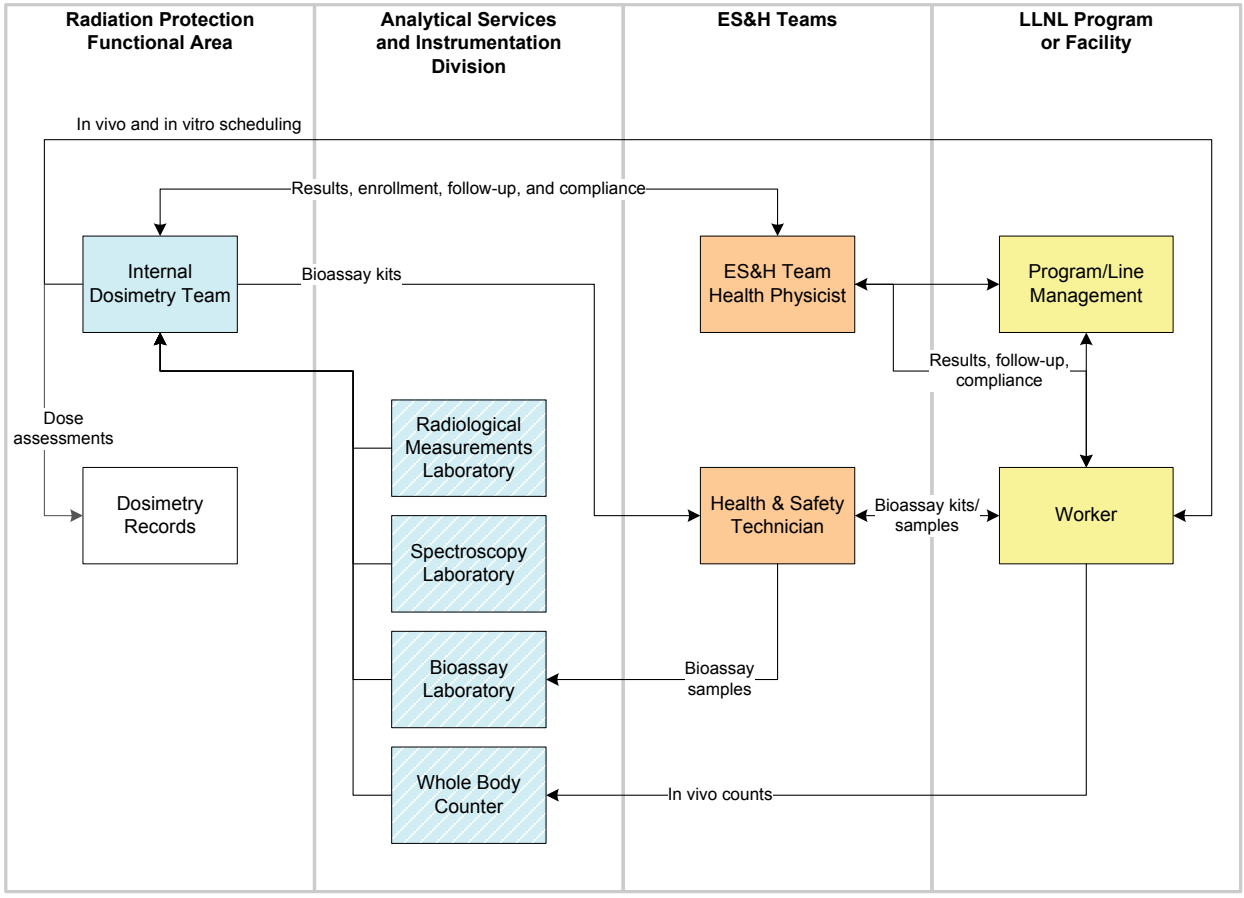
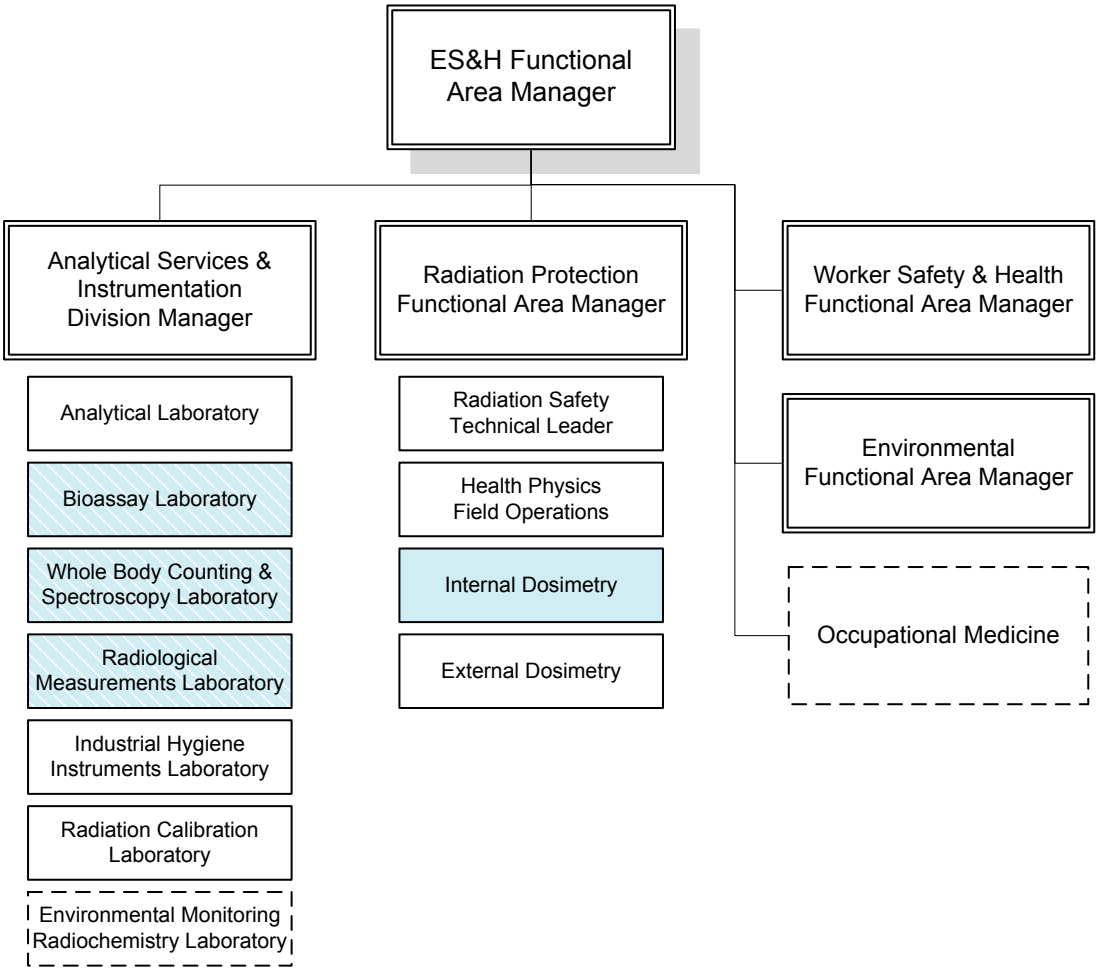


Figure 4.3 ES&H Functional Areas Supporting Internal Dosimetry



4.2 RESPONSIBILITIES

General responsibilities are detailed in Section 9 of ES&H Manual Document 20.1 and Section 8 of ES&H Manual Document 20.2. Responsibilities with respect to internal dose monitoring programs are listed below.

4.2.1 The ES&H Team HP is responsible for:

- Reviewing work authorization documents to verify that radiological hazards are appropriately characterized,
- Identifying the physical and administrative controls required for maintaining personnel doses, effluent discharges, and contamination levels ALARA,
- Working with the Internal Dosimetry Team to establish individual and area monitoring requirements and recommendations, including the type and frequency of bioassay and nature and location of workplace monitoring,
- Identifying individuals that are required to participate in a routine internal dose monitoring program in accordance with this Manual,
- Documenting the area monitoring program in the Health Physics Discipline Action Plan (HP-DAP) and appropriate safety documents,
- Updating the individual and area monitoring programs as necessary to reflect changes in materials, operations, or personnel,
- Promptly notifying the radiological worker of bioassay results that warrant follow-up evaluation,
- Assisting the Internal Dosimetry Team and program or facility management in the follow-up of elevated and anomalous results, and
- Responding to radiological spills, accidents, and emergencies.

4.2.2 The ES&H Team Health and Safety Technician is responsible for:

- Conducting and documenting the routine radiation and contamination surveys prescribed in the HP-DAP,
- Distributing, collecting, and returning bioassay kits,
- Responding to radiological spills, accidents, and emergencies, and
- Notifying the facility point of contact (or the facility manager), the ES&H Team Leader, and the ES&H Team HP of incidents or conditions that may warrant their attention.

4.2.3 The Analytical Services and Instrumentation (ASI) laboratories are responsible for:

- Providing appropriate in vivo and in vitro radiobioassay measurement laboratory support in accordance with this Manual, and
- Providing dosimetry records management, recording, and reporting services to ES&H and LLNL in accordance with this Manual and ES&H Manual requirements.

4.2.4 The Internal Dosimetry Team Lead is responsible for:

- Assuring the technical adequacy of the LLNL Internal Dosimetry Program,
- Developing and maintaining appropriate internal dose monitoring program documentation, including this Manual, the ID TBM, and supporting procedures, and
- Coordinating and prioritizing the functions of the Internal Dosimetry Team.

4.2.5 The Internal Dosimetry Team members are responsible for:

- Providing internal dosimetry expertise and support for both routine programs and incident response,

- Performing the routine administrative, data management, and dosimetry tasks necessary for the LLNL Internal Dosimetry Program,
- Notifying the ES&H Team HP of individual internal dose monitoring results that warrant follow-up evaluation,
- Performing evaluation of internal dose monitoring results that warrant follow-up, and
- Assessing internal doses for confirmed occupational intakes.

4.3 FACILITIES AND RESOURCES

The dedicated facilities for radiobioassay used by the Internal Dosimetry Program are provided by ASI, including:

- The Bioassay Laboratory (housed in Buildings 253 and 254),
- The Radiological Measurements Laboratory (Building 253),
- The Whole Body Counting Laboratory (Building 253), and
- The Spectroscopy Laboratory (Building 253).

5. TECHNICAL BASIS FOR A ROUTINE INTERNAL DOSE MONITORING PROGRAM

The criteria and values used in the design of internal dosimetry programs are based on specific assumptions about the nature of the radioactive materials present, the biokinetic models which describe the intake, retention, and excretion of those materials, and the analytical methods used to monitor for those materials. The dosimetry methods and biokinetic models used for specific radionuclides are described in the ID TBM. For convenience, this Chapter presents the general concepts and procedures to be used in designing a routine bioassay program. If inconsistencies exist between the values and guidelines of the ID TBM and this Manual, the ID TBM prevails.

Figure 5.1 illustrates the general sequence for establishing the technical basis for an internal dose monitoring program. This sequence typically involves:

- Selecting appropriate biokinetic and dosimetric models,
- Calculating Intake Retention and Excretion Fraction (IRF or IEF) values,
- Calculating Dose Conversion Factors (DCFs),
- Estimating intake and dose from single bioassay measurement results,
- Establishing Minimum Detectable Doses (MDDs) for bioassay measurements,
- Establishing Derived Investigation Levels (DILs) for bioassay measurements, and
- Based on the above, selecting appropriate measurement methods and frequencies.

Each of these technical basis concepts are discussed in Sections 5.1 through 5.8 below. The technical consideration of these steps as they are applied to the design of a specific routine monitoring program is discussed in Section 5.9. This general technical basis, with the detailed isotopic technical bases presented in the ID TBM, serves as the foundation for the recommended internal dose monitoring programs presented in Chapter 6 of this Manual.

5.1 SELECTION OF BIOKINETIC MODELS TO ESTABLISH A TECHNICAL BASIS

5.1.1 Current Biokinetic Models

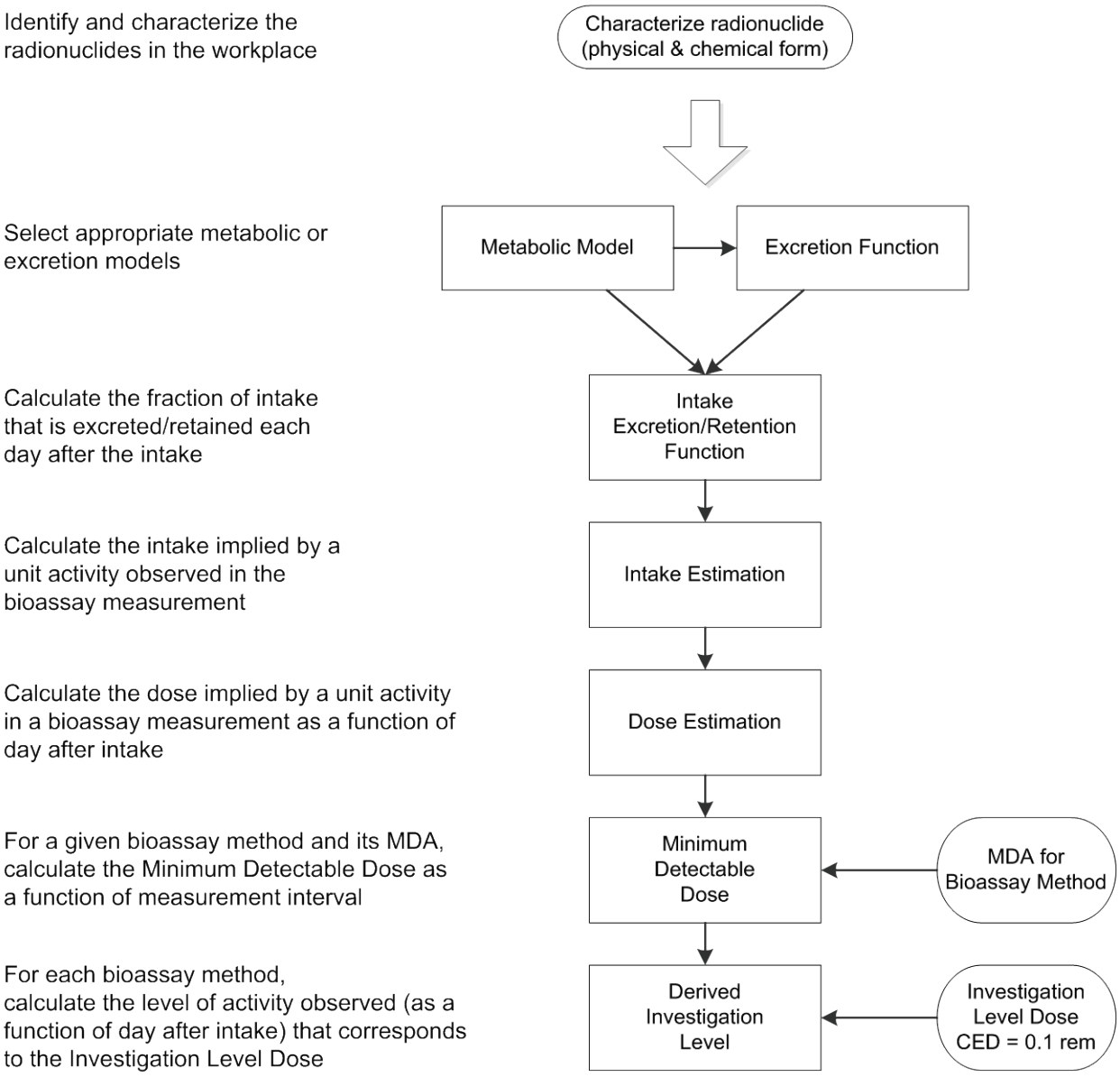
The models used to describe the deposition, retention, and excretion of radioactive materials taken into the body need to be appropriate for the particular material in use. The models presented in the ID TBM are appropriate for establishing a routine internal dose monitoring program and for making initial interpretations of bioassay results.

The biokinetic models in use are:

- The ICRP 66 Human Respiratory Tract Model,
- The ICRP 30 Gastrointestinal Tract Model (as confirmed by ICRP 78),
- The ICRP “60s and 70s” series of biokinetic models for various radionuclides (some of which are still essentially the “ICRP 30” models), and
- The NCRP Report No. 156 wound model.

When using biokinetic and dosimetry models for designing bioassay programs and for initial interpretation of routine monitoring results, it is considered sufficiently accurate to use metabolic and organ parameters of a reference male worker (e.g., values given in ICRP Publication 89, *Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values*). LLNL policy is to use DCFs based on the organ masses of a reference male for bioassay program design and initial interpretation. In accordance with 10 CFR 835, the tissue weighting factors and associated “remainder” calculation rules of ICRP Publication 68 are used to calculate committed effective dose conversion factors.

Figure 5.1 Establishing the technical basis for an internal dose monitoring program



In cases of significant intakes, Internal Dosimetry will evaluate the nature of the intake and the characteristics of the individual involved in the intake (e.g., gender, body mass) to determine whether or not the standard assumptions presented in this Manual are appropriate. In general, implementation of these models is done via the IMBA internal dosimetry code (James 2004a, James 2004b). Where necessary, this code is supplemented by LLNL-developed worksheets and spreadsheets, which are validated and verified against other sources.

5.2 INTERPRETATION OF BIOASSAY RESULTS FOR BIOASSAY PROGRAM DESIGN

5.2.1 Intake Retention and Excretion Fractions

Once the appropriate intake and systemic retention and excretion models are determined, they are used to derive intake retention functions and intake excretion functions. By specifying the assumed distribution, retention, and excretion pathways, such functions predict the fraction of the initial intake that is either retained in a particular organ (e.g., the lungs) or excreted via a particular pathway (e.g., urine) at a given time after the intake. As discussed below, such values are used in the design of monitoring programs and form the basis for interpretation of bioassay results.

The fraction of the intake present in the measured medium (e.g., lungs or a 24-hour urine sample) will depend on:

- The route of intake,
- The particle size distribution of the material (if inhaled),
- The chemical element or compound,
- The individual's metabolism, and
- The amount of time elapsed since intake.

This fraction varies drastically (by many orders of magnitude) depending on any or all of the above factors. IRF and IEF values are calculated using appropriate biokinetic models as detailed in the ID TBM.

For the purpose of bioassay program design, LLNL uses standard biokinetic models and standard metabolic parameters for a reference worker. Standard assumptions about particle size distribution and the biokinetic behavior of various chemical compounds are used, as discussed in the ID TBM.

5.2.2 Estimate of Intake

For a single bioassay measurement, the estimate of the initial intake that would have produced such a measurement result is represented in Equation 5.1 and is simply the measured activity divided by the appropriate IRF or IEF. Thus:

$$\mathrm{I}_i = \frac{\mathrm{A}_i}{[\mathrm{IRF}_i \text{ or } \mathrm{IEF}_i]} \qquad \text{Equation 5.1}$$

where:
- I_i = the intake implied by the ith bioassay measurement,
- A_i = the activity measured in the ith bioassay measurement,
- IRF_i = the intake retention fraction (the fraction of the initial intake expected to be retained in an organ on the day of the measurement), and
- IEF_i = the intake excretion fraction (the fraction of the initial intake expected to be excreted on the day of sample collection).

In cases where bioassay measurements of one (or more) radionuclides are used as indicators or "markers" to determine the presence of other radionuclides (e.g., lung counts for ^{241}Am as indicators of weapons-grade plutonium depositions), appropriate isotopic activity ratios must be applied to the estimate of intake. Methods for estimation of intake from multiple bioassay results are discussed in the ID TBM.

5.2.3 Estimation of Dose from Intake

A corresponding estimate of the dose implied by a particular bioassay measurement is represented in Equation 5.2 and is calculated by multiplying the estimated intake value by the appropriate dose conversion factor. Thus:

$$E_i = I_i \cdot DCF \qquad \text{Equation 5.2}$$

where: E_i = the committed effective dose (CED) implied by the i^{th} bioassay measurement,

I_i = the intake implied by the i^{th} bioassay measurement, and

DCF = the appropriate dose conversion factor (dose per unit intake—for example, rem CED per μCi inhaled)

The DCF in Equation 5.2 will depend primarily on:

- The type of radiations emitted (alpha, beta, photon),
- The energy of the emitted radiations,
- The physical half-life of the radionuclide,
- The route of intake, and
- The pattern of distribution and retention of the radionuclide within the body.

The methods and models used to calculate DCFs can be complex and are discussed in detail in the ID TBM. For convenience, DCFs and related derived values for selected radionuclides are presented in Appendix B of this Manual.

In cases where the intake involves mixtures of radionuclides, the total dose is the sum of the products of the intake of each radionuclide multiplied by its corresponding DCF.

5.3 USE OF STATISTICAL CONCEPTS (MDA AND L_C)

The understanding and use of statistical concepts play an important role in designing and managing bioassay programs. Unless otherwise noted, the statistical methods and concepts presented in HPS/ANSI Standard N13.30 are used in the Internal Dosimetry Program at LLNL.

Two fundamental concepts involved in bioassay measurements are:

(1) What level of sensitivity can a particular bioassay measurement be routinely expected to provide (on the average over the long term)? and,
(2) What measurement result (for a given measurement or sample) can be interpreted to mean radioactivity has been reliably detected in that sample?

These two questions are very different, and different (albeit related) statistical concepts are used to provide the answers. The concept of Minimum Detectable Activity (MDA) is used to *predict the performance* (expected level of sensitivity) of a measurement system. The concept of Decision Level (L_C) is used to determine whether or not the analyte has been detected in a *particular* measurement or sample.

In order to evaluate and specify appropriate bioassay monitoring and the associated measurement techniques, one must know the quantity (or concentration) of radioactivity that the measurement system can reliably detect in a specific sample matrix, time after time, sample after sample. The MDA or the Minimum Detectable Concentration (MDC) is the counting statistic used to *predict the performance* of a bioassay measurement system. Thus, the MDA or MDC values are used for

design of bioassay programs and Internal Dosimetry sets MDA or MDC requirements for laboratory performance.

The MDA or MDC is the smallest amount of an analyte in a sample that will be detected with a probability β of non-detection ("false negative") while accepting a probability α of erroneously concluding that a positive (non-zero) quantity of analyte is present in an appropriate blank sample ("false positive"). Typically, the values of α and β are set at 5%.

In contrast, the concept of Decision Level (L_C) is a statistical parameter to which *individual* bioassay measurements are compared. The Decision Level is defined as the activity (or measured value) at or above which a decision is made that the analyte is definitely present.

The analytical sensitivity (MDA or MDC) of a measurement technique is influenced by:

- Whether the radionuclide of interest is being directly measured (e.g., in vivo counts for ^{241}Am as a marker for weapons grade plutonium),
- The type of radiations (alpha, beta, or photon) being measured,
- The energy of the radiations,
- The yield (number of emissions per nuclear transformation) of the radiations in question,
- The processing steps (e.g., radiochemical separation, electroplating) required prior to measurement,
- The measurement geometry,
- The detection efficiency,
- Radiation attenuation in the medium,
- Competing or interfering (e.g., "background") radiations, and
- Duration of measurement (i.e., counting time).

Appendix B of this Manual lists MDA and MDC requirements for selected bioassay methods currently in use at LLNL.

5.3.1 Minimum Detectable Activity (MDA)

The MDA is the smallest amount of a radionuclide that can be reliably detected during normal bioassay analysis and measurement. The MDA is calculated by specifying the acceptable level of two types of errors:

Type I (α): a "false positive"—that is, incorrectly concluding that the analyte *is* present in the sample when in fact it is not. The probability of a Type I error is normally specified at 0.05. Thus, on a routine basis, a small percentage of measurement results will be falsely deemed "positive" for purely statistical reasons.

Type II (β): a "false negative"—that is, incorrectly concluding that the analyte *is not* present in the sample when in fact it is present. The probability of a Type II error is normally specified at 0.05. Therefore, an accepted, small percentage of measurement results will be falsely deemed background for purely statistical reasons, emphasizing the importance of understanding the measurement capabilities and corresponding minimum detectable dose.

5.3.2 Decision Level

The Decision Level (L_C), which may also be referred to as the *critical level* or the *detection level*, is defined as the amount of activity (or measurement value) at or above which the analyte is decided to be definitely present in a sample. The Decision Level is based solely upon the selected value of α (probability of a "false positive") and the background count rate. The Decision Level is a function of the analytical method employed, the associated background count rate, and the selected "false positive" error level. This Decision Level is a purely statistical entity and does not take into account possible environmental interferences (e.g., naturally occurring uranium in the

urine) or dosimetric considerations. The Decision Level should be based on an appropriate population of reagent blanks for a given analytical and processing method.

5.3.3 Calculation of MDA and L_C

MDA and L_C concepts and calculations are discussed further in the ID TBM. Calculations specific to LLNL bioassay results are documented in the procedures or technical basis documents of the specific analytical laboratories.

5.4 INVESTIGATION LEVELS

The Investigation Level is defined as an indicator of intake or projected dose justifying further investigation (e.g., follow-up bioassay). LLNL adopts the recommendations of the Radiological Control Standard and the Internal Dosimetry Standard, that the Investigation Level be defined as a committed effective dose (CED) of 0.1 rem (2% of the limit of 5 rem).

In contrast to the 10 CFR 835 definition of the annual limit on intake (ALI), which is based on the more limiting of either the committed equivalent dose or the committed effective dose (CED), the Investigation Level is based solely on the CED. It is recognized that in some cases (e.g., Type M plutonium, Type F uranium), the ALI derived from limiting committed equivalent doses to the critical organs will be lower than the ALI derived from the CED. However, the conservatism inherent in using an Investigation Level specified at 2% of the CED-derived ALI will assure that any significant committed equivalent doses are also investigated. For example, in the case of Type M plutonium, an Investigation Level intake based on a CED-derived ALI of about 0.042 μCi would result in a committed equivalent dose to the bone surfaces of about 3.1 rem, or about 6% of the annual occupational limit of 50 rem.

5.5 DERIVED INVESTIGATION LEVEL

The Derived Investigation Level (DIL) is an in vivo or in vitro measurement result for a particular radioactive material and route of intake that implies a CED equal to the Investigation Level dose of 0.1 rem. DILs are used in the design of routine bioassay programs and are also used to trigger follow-up investigations if such levels are exceeded in bioassay measurements or by workplace monitoring measurements. The DIL is inversely related to the concept of Minimum Detectable Dose (see Section 5.6).

5.5.1 Definition of Derived Investigation Level

The DIL for a particular radionuclide, route of intake, bioassay measurement, and measurement interval is calculated by Equation 5.3:

$$\mathrm{DIL}(t) = \frac{0.1}{\mathrm{DCF}} \cdot \mathrm{F}(t) \qquad \text{Equation 5.3}$$

where:
- $\mathrm{DIL}(t)$ = the derived investigation level in units of measured activity,
- 0.1 = the Investigation Level dose of 0.1 rem CED,
- DCF = the appropriate dose conversion factor (rem CED per unit activity of intake, where the units of activity are consistent with those of the DIL), and
- $\mathrm{F}(t)$ = the value of the appropriate intake excretion or retention fraction (the fraction of initial intake expected to be present in the measured medium at time *t* after intake).

Since the DIL(t) is a constant value multiplied by the intake excretion or retention fraction F(t), the shape of the DIL curve is identical to that of the excretion or retention fraction curve. It is important to recognize that the DIL has nothing to do with the detection abilities of a particular monitoring method (as represented by the MDA); it is solely a function of the dosimetric significance of activity in a monitoring result.

For the purposes of routine bioassay program planning and operation, DILs are based on the assumption that a single intake occurred *immediately after the last bioassay measurement*. In most cases, this interpretation provides a "worst-case" estimate of intake and dose. For example, in the case of semiannual urine sampling, the IEF value for the 180th day after intake would be used to establish the DIL.

LLNL facilities and operations are designed so that no significant intakes of radioactive materials are expected to occur during normal operations. With the exception of tritium operations and some depleted uranium operations at Site 300, multiple intakes occurring in one calendar year are considered unlikely. Accordingly, LLNL does not partition the Investigation Levels and associated DILs as a function of the number of monitoring intervals during the year.

If operations do arise in which multiple intakes are expected during routine operations, partitioned DILs will be developed by the Internal Dosimetry Team and the ES&H Team HP on a case-by-case basis.

5.6 MINIMUM DETECTABLE DOSE

5.6.1 Definition of Minimum Detectable Dose

The concept of Minimum Detectable Dose (MDD) may be used as a measure of the "dosimetric sensitivity" of a particular bioassay method and frequency. The MDD is the smallest dose expected to be reliably detected for a given radioactive material, route of intake, bioassay measurement interval, and bioassay measurement technique. The MDD is therefore determined by the analytical (detection) sensitivity of the measurement method, the fraction of an intake expected to be present in the measured medium (e.g., urine sample, lung count) as a function of the time elapsed between intake and measurement, and the DCF of the material in question.

The premises upon which the MDD is based are as follows:

(1) On an unknown date during a monitoring interval, an *otherwise unrecognized* intake occurs.
(2) By the time of the next routine bioassay measurement, the activity to be measured is just below the MDA of the measurement system.
(3) Thus, it is concluded that *no* intake occurred during that monitoring interval, and the dose resulting from that hypothetical intake would be "missed" in the sense that no intake would be recognized and no dose would be assessed or recorded.

5.6.2 Calculation of MDD

For a particular radioactive material and a particular internal dose monitoring method, the MDD is a function of:

- The analytical sensitivity of the measurement method (MDA or MDC),
- The fraction of the intake expected to be present in the measured medium on the date of interest (IEF or IRF), and
- The dose per unit intake for that particular radioactive material (DCF).

Thus, the MDD is the intake implied by a result equal to the MDA multiplied by the appropriate DCF. The MDD is calculated as:

$$\mathrm{MDD}(t) = \mathrm{DCF} \cdot \frac{[\mathrm{MDA\ or\ MDC}]}{\mathrm{F}(t)} \qquad \text{Equation 5.4}$$

where:
- $\mathrm{MDD}(t)$ = the minimum detectable dose (rem CED) for a particular type of bioassay measurement made at time *t* after intake,
- DCF = the appropriate dose conversion factor (rem CED per unit activity of intake, where the units of activity are consistent with those of the DIL), and
- $\mathrm{MDA\ or\ MDC}$ = the minimum detectable activity or minimum detectable concentration for the bioassay method of interest, in the same units of activity as the DCF, and
- $\mathrm{F}(t)$ = the value of the appropriate intake excretion or retention fraction (the fraction of initial intake expected to be present in the measured medium at time *t* after intake).

The MDD and DIL are used to determine whether or not a particular bioassay measurement procedure and frequency is sufficiently sensitive to detect intakes at or near the Investigation Level of 0.1 rem CED. The value of the MDD is dependent on intake date assumptions. For program planning purposes, it is sufficient to make the conservative assumption that the hypothetical intake occurred at the beginning of the sampling period.

5.7 OTHER FACTORS AFFECTING INTERPRETATION OF MEASUREMENT RESULTS

The above discussions and definitions of DILs and MDDs assume that *all* of the activity in the measurement is due to an occupational intake. In circumstances where significant levels of environmental ("background") activity are expected to be present in bioassay measurements (e.g., excretion of environmental uranium and potassium in urine), such a contribution must be accounted for when determining monitoring MDAs and reference levels.

Details of establishing adjusted notification levels to account for preexisting radioactivity (e.g., environmental background or previous intakes) are discussed in the ID TBM. Some examples regarding environmental uranium are discussed briefly below.

5.7.1 Natural Uranium Notification Level

Perhaps the foremost example of "environmental interference" in bioassay measurements is the presence of natural uranium in the urine. On average, humans ingest about 2 μg of natural uranium per day. Most of this uranium is excreted in the feces, but a small amount (ranging from about 0.05 to 0.5 μg per day) is excreted in the urine. This rate corresponds roughly to a concentration of about 0.04 to 0.4 μg of uranium per liter of urine.

The MDC for inductively coupled plasma mass spectrometry (ICP-MS) analysis for uranium is about 0.004 μg per liter. However, this analytical MDC cannot be used to calculate MDDs for this monitoring method, since almost all samples will contain a readily detectable "background" level of environmental uranium above this level. Thus, an effective MDC must be established for ICP-MS analysis for natural uranium. The effective MDC represents the level *above which* the result is considered greater than expected from environmental background uranium.

By examining the expected concentration range of this environmental background, one can establish a uranium notification level (NL) below which the activity in a sample is assumed to be

due to environmental contributions, not occupational intakes. Since uranium-in-urine results below the NL will not normally initiate any follow-up actions, the NL alters the effective MDC for the measurement method. The effective MDC becomes the difference between the NL and the average concentration—in other words, the *additional* concentration needed to raise an average sample above the NL. This effective MDC is then used for calculations of MDDs for natural uranium.

5.7.2 Gross Alpha NLs

The presence of naturally-occurring uranium and thorium isotopes is readily detected by the Gross Alpha screening analysis. Method-specific NLs have been developed and applied by the Bioassay Laboratory and are detailed in the associated BLAB procedures.

5.7.3 Accounting for Previous Intakes

A related problem results from continuing excretion or retention of detectable levels of activity from a previously identified (and presumably previously assessed) intake. In such a case, the problem becomes one of determining whether or not subsequent bioassay measurements are significantly greater than those expected from the previous intake, thus indicating a new occupational intake. Such situations are complex and must be dealt with on a case-by-case basis.

5.8 PROGRAM NOTIFICATION LEVELS

Program NLs are the activity or concentration values of individual or area monitoring results at which the ES&H Team HP or the Internal Dosimetry Team has requested prompt notification from the processing laboratory. Typically, default NLs are used, but in some cases, the ES&H Team HP may choose to set program- or exposure area-specific NLs that are different from the defaults. Section 6.7 of this Manual contains some implementation guidance for deviating from default NLs.

5.9 UTILIZING TECHNICAL BASIS CONCEPTS IN DESIGNING A ROUTINE MONITORING PROGRAM

Sections 5.1 through 5.8 discussed the general concepts that form the technical basis of a routine monitoring program. In summary, bioassay measurement methods and frequencies are determined by considering the following general factors:

- Expected patterns of retention and excretion (IRFs and IEFs) based on biokinetic models,
- Required dosimetric sensitivity (DILs and MDDs),
- Detection sensitivities (MDAs and MDCs) of available measurement methods, and
- Bioassay analysis turnaround times.

The technical consideration of these steps as they apply to the design of a specific routine monitoring program is discussed herein.

5.9.1 Level of Dosimetric Sensitivity Required

The choice of monitoring method is often largely determined by the dosimetric sensitivity of that method—that is, how small of an intake (and corresponding dose) can that measurement method reliably detect and measure? 10 CFR 835.402 requires internal dose monitoring programs that are implemented to demonstrate compliance with monitoring requirements to be adequate to demonstrate compliance with the dose limits.

The Internal Dosimetry Standard states:

> In cases where it is practical, feasible, and affordable, internal dose evaluation programs should have a goal of assessing intakes of radioactive materials that occur in a year and that deliver a committed effective dose at the IL, that is, intakes of 0.02 stochastic annual limit on intake (SALI) for general employees and 0.01 SALI (or less) for declared pregnant workers, minors, and visitors.

With respect to program design, the RPP Guide states:

> Where practicable, the method of individual monitoring, analytical methodology, and measurement parameters should result in an MDA less than the corresponding DIL for all radionuclides to which an individual might be exposed.

5.9.2 Criteria for Selection—Use of DILs or MDDs

If practicable, the type and frequency of measurements used in routine bioassay programs should be selected such that it is unlikely for intakes leading to doses of 0.1 rem CED or greater to go unrecognized and unassessed. In order to meet this level of sensitivity, the MDD for a particular radioactive material and selected measurement frequency should be less than 0.1 rem. Equivalently, the measurement method should be able to detect levels of activity at or below the appropriate DIL.

A standard method for comparing bioassay methods and frequencies is to compare the DIL for a particular type and frequency of bioassay to the MDA for that measurement method. The DIL should not be confused with the statistical *Decision Level* (L_C) presented in Section 5.3.2 of this Manual. The DIL is related solely to the dosimetric significance of the activity in the bioassay measurement and has nothing to do with the detection decision for that measurement. In contrast, the Decision Level is based solely on measurement statistics and has nothing to do with implied intake or dose.

5.9.3 Relationship between DIL and MDA

The relationship between MDAs and DILs should be carefully considered when selecting bioassay methods and frequencies for a monitoring program. In general, the value of the DIL will decrease as the length of the monitoring interval increases. This decrease is due to the fact that as the time between the intake and the measurement increases, the fraction of intake that is represented by that measurement results usually decreases. Thus, all other things being equal, the dosimetric significance of a unit of activity in the sample increases. Thus, DILs are used to visualize the dosimetric sensitivity of a particular monitoring method as a function of monitoring interval.

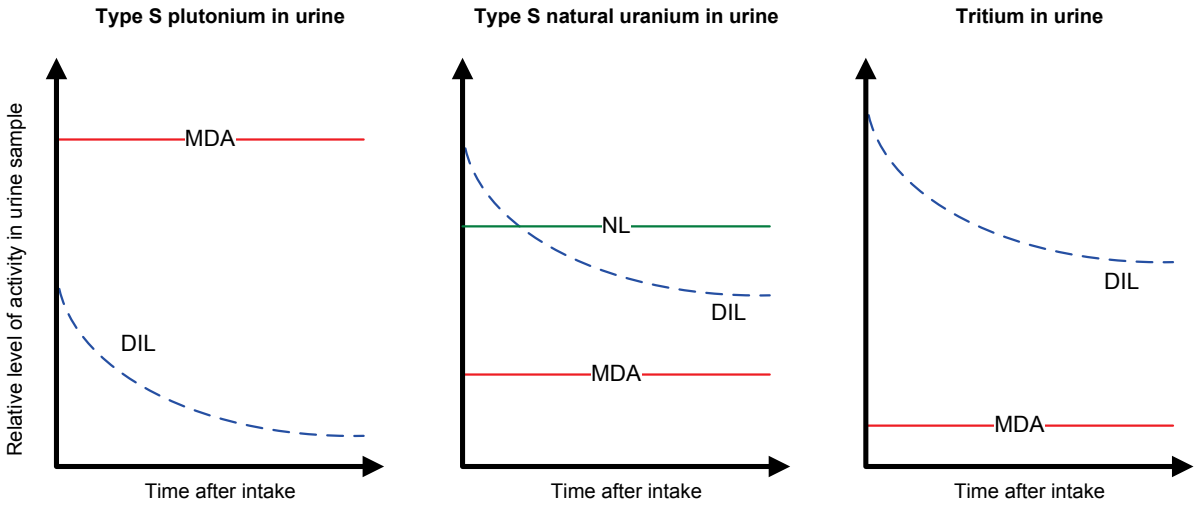
When using DILs to design a bioassay program, one would typically compare the DIL values to the MDA for a particular monitoring method. It would not be unusual, for example, to find that as the monitoring interval is increased, the DIL remains above the MDA for some time, then drops below the MDA as the monitoring interval reaches some critical time post-intake.

If the slope of the DIL as a function of monitoring interval is relatively flat, the implication is that the dosimetric sensitivity of the monitoring method is not particularly sensitive to changes in monitoring interval. If, however, the slope is relatively steep, the implication is that dosimetric sensitivity may be lost very rapidly as the monitoring interval increases. This consideration may have a significant impact on the selection of appropriate or desirable monitoring frequencies.

The relative relationship between these two concepts will depend upon the particular radionuclide; some representative cases are illustrated in Figure 5.2. In these example graphs, the

calculated DIL is represented by the dashed line. (Note that the Y-axes merely represent relative levels of activity and are not meant to be quantitative.)

Figure 5.2 Examples of the relationship between DIL and MDA



The leftmost graph schematically represents analysis of urine samples for Type S plutonium by alpha spectroscopy measurements. Due to the relatively poor detection sensitivity and the high dose leverage of plutonium the DIL is well *below* the MDA for essentially any monitoring frequency. Thus, there is no sampling frequency for this method that would satisfy the desired detection sensitivity for an Investigation Level dose of 0.1 rem.

The middle graph represents urine sampling for Type S natural uranium. In this case, the analytical sensitivity is such that the MDA is below the DIL. Thus, this method would be expected to detect intakes at or below the Investigation Level. However, the presence of environmental uranium in the urine from dietary sources can easily produce uranium concentrations in urine well above the DIL. Although the analytical sensitivity is more than adequate, the overall dosimetric sensitivity may not be adequate.

Finally, in the case of tritium urine bioassay, represented by the rightmost graph, the analytical sensitivity is such that for weekly, biweekly, or even monthly sampling intervals, the DILs for tritium are always well above the MDA. Thus, tritium-in-urine samples can easily be above the MDA but well below a DIL.

DILs for selected radionuclides, measurement methods, and monitoring intervals are summarized in Appendix B of this Manual. The nuclide-specific discussions and excretion or retention curves in the ID TBM provide further information on the variation of DIL with time for a particular monitoring method.

5.9.4 Use of MDD Concept

In a similar manner, MDDs also provide information on the dosimetric sensitivity of various bioassay measurement techniques. MDDs for selected radionuclides, measurement methods, and monitoring intervals are summarized in Appendix B of this Manual.

5.9.5 Bioassay Analysis Result Turnaround Time

The impact of bioassay analysis result turnaround time may be an important factor in the design and implementation of an operation-specific routine bioassay program. Recall that one of the main purposes of routine bioassay is to detect significant intakes of radioactive materials that may otherwise go unrecognized. If routine bioassay plays only a small role in the detection of possible intakes (e.g., air sampling would be expected to rapidly detect significant intakes, and bioassay is being used as supplemental confirmation) then the turnaround time for routine samples assumes a less important role.

In contrast, if bioassay is the only means of detecting significant intakes, then the monitoring program is blind to intakes during the time required for bioassay processing. Temporally distributed sampling of a group of workers (staggering) effectively reduces this blind time period, if the workers can be assumed to have an equal chance of exposure. Use of other intake detection systems (e.g., air sampling and surface contamination monitoring) may mitigate these concerns.

The other major impact of turnaround time is the effect it has on the ability to confirm a suspected intake. This consideration may be illustrated by considering the following hypothetical example:

Example

An otherwise unrecognized intake occurs at the beginning of a monitoring interval (i.e., just after submitting a routine sample). At the end of that interval, the worker collects a urine sample which is submitted for processing. After processing (perhaps a month later), the sample is found to contain activity above the DIL. A follow-up sample is then requested and collected.

However, during the time interval between the collection of the first sample and the collection of the follow-up sample, the level of activity in the urine has dropped below the L_C for that sample. Thus, an intake cannot be *confirmed* (see Chapter 7 of this Manual) when in fact an intake resulting in a dose greater than the Investigation Level occurred.

As might be expected, the impact of turnaround time on confirmation ability, operational implications, and subsequent follow-up is highly dependent on the particular radioactive material and monitoring method. Acceptable processing times are influenced by:

- The presence of other intake detection systems (e.g., air sampling and surface contamination monitoring) for worker protection,
- Periodic or staggered sampling of other workers in the monitored group,
- The effect of sample turnaround time on the ability to confirm an intake, and
- The likelihood that workers may continue to incur unrecognized internal exposure.

General expectations for sample turnaround times are provided in Table 7.1 of this Manual.

5.9.6 Other Considerations

In some cases, a combination of measurement methods may be necessary or desirable, particularly when different compounds of materials might be encountered. For example, lung counts may be appropriate for Type S uranium, whereas urine bioassay would be more appropriate for Type M or F uranium. Accordingly, a worker who might be exposed to any of those compounds would be scheduled for both lung counts and urine bioassay.

Other important factors to be considered in the choice of monitoring methods and frequencies include availability of the measurement method, cost, reliability, invasiveness and inconvenience to the worker, and other radiological or non-radiological facility- or operation-specific factors that may complicate implementation of the bioassay program. For example, analysis of routine fecal samples for plutonium can theoretically provide a great deal of sensitivity for inhalation intakes. However, the inconvenience to the worker, cost and difficulty of sample preparation and analysis,

and susceptibility to "falsely significant" results (due to the extremely high initial fecal clearance rates of inhaled plutonium) reduce the overall attractiveness and efficacy of this method (Bihl 1993).

6. DESIGN OF ROUTINE INTERNAL DOSE MONITORING PROGRAM

6.1 OVERVIEW OF ROUTINE BIOASSAY PROGRAM EVALUATION AND DESIGN

This Chapter presents guidelines for the initial evaluation, design and documentation of a routine internal dose monitoring program, including selection of monitoring methods, monitoring frequencies, and derived reference and action levels. Information on the day-to-day operation of the routine monitoring program is presented in Chapter 7 of this Manual.

For activities and areas with known or potential internal radiological hazards, the need for an operation- or facility-specific internal dose monitoring program should be evaluated and documented in accordance with this Chapter. The initial evaluation for and design of an operation- or facility-specific internal dose monitoring program should be performed by the ES&H Team Health Physicist in conjunction with the Internal Dosimetry Team, and verified thereafter during the HP-DAP or work authorization document review and update process.

It is important to note that the purpose of *routine* individual and workplace monitoring programs is to detect *otherwise unrecognized* intakes. All of the components of the monitoring program (e.g., bioassay, air sampling, contamination monitoring) serve as indicators of possible intakes. Where there are obvious incidents, workplace intake indicators, or a possible intake is detected via routine personnel monitoring, the internal dose monitoring program switches into a follow-up and assessment mode, to determine if an occupational intake took place and to assess the nature and magnitude of any intake.

6.2 CHARACTERIZATION OF POTENTIAL INTERNAL HAZARDS

The first step in determining the need for a routine bioassay program, as well as determining other appropriate radiological protection measures, is to fully characterize the nature of the radiological hazards present in the workplace. The following factors should be considered and documented when characterizing the potential for internal contamination from radiological hazards in the workplace:

- The identity of radionuclides in use,
- The identity of progeny radionuclides,
- The identity and concentration of any impurity radionuclides,
- The chemical and physical forms of materials in use,
- The quantities and concentrations of radionuclides in use,
- The expected particle size distributions,
- The potential for dispersal (nature of operations or energy sources),
- Potential routes of intake (inhalation, ingestion, wounds, absorption through skin),
- Confinement methods (hood, glovebox, sealed drum),
- Occupancy factor,
- Respiratory protection, and
- Frequency of handling.

Any or all of these factors may play an important role in determining the likelihood of a significant intake during routine operations. A worksheet such as the *ID Workplace Characterization*[1] may be used to characterize the potential internal radiological hazards.

[1] Available internally on UCM at *ES&H Directorate Organization – Radiation Protection Functional Area – Health Physics Technical Program – Dosimetry (Internal and External) – Internal Dosimetry – Internal Dosimetry Program Manuals*

Another factor that must be considered is the degree of uncertainty about the radiological materials introduced into the work process. In most instances, there will be fairly strict control over the quantities and types of radioactive materials in process. However, some operations by their very nature (e.g., waste processing, decontamination and decommissioning) deal with sometimes unexpected quantities, concentrations, or types of radioactive material.

This uncertainty is particularly important in situations where one operational entity (e.g., the waste handling organization) may be dependent on a different operational entity (e.g., the material processing organization) for characterization of the material. In such situations, a hazards analysis should be made of the worst-case possibilities. To the extent practicable, workplace (and possibly worker) monitoring programs should be designed to warn personnel of radiological conditions that exceed the bounds of normal, expected conditions.

Actual analytical determination of the solubility and particle size distribution of airborne contaminants (e.g., as collected on air sampling filters) can be extremely valuable in design and operation of the internal dose monitoring program. Where practicable, such samples should be collected and analyzed.

6.3 EVALUATION OF NEED FOR PARTICIPATION IN A ROUTINE INTERNAL DOSE MONITORING PROGRAM

The need for participation in a routine internal dose monitoring program is determined by the ES&H Team Health Physicist based on the potential for internal radiological hazards associated with the workplace and the likelihood of a worker receiving a significant intake of radioactive materials that would *otherwise go unrecognized*. For regulatory purposes, it is important to distinguish between monitoring that is required by 10 CFR 835 and monitoring that is confirmatory or discretionary. LLNL has established three categories of individual monitoring, which can be summarized as:

(1) Required by 10 CFR 835,
(2) Confirmatory, as recommended by this Manual, or
(3) Discretionary.

This categorization scheme for radiological workers is summarized in Table 6.1 with specific implementation details presented in subsequent Sections. For new work activities, the initial evaluation of the need to participate in a routine internal dose monitoring program should be documented, even if it is determined that routine monitoring is unnecessary.

Table 6.1 Requirements for participation in an individual dose monitoring program

Radiological Workers	Monitoring Category
Under *typical* conditions, are likely to receive a CED of 0.1 rem or more from all occupational radionuclide intakes in a year	Required
Are *not* likely to receive more than 0.1 rem CED under typical conditions, but have a *reasonable potential* for internal exposure to radioactive materials	Confirmatory
Are not likely to receive any significant intakes of radioactive materials	Discretionary

Internal dose monitoring requirements for Declared Pregnant Workers, occupationally exposed minors, and members of the public must be considered on a case-by-case basis. For certain nuclides (notably, insoluble forms of plutonium), routinely used bioassay techniques are not sufficient to demonstrate compliance with the 0.1 rem dose limit for minors and members of the public.

6.3.1 Required Monitoring

As discussed in Chapter 3 of this Manual, LLNL requires its programs to design and operate their facilities so that no significant intakes of radioactive materials are expected during normal operations. Accordingly, few, if any, workers at LLNL fall into the category of monitoring that is required by 10 CFR 835, since it is not likely that they would, "under typical conditions," receive an intake that would result in a CED of 0.1 rem or greater.

Some clarifying comments:

"Likely" vs. "Possible"

There has been some confusion regarding the meaning of the word "likely" in this section of 10 CFR 835. In agreement with the rest of the DOE internal dosimetry community, LLNL has chosen to use the common-sense definition of this term—that is, an event that is *expected*, as opposed to an event that is *possible*.

Applicability of Routine Bioassay Monitoring

The requirement for monitoring in 10 CFR 835 does not apply to incidents or accidents which would be otherwise recognized (due to the physical circumstances of the event) as possibly causing significant intakes. The purpose of a routine bioassay program is to detect significant intakes of radioactive materials that *would otherwise go undetected*—thus assuring that all such intakes are assessed. If, for example, other workplace monitoring indicators (e.g., alarming air monitors or passive air samples) could be *absolutely* relied upon to detect any significant intake, routine bioassay may be superfluous.

For example, if the only credible means of producing a CED in excess of 0.1 rem was some sort of obviously recognizable physical event (e.g., a fire, explosion, or spill), routine bioassay would not be necessary, as the intake event would have already been detected. In other words, a routine bioassay program is not needed to indicate whether or not a glove box has exploded. (*Follow-up* bioassay sampling would be performed, which is different from *routine* bioassay monitoring.)

Thus, the purpose of routine bioassay monitoring is to detect significant intakes that may occur during relatively routine operations, in which there is no other sufficiently reliable indicator that a significant intake may have taken place (e.g., when there is a reliance on administrative techniques to detect loss of contamination control).

Interpretation of whether a CED greater than 0.1 rem is "likely" is a matter of professional judgment and experience, as discussed in the Internal Dosimetry Standard. This document discusses a number of criteria that may be used to select workers for participation in routine bioassay programs:

(1) Quantity of radioactive material in process
(2) Worker training and tasks
(3) After-the-fact determination of bioassay need based on actual work performed (does not apply to air sampling)
(4) Use of respiratory protection to limit intake and dose
(5) Long-term chronic exposure to air concentrations exceeding 2% of the Derived Air Concentration (DAC)
(6) Short-term chronic airborne exposure, or multiple acute airborne exposures
(7) Tracking individual exposure in DAC-h

Combining and documenting retrospective operational monitoring and assessment information with prospective area and air monitoring techniques is an acceptable method for determining if a CED greater than 0.1 rem is likely. For example, since 2000, representative air monitoring in Building 332 indicated less than 0.1 rem intake potential from chronic releases or area conditions on an operational basis. Routine bioassay monitoring for workers in this facility has not identified any previously unrecognized intakes. Event-driven bioassay monitoring (nasal, urine, and fecal sampling in response to CAM alarms or identification of elevated area or personnel contamination) confirmed eight intakes, only two of which were greater than 0.1 rem. This monitoring history indicates that it is unlikely that radiological workers performing operations in Building 332 will receive intakes resulting in 0.1 rem in a year.

In the absence of sufficient representative historical operational information, a worksheet such as the *ID Workplace Characterization* may be used to determine if, under typical conditions, workers are likely to receive a CED of 0.1 rem or more from a specific operation. This form is based on the guidance in Appendix A of ANSI/HPS Standard N13.39-2001. This standard uses a methodology similar to the NUREG-1400 approach used for determining LLNL air monitoring requirements; however, the ANSI/HPS standard applies conservative modifications to ensure consistency with industry practices. Alternative approaches and assumptions may be used and documented with concurrence from the Internal Dosimetry Team Lead.

6.3.2 Confirmatory Monitoring

The intent of confirmatory monitoring is to include in a routine monitoring program workers who are not required to be monitored by a strict interpretation of 10 CFR 835, but who work with unencapsulated radioactive material in such quantities that internal dose monitoring is warranted to provide verification that engineered controls and workplace practices are effective.

Clearly, there is a good deal of experience and professional judgment involved in determining which workers fall into this category. As a guideline, ICRP Publication 75, *General Principles for the Radiation Protection of Workers*, states:

> Experience has shown that it is necessary to give consideration to routine individual monitoring for internal exposure of workers involved in the following operations:
> (a) the handling of large quantities of gaseous and volatile materials, e.g. tritium and its compounds in large scale production processes, in heavy water reactors and in luminising,
> (b) the processing of plutonium and other transuranic elements,
> (c) the processing of thorium ores and use of thorium and its compounds (these activities can lead to internal exposure from both radioactive dusts and thoron [^{220}Rn] and its progeny),
> (d) the milling and refining of high grade uranium ores,
> (e) natural and slightly enriched uranium processing and reactor fuel fabrication,
> (f) the production of large quantities of radionuclides,
> (g) workplaces where radon levels exceed the action level, and
> (h) the handling of large quantities of iodine-131, e.g. for therapy.

The Radiological Control Standard states,

> Individuals whose routine duties may involve exposure to surface or airborne contamination or to radionuclides readily absorbed through the skin, such as tritium, should be considered for participation in the bioassay program.

At LLNL, confirmatory monitoring should be performed when workers have a reasonable potential for internal exposure to radioactive materials, such as:

- Under typical conditions, workers are likely to receive a CED of 0.025 rem,
- Under credible non-normal conditions, such as failure of administrative or engineering controls, workers are likely to receive a CED of 0.1 rem,
- Routine work with unencapsulated radioactive material and reliance on respiratory protection to limit exposures,
- Work performed inside High Contamination Areas or posted Airborne Radioactivity Areas,
- Operations where there is a higher potential for the generation of airborne radioactivity (e.g., grinding or milling performed outside a glovebox),
- Operational experience indicates the occurrence of multiple low-level intakes or unrecognized (by routine workplace monitoring) intakes, or
- Radioactive material work with "sharps" where wound intakes have the potential to be unrecognized (e.g., ultra-fine needles or other objects that can penetrate PPE and skin with minimal applied force).

The following types of operations and facilities at LLNL typically fall into the confirmatory monitoring category:

- Routine uranium handlers, such as in the Building 321 metal shops and at Site 300,
- Routine tritium handlers, such as in Buildings 298 and 331,
- Routine plutonium handlers in Building 332,
- Routine Radioactive and Hazardous Waste Management (RHWM) workers exposed to dispersible radioactive materials, and
- Various radiochemical laboratory work involving Type II or Type III workplaces with dispersible radioactive materials (as isotopically applicable).

Additional discussion regarding confirmatory monitoring for specific radionuclides of interest (including tritium, uranium, neptunium, plutonium, and americium) is provided in the element-specific appendices of the ID TBM.

6.3.3 Discretionary Monitoring

Discretionary monitoring may be recommended by the ES&H Team Health Physicist or program or facility management. Examples of discretionary monitoring include:

- More frequent monitoring of workers involved in new operations, multiple or simultaneous operations, or work performed at other DOE sites that overlaps with LLNL operations,
- Less frequent monitoring than recommended for a confirmatory monitoring program for workers involved in operations that do not meet the confirmatory monitoring thresholds (e.g., workers performing occasional radioactive material handling in a hood who are not likely, under typical conditions, to receive a CED of 0.025 rem), or
- Supplemental monitoring for additional program or worker assurance.

For example, although monthly urine sampling for tritium is normally sufficient to meet the sensitivity requirements of 10 CFR 835, weekly or biweekly sampling has provided valuable operational feedback to safety and facility management. Since urine sampling for tritium is relatively quick, easy, and convenient, it is a good practice to use the shorter sampling intervals for tritium operations that have significant potential for exposure (e.g., decontamination and decommissioning operations or tritium glovebox operations).

Similarly, although quarterly uranium-in-urine samples might be sufficient to meet the regulatory requirements or monitoring recommendations for certain operations, monthly samples might be desired to assist in more readily distinguishing between environmental background uranium and operational intakes of natural uranium.

6.3.4 Monitoring for Declared Pregnant Workers

Internal dose monitoring requirements for Declared Pregnant Workers should be considered on a case-by-case basis. Monitoring should be performed if the ES&H Team HP determines that intakes are likely, or if monitoring is desired to document the absence of significant intakes.

6.3.5 Monitoring for Occupationally Exposed Minors

Internal dose monitoring requirements for occupationally exposed minors need to be considered on a case-by-case basis. For certain nuclides (notably, insoluble forms of plutonium), routinely used internal dose monitoring techniques are not capable of detecting intakes that would result in a CED of 0.1 rem, the radiation dose limit for occupationally exposed minors. Accordingly, as it would not be possible to demonstrate compliance with the regulatory dose limit, minors should not be permitted to perform work where intakes of such materials are likely.

6.3.6 Monitoring for Special Cases

In addition to the categories of workers mentioned in this Chapter, the ES&H Team HP may become aware of other special cases that may warrant individual monitoring. In some cases, factors considered in determining whether monitoring is recommended may extend to include non-technical considerations.

For example, a nursing mother who works with dispersible radioactive materials may be have significant concerns regarding the potential for transfer of radioactivity from mother to child. Accordingly, a conservative discretionary monitoring may be conducted to address such issues.

6.4 LLNL INTERNAL DOSE MONITORING CAPABILITIES

The internal dose monitoring techniques routinely used at LLNL are briefly described in the sections below. Additional information is available in the Bioassay Laboratory Procedures, the Spectroscopy Laboratory Manual, and the Whole Body Counter Manual. A summary of methods that are accredited by DOELAP is provided in Appendix B.

6.4.1 In vivo monitoring capabilities

In vivo monitoring is conducted in the Whole Body Counter (WBC) facility in B253. The facility consists of a graded-Z shielded counting room approximately 20 feet underground and surrounded by approximately 5 feet of low-background serpentine rock fill.

(a) **Whole body scans** are performed using a moving bed that traverses over a system of four P-type high purity germanium detectors. This system is used to determine whether detectable quantities of high-energy gamma-emitting radionuclides are present in the body. Spectra are routinely analyzed for ^{22}Na, ^{40}K, ^{57}Co, ^{60}Co, ^{131}I, and ^{137}Cs and can be reanalyzed for alternate radionuclides based on review of unidentified spectral peaks from the routine analysis, field indicators, or process knowledge. This system can only detect transuranic radionuclides in cases of extremely large intakes. MDAs are fairly consistent from person to person.

(b) **Lung counts** are performed using a system of four Canberra ACT-II low-energy high purity germanium detectors placed over the subject's chest. This system is used to measure low-energy gamma and x-ray radiation emitted from radionuclides deposited in the lungs. Spectra are routinely analyzed for ^{235}U, ^{238}U (via ^{234}Th), ^{238}Pu, ^{239}Pu, and ^{241}Am and can be reanalyzed for alternate radionuclides based on review of unidentified spectral peaks from the routine

analysis, field indicators, or process knowledge. The MDA is affected by the chest wall thickness of the subject.

(c) **Thyroid counts** are performed using one of the ACT-II detectors to measure gamma and x-ray emissions from isotopes that concentrate in the thyroid. Typically monitored isotopes are ^{125}I and ^{131}I; however, additional isotopes can be added and spectra reanalyzed based on unidentified spectral peaks, field indicators, or process knowledge. In cases of emergency or other needs, a portable sodium iodide detector is available to provide qualitative results with order-of-magnitude estimates of activity.

(d) **Wound counts** are performed using the ACT-II detectors to measure gamma and x-ray emissions from isotopes contained within a wound site. Wound counts provide screening for radionuclides with gamma or x-ray energies below 400 keV and are more sensitive than field instrumentation. This technique provides rapid feedback on the observed contamination levels and the radionuclides present to guide medical treatment. However, unknown source distribution and depth within the wound make absolute quantification of activity difficult. In cases of emergency or other needs, a portable sodium iodide detector is available to provide qualitative results with order-of-magnitude estimates of activity.

(e) **Organ counts** are not performed as part of the routine bioassay program, but may be performed using the ACT-II detectors. Measurements of the liver, bone (skull or knees), kidney, and tracheal-bronchial lymph nodes provide screening for radionuclides with gamma or x-ray energies below 400 keV. Limitations with the system include potential interferences on the measurement of the organ of interest from radionuclides deposited in adjacent organs. If sufficient activity is deposited in adjacent organs, mathematical adjustments can be made to compensate for these interferences.

6.4.2 In vitro monitoring capabilities

After bioassay samples are received, in vitro monitoring is coordinated by the Bioassay Laboratory (BLAB) in Buildings 253 and 254. Bioassay samples are initially received in Building 254, but processing and analysis may be conducted in one of several laboratories.

(a) **Element-specific radiochemical separation and alpha spectroscopy is performed for specific transuranics (^{238}Pu, $^{239+240}$Pu, ^{242}Pu, ^{241}Am, ^{244}Cm)** for the routine urine bioassay program and as needed for fecal samples. BLAB performs the radiochemical separation and the Spectroscopy Laboratory (SLAB) performs the subsequent alpha spectroscopy. The Pu analysis and Am/Cm analysis are two separate procedures and may be performed sequentially on the same sample. Requests for ^{239}Pu analysis will also include results for ^{238}Pu. Requests for ^{242}Pu analysis will also include results for ^{238}Pu and ^{239}Pu. Routine monitoring is by simulated 24-hour urine samples with a minimum volume of 500 mL needed to meet routine detection level expectations. As needed, fecal samples may also be processed in the same manner.

(b) **Inductively coupled plasma mass spectrometry (ICP-MS) is performed for uranium** in urine samples by the BLAB. Two separate procedures are available for analyzing uranium in urine samples. The "U-238" procedure requires only minimal sample preparation before the direct determination of ^{238}U by ICP-MS and should be used if the only occupational exposure potential is for natural uranium. The "U-235/U-238" procedure (developed in 2009) includes chemical separation in the sample preparation, which provides increased sensitivity sufficient to quantify ^{235}U and give an accurate calculation of the ^{235}U/^{238}U mass ratio for urine samples. This procedure should be used if either depleted or enriched uranium is used in the workplace. For both procedures, routine monitoring is by single voiding ("spot") samples, which provide sufficient volume for the analyses. If simultaneous monitoring for other

transuranics is requested, the aliquot for uranium analysis will be taken from the simulated 24-hour urine sample. In cases of elevated natural uranium results suspected to result from drinking water sources, these procedures may also be performed on a sample of drinking water.

(c) **ICP-MS is also performed for neptunium-237** in urine samples by the BLAB. This technique is performed with minimal sample preparation before measurement. Analysis for ^{237}Np requires only a spot urine sample, but if simultaneous monitoring for other transuranics is requested, the aliquot for ^{237}Np analysis will be taken from the simulated 24-hour urine sample.

(d) **Liquid scintillation counting is performed for specific beta-emitting nuclides (e.g., ^{3}H, ^{14}C, ^{32}P, ^{35}S, ^{125}I, and ^{131}I)** by the Radiological Measurements Laboratory. Due to the small sample aliquot used for analysis (1 mL), detection limits are relatively high (about 6,000 dpm/L for tritium). Samples containing volatile forms of radionuclides (e.g., iodine) may be biased low due to losses during storage and processing, and should be delivered to BLAB and processed as soon as possible after collection.

(e) **The Gross Alpha screening technique** (also referred to as “Gross Actinide” technique) is routinely used to screen urine samples for certain alpha-emitting radionuclides with energies in two separate regions of interest. The GA-1 region of interest ranges from about 3.9 MeV to 5.1 MeV and includes ^{232}Th, ^{228}U, ^{235}U, and ^{234}U. The GA-3 region of interest ranges from about 5.4 MeV to 6.1 MeV and includes ^{241}Am, ^{228}Th, ^{244}Cm, and ^{252}Cf. This procedure is typically used as part of a sequential analysis with the plutonium technique, but cannot be performed on the same sample if Am/Cm analysis is requested. Since this procedure is a screening analysis and cannot be used to quantitatively determine the activity present in the sample, results cannot be used for dose assessment.

6.5 SELECTION OF OPTIMAL MONITORING METHODS AND FREQUENCIES

Default monitoring types and frequencies appropriate for most LLNL operations are discussed in Sections 6.5.1 and 6.5.2. If more specific information is available about the material in the workplace, monitoring programs may be adjusted and documented accordingly, with consideration of the discussion provided in Chapter 5 of this Manual. When a default monitoring program is not available or appropriate for a given exposure scenario (e.g., alternate isotopes, special forms, or workplace controls), Internal Dosimetry is responsible for identifying appropriate monitoring methods and frequencies in general accordance with the concepts and guidance described in this Manual and the ID TBM.

6.5.1 Minimum Recommendations for Required Monitoring

The ES&H Team HP should coordinate with Internal Dosimetry to determine the best available methods and frequency for required monitoring. Monitoring methods and frequencies for required monitoring should be selected in general accordance with the recommendations in Table 6.2 and the guidance and discussion provided in Section 5 of this Manual.

For required monitoring, Table 6.2 presents recommended default bioassay methods and minimum monitoring frequencies for common radioactive materials at LLNL. The bases for these recommendations are presented in the ID TBM. In some cases, the recommended minimum monitoring program is not sufficient to detect intakes at or near the Investigation Level of 0.1 rem CED. Such technology shortfalls are discussed in more detail in Section 6.6 of this Manual.

Table 6.2 Default recommendations for Required bioassay monitoring

Radioactive Material	In vivo	Urine	Notes
Tritium	*Not recommended*	Monthly Single void	Consider personal air sampling if potential for STC intakes.
Natural Uranium	Annual Lung Count	Monthly Single void	Analyze urine for U-238.
Depleted or Enriched Uranium	*Not recommended*	Quarterly Single void	Analyze urine for U-235/U-238 ratio.
Neptunium-237	Semiannual Lung Count	Quarterly Simulated 24-hr[2]	Analyze urine for Gross Alpha, Np-237, and Pu-239.
Weapons Grade Plutonium	Semiannual Lung Count	Semiannual Simulated 24-hr	Note technology shortfall; consider personal air sampling.
"Pure" Plutonium[3] (^{238}Pu, ^{239}Pu, ^{242}Pu)	*Not recommended*	Semiannual Simulated 24-hr	Note technology shortfall; consider personal air sampling.
"Pure" Americium	Annual Lung Count	Semiannual Simulated 24-hr	Analyze urine for Am-241. Note technology shortfall; consider personal air sampling.

[2] Interim recommended sampling method for ^{237}Np, pending completion of urine background study for ^{237}Np by ICP-MS analysis (planned for end of Calendar Year 2015).

[3] If material is an isotopically pure plutonium mixture (i.e., has no significant activity contribution from ^{241}Am)

6.5.2 Recommendations for Confirmatory and Discretionary Monitoring

Monitoring methods and frequencies for confirmatory and discretionary monitoring should be selected in general accordance with the recommendations in Table 6.3 and the guidance and discussion provided in Section 5 of this Manual. The measurement types and frequencies listed in Table 6.3 are based on conservative assumptions about the nature of the material handled. More frequent sampling or supplemental monitoring should be coordinated with Internal Dosimetry.

Discretionary monitoring may be performed on a routine frequency or as needed (e.g., post-job sampling for specific workplace activities).

Table 6.3 Default recommendations for Confirmatory and Discretionary bioassay monitoring

Radioactive Material or Nature of Work	Monitoring Category	In vivo	Urine	Notes
Tritium	Confirmatory	*Not recommended*	Quarterly Single void	More frequent sampling is preferred but optional. Consider personal air sampling for STCs.
	Discretionary	*Not recommended*	Quarterly Single void	
Depleted or Enriched Uranium	Confirmatory	*Not recommended*	Semiannual Single void	Analyze for U-238 if working with natural uranium only. Analyze for U-235/U-238 ratio if working with depleted or enriched uranium.
	Discretionary	*Not recommended*	Annual Single void	
Natural Uranium	Confirmatory	*Not recommended*	Monthly Single void	
	Discretionary	*Not recommended*	Quarterly Single void	
Neptunium-237	Confirmatory	Annual Lung Count	Semiannual Simulated 24-hr[4]	
Weapons Grade Plutonium	Confirmatory	Annual Lung Count	Semiannual Simulated 24-hr	Note technology shortfall; consider personal air sampling.
	Discretionary	Baseline Lung Count	Baseline Simulated 24-hr	
"Pure" Plutonium[5] **(^{238}Pu, ^{239}Pu, ^{242}Pu)**	Confirmatory	*Not recommended*	Semiannual Simulated 24-hr	Note technology shortfall; consider personal air sampling.
	Discretionary	*Not recommended*	Baseline Simulated 24-hr	
Typical β or β/γ emitters (^{14}C, ^{32}P, ^{125}I, ^{131}I, fission or activation products)	Confirmatory	Annual Whole Body Scan (for fission or activation products) Post-job Thyroid Count (for radioiodines)	Post-job Single void	*As applicable:* Analyze urine for ^{14}C, ^{32}P, ^{125}I, ^{131}I.

[4] Interim recommended sampling method for ^{237}Np, pending completion of urine background study for ^{237}Np by ICP-MS analysis (planned for end of Calendar Year 2015).

[5] If material is an isotopically pure plutonium mixture (i.e., has no significant activity contribution from ^{241}Am).

6.6 EVALUATION OF NEED FOR SUPPLEMENTAL (WORKPLACE) MONITORING AND CONTROLS

In some circumstances (notably, work with Type M and S plutonium), practically available bioassay methods do not provide sufficient sensitivity to reliably detect intakes resulting in doses of 0.1 rem CED. Such circumstances are recognized in the RPP Guide and the Internal Dosimetry Standard as a "technology shortfall," which is defined to exist when the bioassay program's Derived Investigation Level is less than the Minimum Detectable Activity or Minimum Detectable Concentration.

In such cases, the bioassay program should be supplemented with enhanced workplace monitoring and controls. Personal air monitoring, which is often more representative of the worker's breathing zone than fixed air samplers, may also be implemented to supplement the routine bioassay program. As stated in the RPP Guide, the facility should consider the following actions:

- Enhance contamination and air monitoring and the use of indicators (e.g., unexpected glove or surface contamination, increase in airborne radioactive material contamination) to trigger early special radiobioassay monitoring;
- Enhance personal contamination monitoring (e.g., clothing, skin, nasal smears) to trigger special radiobioassay monitoring;
- Use the best practicable radiobioassay monitoring methods;
- Implement enhanced design, operation, controls, and personal protection equipment and procedures to minimize intakes;
- Implement supplementary air monitoring; and
- Document the planned supplementary approach in the facility's internal dosimetry technical basis documentation.

Further guidelines and requirements for air monitoring programs are provided in ES&H Manual Document 20.2 and HP Field Operations procedures. The ID TBM also provides discussion of supplementary monitoring and control requirements for uranium, plutonium, and other transuranics.

6.7 ESTABLISHING NOTIFICATION LEVELS

As discussed in Sections 5.7 and 5.8 of this Manual, Notification Levels (NLs) are established for each monitoring type and frequency. Default NLs for typical bioassay and in vivo monitoring are listed in Appendix B of this Manual. In some cases, the ES&H Team HP may choose to set program- or exposure area-specific NLs that are different from the defaults; for example, setting a higher NL for routine tritium operations or a lower NL for non-routine uranium operations The use of such custom NLs should be coordinated with Internal Dosimetry and the processing laboratories. If NLs less conservative than default values are selected, they should be documented and concurred with by Internal Dosimetry.

6.8 PROGRAM DOCUMENTATION

6.8.1 Documentation of Program Evaluation and Design

The evaluation, design, and basis for each internal dose monitoring program (individual and workplace) should be documented. Evaluation of the need for participating in a routine internal dose monitoring program should be documented, even if it is determined that routine monitoring is unnecessary. This documentation should:

- Include a characterization of the potential internal hazards,
- Distinguish between required, confirmatory, and discretionary monitoring,
- Establish monitoring methods, frequencies, and custom notification levels as appropriate, and
- Summarize (or refer to) the technical basis for the chosen monitoring method, if default values are not used.

A worksheet such as the *ID Workplace Characterization* may be used to characterize the potential internal hazards and determine monitoring requirements.

6.8.2 Documentation of Program Operation

General internal dose monitoring requirements and recommendations for generic operations in fixed facilities, areas, or programs are typically incorporated in the facility or program Health Physics Discipline Action Plan (HP-DAP). In the case of operations not covered by an HP-DAP, the work authorization and control documents should be used to specify internal dose monitoring and to distinguish if it is required, confirmatory, or discretionary.

7. OPERATION OF ROUTINE INTERNAL DOSE MONITORING PROGRAM

7.1 OVERVIEW OF INTERNAL DOSE MONITORING PROGRAM OPERATION

Once the routine internal dose monitoring program has been designed according to Chapter 6 of this Manual, the program must be implemented and operated. The key steps for implementation are:

- Select and identify participants,
- Obtain baseline monitoring as necessary,
- Schedule routine monitoring,
- Provide training and instructions to participants,
- Distribute and collect sample kits,
- Process and analyze samples,
- Manage and provide appropriate notification of results,
- Detect and confirm intakes,
- Schedule appropriate follow-up monitoring,
- Ensure compliance with monitoring requirements,
- Obtain termination monitoring as necessary, and
- Report results.

Each of these steps is generally discussed in this Chapter. Specific procedures are detailed in the applicable Internal Dosimetry Program Procedures.

7.2 SELECTION AND IDENTIFICATION OF PARTICIPANTS

The selection of workers for inclusion in a routine internal dose monitoring program should be based on the hazard characterization and evaluation of need for routine monitoring detailed in Chapter 6 of this Manual. This analysis, typically performed by the ES&H Team HP in conjunction with program or facility management, identifies a type of operation, facility, or area within a facility that warrants participation in a routine monitoring program.

Once such operations or areas are identified, the ES&H Team HP, in conjunction with program or facility management, must identify workers who require bioassay monitoring. This identification should be documented, such as in the Integration Work Sheet (IWS), Radiation Work Permit (RWP), Safety Plan, or attachment to the Health Physics Discipline Action Plan (HP-DAP). This list of personnel should be kept current. The ES&H Team HP and H&S Technician may assist program or facility management in maintaining such a "bioassay list," but the primary responsibility lies with the program or facility management to notify the ES&H Team HP of changes in personnel. The ES&H Team HP-DAP should include requirements for a periodic (at least annual) review of personnel selected for routine bioassay.

As discussed in Chapter 6, for regulatory reasons it is important to distinguish between workers who are required to be monitored by 10 CFR 835 and workers who are included in a confirmatory or discretionary monitoring program. Few, if any, workers at LLNL are required to be monitored; most workers fall into the confirmatory and discretionary monitoring categories.

7.3 BASELINE BIOASSAYS

10 CFR 835 requires all occupational exposure received during the current year to be included when demonstrating compliance with dose limits, and that "reasonable" efforts be made to obtain complete records of prior years' occupational internal and external doses. In order to meet this requirement, the internal dose status of new employees should be characterized to the extent

practicable prior to beginning work in which it is likely that they would incur an intake greater than 0.1 rem CED in the current calendar year.

Accordingly, baseline monitoring (bioassay samples or in vivo counts, as appropriate) may be necessary to determine and document the internal dose status of a new worker before he or she begins work with radioactive materials. Baseline monitoring is recommended if:

- The worker has had previous exposure (or potential exposure) to radionuclides that will be present in the new workplace,
- The worker is known to have had previous occupational intakes of radioactive materials that will be present in the new workplace, and the clearance or retention of these materials should be documented prior to beginning work in the new workplace,
- The previous internal exposure history of the worker is inconclusive, or
- The "normal" level of environmental background radionuclides needs to be established to determine potential interferences for radionuclides that will be present in the new workplace.

If baseline bioassay is necessary, such monitoring should be performed *before* the worker begins work requiring routine individual internal dosimetry monitoring. In most cases, the worker may be permitted to begin radiological work as soon as the baseline sample has been collected or in vivo measurement made. In some cases, however, it may be desirable or necessary to implement a temporary work restriction in order to ascertain the worker's dose status prior to beginning work in which occupational doses in excess of 0.1 rem from internal sources may be received during the current calendar year. Such restrictions will be coordinated closely with the individual, program or facility management, ES&H Team HP, Internal Dosimetry, and Health Services, as appropriate. (See the discussion of work restrictions and dose management in Chapter 10 of this Manual.)

7.4 SCHEDULING ROUTINE MONITORING

Changes to routine bioassay schedules (e.g., addition of new workers, changes to sample frequencies and types) are typically made by the ES&H Team HP. The request is sent to Internal Dosimetry staff, who make the requested changes in the routine monitoring schedules.

7.4.1 Scheduling Bioassay Samples

The Scheduler portion of the Bioassay Laboratory Information Management System (BLIMS) provides a database for bioassay scheduling and tracking, and its various functions are used by both Internal Dosimetry and the Bioassay Laboratory (BLAB). The Internal Dosimetry Team uses the BLIMS Scheduler for the following processes:

- Generating "bioassay request" email notices for workers,
- Generating labels and instructions for sample kits,
- Facilitating management, change, and review of bioassay schedules,
- Generating various program reports, and
- Generating noncompliance reports and notices.

7.4.2 Scheduling In Vivo Counts

In vivo counts are managed and scheduled using an Excel spreadsheet and an Outlook calendar. The Excel spreadsheet serves as a database of workers enrolled in the in vivo monitoring program and is used to track completed counts and to manage due dates. The Outlook calendar is jointly used by the Internal Dosimetry Team and the Whole Body Count (WBC) Team to schedule in vivo counting appointments directly with the workers.

7.5 INSTRUCTIONS AND TRAINING FOR WORKERS

All workers included in a routine internal dose monitoring program should be provided with information about the nature of the potential internal hazards present in their workplace or operation and the associated individual monitoring requirements. Such information may be provided in the work-specific IWS, RWP, Safety Plan, or other program documentation. Section 7 of ES&H Manual Document 20.1 presents general training requirements for work with radioactive materials.

Workers who are handling significant quantities of transuranic radionuclides (e.g., B332 glovebox workers) should receive specific additional training that covers medical interventions (e.g., chelation therapy or excision) in the event of suspected intakes of such materials.

Some medical uses of radioactive isotopes may interfere with certain bioassay measurement procedures. Workers are instructed to notify their ES&H Team HP if they have received such diagnostic or therapeutic procedures. The ES&H Team HP, in conjunction with the Internal Dosimetry Team, will determine the necessary actions (e.g., alternate monitoring methods or temporary work restrictions).

7.6 SAMPLE KIT DISTRIBUTION AND NOTIFICATION

Preparation and distribution of bioassay sample kits is managed by the Internal Dosimetry Team. In some circumstances, programs may purchase their own bioassay collection supplies. In such cases, the particular type of collection containers needs be determined acceptable by the BLAB Team Lead prior to use.

Bioassay kit distribution and collection is coordinated by the Internal Dosimetry Team and the appropriate ES&H Team Health and Safety (H&S) Technician. Kits for routine bioassay samples are labeled with the worker's name, employee number, and analyses requested. Each kit contains sampling instructions.

Supplies and kits for bioassay sampling should be stored in areas that are radiologically clean. Areas in each facility used for storage and staging should be routinely surveyed for possible contamination.

On a monthly basis, Internal Dosimetry issues notices and reminders to workers who are scheduled to submit a bioassay sample or to complete an in vivo count that month.

7.7 BIOASSAY SAMPLE COLLECTION

Workers are instructed to collect bioassay samples in such a manner as to avoid or minimize the chance of contamination of the sample. Simulated 24-hour samples should be collected at home, not at work. Stations for collection of single-void (also known as "spot" or "one-bottle") urine samples may be set up in facility restrooms. Ideally, such restrooms should not be adjacent to or within contaminated or potentially contaminated areas.

Instructions for proper collection and identification of samples should be posted or made available at the sampling station. These instructions should include a reminder to wash hands before collecting the sample to minimize the potential for inadvertent contamination of the sample. The half-page "labels" provided by Internal Dosimetry with routine sample kits uniquely identify the sample to the worker using name and employee number and provide space for the worker to log the sample date and time.

7.8 BIOASSAY SAMPLE RETURN

Sample kits are typically returned to the BLAB in Building 254 by the ES&H Team H&S Technician, who collects the sample kits or containers from each facility and transports them to the BLAB after logging the samples into the Sample Tracking and Reporting (STAR) database. The H&S Technician transfers custody of the samples to the BLAB via the Chain of Custody logbook located at the sample drop-off location. The H&S Technician is responsible for coordinating the timely return of samples to the BLAB, ideally within a week of the sample collection date.

7.9 SAMPLE PROCESSING AND ANALYSIS

Upon drop-off at BLAB, samples are transferred from the STAR database to the BLIMS database. Samples are then directed through the preparation and analysis processes as detailed in the Bioassay Laboratory Procedures.

7.9.1 Sample Processing Priorities

There are five sample processing priorities: *Urgent*, *Rush*, *Priority*, *Normal*, and *Hold*, described further below. Unless indicated otherwise in STAR or by Internal Dosimetry, routine samples are given Normal priority and processed in the order received. In some circumstances, the ES&H Team HP or the Internal Dosimetry Team may wish to accelerate the processing of selected bioassay samples for more timely evaluation of workplace conditions or potential intakes. Such circumstances may include recognized incidents (as discussed in Chapter 11 of this Manual) or non-incident situations in which expedited feedback may be warranted. Any such acceleration of sample processing is coordinated by the Internal Dosimetry Team.

(a) **Urgent** samples are given the highest priority in the processing laboratories. Work begins immediately and overtime for the processing laboratory staff is considered appropriate to expedite processing. This priority is normally reserved for samples from a recognized incident where significant intakes are known or suspected to have occurred.

(b) **Rush** samples are given the next-highest priority, with work beginning as soon as possible *without* overtime for the processing laboratory staff. Samples may be processed in a separate Rush batch if necessary.

(c) **Priority** samples are moved ahead of other samples to the top of the work list, but processing is done at normal speed.

(d) **Normal** samples are processed in the order received at the Bioassay Laboratory.

(e) **Hold** samples are *not* processed or discarded until further notified by the group initiating the hold.

7.9.2 Sample Processing Time Expectations

General expectations for sample turnaround times (i.e., from receipt to result approval) are listed in Table 7.1. In cases of Urgent, Rush, or Priority requests, the BLAB Team Lead will notify the Internal Dosimetry Team if the accelerated processing times in Table 7.1 cannot be met. The BLAB Team Lead will notify the Internal Dosimetry Team and RPFA management if it is anticipated that processing times for Normal samples may exceed the expected estimate by more than 30 days (e.g., if processing for plutonium-in-urine analysis may exceed 90 days).

Table 7.1 Bioassay sample processing time expectations[1]

Analysis	Urgent (working days)	Rush (working days)	Priority (working days)	Normal (calendar days)
Tritium in Urine	1	1–2	≤ 10	15–30
Other LSC analyses (^{14}C, ^{32}P, ^{35}S ^{125}I, ^{131}I)	1	1–2	≤ 10	N/A
^{238}U in Urine	2–3	2–5	10–15	15–30
$^{235}U/^{238}U$ Ratio in Urine	2–3	2–5	10–15	30–60
^{237}Np in Urine (ICP-MS)	2–3	2–5	10–15	30–60
Pu in Urine	5	5–10	15–20	30–60
Pu in Feces	20–25	25–30	N/A	N/A
Am or Cm in Urine[2]	7–10	10–15	20–25	30–60
Am or Cm in Feces	22–27	27–32	N/A	N/A
Gross Alpha in Urine	7–10	10–15	20–25	30–60

7.9.3 Criteria for Acceleration of Bioassay Processing

In most cases, the ES&H Team HP will be in the best position to determine whether the processing of bioassay samples should be accelerated. The guidelines below should normally be used as the basis for requesting accelerated sample processing. The ES&H Team HP may also establish and document workplace-specific action levels for conditions corresponding to the guidelines below (e.g., "in cases of widespread surface contamination in excess of 1,000 dpm/100 cm^2 alpha, request Rush bioassay processing").

(a) Samples may be given Urgent status in the following circumstances:

- Unexpected airborne radioactivity, significant surface contamination, or loss of engineering control with no respiratory protection equipment in use, resulting in potential for an intake greater than 0.5 rem CED as determined by estimates of exposure (e.g., DAC-h, levels of personnel or area contamination, or nasal swab results), or
- In cases where there is significant worker, ES&H Team HP, or programmatic concern or impact, such as major operations placed on hold until bioassay results become available.

[1] These values represent *approximate* turnaround times to assist the ES&H Team HP in selection of the appropriate processing category. **These values do not represent Bioassay Laboratory performance commitments.** The requesting ES&H Team HP should coordinate any specific processing time needs or expectations with Internal Dosimetry and BLAB staff.

[2] Time estimates for the Am, Cm, and Gross Alpha analyses assume sequential processing with Pu. If Pu analysis is not requested, the processing times for these are the same as for Pu.

(b) Samples may be given Rush status in the following circumstances:

- Unexpected airborne radioactivity, significant surface contamination, or loss of engineering control with no respiratory protection equipment in use, resulting in potential for an intake greater than 0.1 rem CED as determined by estimates of exposure (e.g., DAC-h, levels of personnel or area contamination, or nasal swab results),
- Work during which air-purifying respirators are relied on as the primary intake control (i.e., minimal or no engineered barriers between the worker and material), in conditions that could result in doses greater than 0.5 rem CED if no respiratory protection was used or if the respiratory protection failed,
- The bioassay result is expected to assist in ruling out or confirming whether significant intakes are occurring or have occurred (e.g., follow-up to a previous elevated or anomalous bioassay result or follow-up to anomalous workplace conditions such as low-to-moderate levels of surface contamination), or
- When the ES&H Team HP, worker or program needs results as soon as practicable (e.g., worker is terminating, response to worker concerns, or as part of operational closeout evaluations).

(c) Samples may be given Priority status in the following circumstances:

- Work during which air purifying respirators are relied upon as the primary intake control in posted or anticipated airborne radioactivity or high contamination areas,
- No significant intakes are expected to have occurred, but results are needed sooner than the typical turnaround time to meet needs such as operational hold points or reporting requirements, or
- The Internal Dosimetry Team needs expedited processing in order to assist in the assessment of a confirmed intake, but the result is not expected to have any direct effect on workplace operations.

There may be some circumstances in which the ES&H Team HP desires sample expediting criteria different from those listed above. Priority determinations less conservative than those listed above should be made with the concurrence of the Internal Dosimetry Team.

Particular attention should be paid to workplaces in which there is a technology shortfall for in vitro or in vivo bioassay monitoring (e.g., plutonium workplaces as discussed in Section 6.6 of this Manual). In such workplaces, routine bioassay monitoring alone cannot be relied on to detect low-level or even relatively significant intakes of radionuclides (e.g., intakes resulting in 0.1–0.5 rem CED). Comprehensive air sampling and surface contamination monitoring in conjunction with conservative result interpretation is the primary means for assessing the effectiveness of workplace controls. Thus, when unexpected or non-routine workplace contamination or control conditions exist, the ES&H Team HP may wish to accelerate the processing of routine or non-routine samples.

7.9.4 Mechanism for Requesting Expedited Bioassay Sample Processing

The formal mechanism for expediting bioassay sample processing is to specify the desired processing priority when the sample is logged into the STAR database by the H&S Technician. In addition, the ES&H Team HP or the H&S Technician should notify BLAB when delivering samples with Urgent or Rush status. If sample priorities need to be changed after STAR entry is already complete, the ES&H Team HP or H&S Technician should contact the Internal Dosimetry Team or BLAB for assistance.

7.10 MANAGEMENT OF RESULTS

7.10.1 Initial screening of Results

Upon completion of the measurement analysis, a preliminary screening of results is performed by the BLAB staff. Anomalous or unexpected results are evaluated and brought to the attention of the Internal Dosimetry staff as necessary. This informal notification may occur while the result is still considered "preliminary," that is, before the result is approved in BLIMS.

7.10.2 Comparison to Notification Levels

Preliminary measurement results are compared to analyte and exposure area-specific NLs by both BLAB staff and BLAB Quality Assurance (QA) staff. A final review of bioassay results and comparison to NLs is performed by the Bioassay or Whole Body Counter Team Lead, as appropriate. Default NLs are specified in Table 7.2 and Table 7.3, but the ES&H Team HP may specify different NLs in accordance with Section 6.7 of this Manual.

Table 7.2 Bioassay Laboratory default notification levels

Analyte	Analysis Method	Notification Level	Minimum Detectable Activity or Concentration
^{3}H	Liquid scintillation	0.01 µCi/L	0.01 µCi/L
^{238}U	ICP-MS	0.05 µg/L	0.0042 µg/L
^{235}U/^{238}U Ratio	ICP-MS	Sample-specific flag[3]	0.54 ng/L (^{238}U) 0.0092 ng/L (^{235}U)
^{237}Np	ICP-MS	L_C[4]	0.032 ng/L
^{238}Pu	Alpha spectroscopy	L_C	0.01 dpm/sample
$^{239+240}$Pu	Alpha spectroscopy	L_C	0.01 dpm/sample
^{242}Pu	Alpha spectroscopy	L_C	0.01 dpm/sample
^{241}Am	Alpha spectroscopy	L_C	0.02 dpm/sample
^{244}Cm	Alpha spectroscopy	L_C	0.02 dpm/sample
Gross Alpha (total)	Alpha spectroscopy	0.12 dpm/sample	0.01 dpm/sample
Gross Alpha (GA-1)[5]	Alpha spectroscopy	0.10 dpm/sample	0.01 dpm/sample
Gross Alpha (GA-3)[6]	Alpha spectroscopy	0.03 dpm/sample	0.01 dpm/sample
Gamma screening	Gamma spectroscopy	L_C	Varies

[3] Sample-specific flag for a ^{235}U/^{238}U ratio result considered statistically different from natural uranium.
[4] Interim NL, pending completion of urine background study for ^{237}Np by ICP-MS analysis (planned for end of Calendar Year 2015).
[5] GA-1 region of interest ranges from 3.9 MeV to 5.1 MeV and includes ^{232}Th, ^{228}U, ^{235}U, and ^{234}U.
[6] GA-3 region of interest ranges from 5.4 MeV to 6.1 MeV and includes ^{241}Am, ^{228}Th, ^{244}Cm, and ^{252}Cf.

Table 7.3 Whole Body Counting Laboratory default notification levels

Analyte	Count Type	Notification Level	Minimum Detectable Activity (nCi)[7]
^{57}Co	Lung	0.5 nCi	0.03
	Whole Body	5 nCi	1.2
^{60}Co	Whole Body	1 nCi	0.5
^{125}I	Thyroid	L_C	0.3
^{131}I	Thyroid	L_C	0.04
^{137}Cs (pure)	Whole Body	5 nCi	1
^{137}Cs (marker for inhalation of MI soil)	Whole Body	1 nCi	1
^{137}Cs (marker for ingestion of MI food)	Whole Body	5 nCi	1
^{234}Th	Lung	L_C	0.8
^{235}U	Lung	L_C	0.09
^{237}Np	Lung	L_C	0.4
^{238}Pu	Lung	L_C	140
^{239}Pu	Lung	L_C	215
^{242}Pu	Lung	L_C	200
^{241}Am	Lung	L_C	0.15
^{244}Cm	Lung	L_C	85

7.10.3 Notification and Reporting of Measurement Results

Anomalous results and any results exceeding NLs are reported to Internal Dosimetry by the processing laboratories. Specific procedures for recount, re-analysis, and reporting are documented by the laboratories.

7.10.4 Processing and Management of Elevated and Anomalous Measurement Results

An elevated or anomalous measurement result is evaluated by the Internal Dosimetry Team to determine whether it is indicative of a significant occupational intake of radionuclides. A bioassay investigation is initiated to track and document the evaluation. A preliminary internal dose analysis using standard assumptions is reported to the ES&H Team HP if the measurement results warrant follow-up. Upon completion of the investigation, the final disposition is entered in BLIMS for each associated measurement result and the investigation documentation is documented as part of the worker's personnel dosimetry file.

[7] MDAs listed for lung counting are based on an average chest wall thickness of 4 cm for the LLNL monitored population, since MDA and L_C for lung counting are greatly influenced by chest wall thickness (Hickman 2012).

7.11 DETECTION AND CONFIRMATION OF INTAKES

The process of detecting and confirming suspected occupational intakes of radionuclides is outlined below. The three main questions to be answered are:

(1) Is the bioassay measurement result real?
(2) Is the bioassay measurement result unexpected?
(3) Does the magnitude of the implied dose warrant any further action?

7.11.1 Bioassay Result Review

The first question above, *"Is the bioassay measurement result real?"* can be restated as: "Is the measurement result statistically different from a similar sample that did not contain any of the analyte?" Normally, this question is answered by comparing the measurement result with the analytical Decision Level (L_C) which is based on an appropriate reagent or measurement system blank (i.e., statistical hypothesis testing). It is important to note that L_C is set using an acceptable false positive rate (α); therefore, a small percentage of samples will be deemed greater than background when in fact they do not contain the analyte above background levels.

As a confirmation of results with significant dose implications, Internal Dosimetry requests recounts or re-analyses of the sample, reviews the quality control of the analytical batch (e.g., blanks within acceptable limits, no other potentially elevated samples in the batch), and reviews the possibility of cross-contamination from ASI laboratory processing.

7.11.2 Individual History Review

If the bioassay result review confirms the measurement result, the next issue is whether or not the result is expected due to the presence of radionuclides from previous intakes, medical administration of radionuclides, or the presence of environmental radionuclides such as natural uranium in the urine. In other words, *is the result unexpected?* A review of the individual's occupational exposure history, current medical status, and historical monitoring results should resolve whether or not the result is expected. This review is documented as part of the internal dose investigation.

7.11.3 Graded Approach Based on Estimated Dose

Finally, a measurement result may be above the analytical Decision Level and above a Notification Level, but may imply a dose that is too low to warrant further follow-up or assessment. For example, measurement of tritium in urine can readily detect intakes resulting in doses of fractions of a millirem. In most circumstances, further internal dosimetry follow-up, investigation, and assessment of such small doses is not warranted. However, such results may warrant a review of operations or work practices by the ES&H Team HP and program or facility management to assure that they are not indicators of other isotopes not as readily detectable, and that intakes of radioactive materials are being kept ALARA.

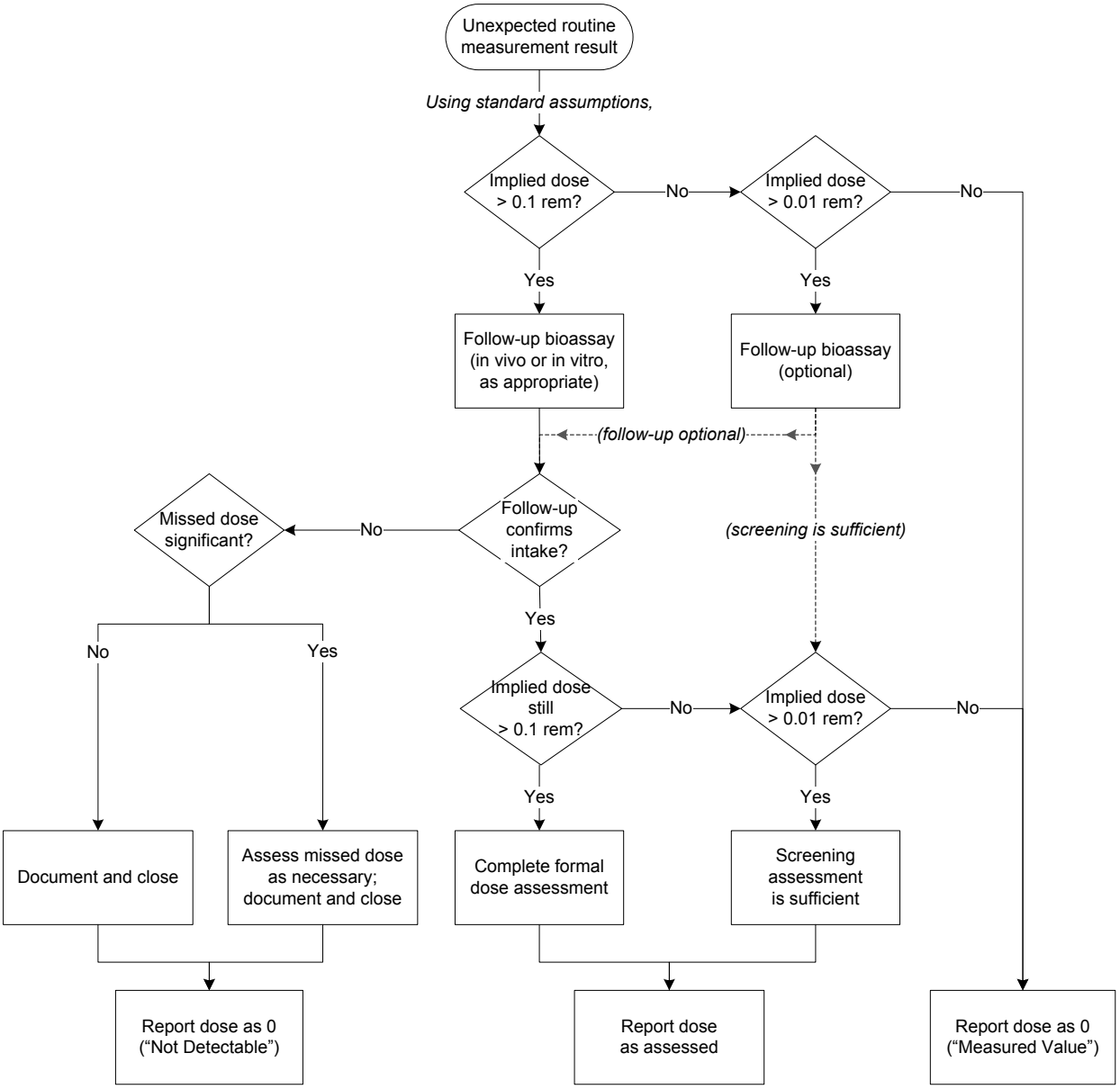
If the monitoring result is confirmed, unexpected, and dosimetrically significant, an appropriate follow-up investigation is conducted to confirm the potential intake, and if confirmed, to assess the internal dose. Follow-up internal dosimetry monitoring should be performed when routine individual monitoring or workplace conditions indicate an intake with the potential to result in a CED of 0.1 rem or more in a single year.

The follow-up investigation is a coordinated effort between the ES&H Team HP, Internal Dosimetry, program or facility management, Health Services (as necessary), and the worker. The first priority of such a follow-up investigation is to prevent any further intakes to the worker or coworkers similarly exposed. Follow-up investigations typically include:

- Review of the individual's recent work history for possible indications of intake (with particular attention paid to changes in materials, facilities, or operations),
- Review of area surface contamination and air sampling data,
- Review of past bioassay and in vivo counting results,
- Review of coworker monitoring results (as applicable), and
- An interview with the individual.

An evaluation of the magnitude of potential internal doses is made for all confirmed intakes, and the follow-up response is based on a graded approach as illustrated in Figure 7.1.

Figure 7.1 Graded approach to internal dose assessments



7.12 FOLLOW-UP MONITORING AND MANAGEMENT

7.12.1 Follow-up Monitoring

Appropriate follow-up monitoring is determined by Internal Dosimetry in conjunction with the ES&H Team HP. The rationale behind the recommended type of follow-up bioassay and associated schedule should be explained to the worker and the worker's supervision by the ES&H Team HP, with support from Internal Dosimetry as necessary.

7.12.2 Coordination with Health Services

In general, the Internal Dosimetry Team will notify, for informational purposes, the Health Services Physician of confirmed intakes that imply a CED greater than 0.5 rem. The Health Services Physician's level of involvement in case management and worker counseling will take a graded approach proportional to the magnitude of the estimated internal dose.

7.12.3 Medical Restrictions

If the magnitude of the internal dose monitoring result suggests that any of the dose limits of 10 CFR 835 may be approached or exceeded, Internal Dosimetry will recommend to the Radiological Control Manager that Health Services issue a medical restriction for the worker. The purpose of a medical restriction for radiation dose limiting purposes is to minimize the likelihood of DOE dose limits being exceeded. In order to provide formal documentation, dose limit-related medical restrictions are issued by Health Services through the medical restriction system, which is also used for Declared Pregnant Workers. Such medical restrictions are not related to injury or illness; they are issued simply as a dose management tool using an established mechanism.

The decision to issue a dose limit medical restriction will be carefully considered and made in consultation with program or facility management, the Radiological Control Manager, the ES&H Team HP, Internal Dosimetry, and Health Services staff. Factors to be considered in such a determination include:

- The magnitude of dose indicated by the bioassay result,
- The results of the work history review and workplace monitoring, and
- The judgment of the ES&H Team HP and Internal Dosimetry regarding the likelihood of the implied intake.

Further information on medical restrictions is detailed in ES&H Manual Document 10.1, *Occupational Medical Program*.

7.12.4 Radiological Work Restrictions for Bioassay Follow-up

In some circumstances, even if the magnitude of the internal dose monitoring result does not suggest that any dose limits of 10 CFR 835 may be approached or exceeded, it may be desirable to temporarily restrict the worker from further possible exposure to the radioactive materials involved. The purpose of such a "bioassay follow-up restriction" is to avoid even small additional intakes which could distort subsequent bioassay results and make interpretation of those results difficult or impossible. Such a radiological work restriction may be implemented, with concurrence from the ES&H Team HP and program or facility management, when there is the potential for a significant intake (e.g., > 0.1 rem CED), but it is not anticipated that the dose will approach or exceed a dose limit.

A radiological work restriction for bioassay follow-up may be warranted are if there is a need to discern a new intake from a previous intake's excretion, or if the intake date, source, and/or intake pathway is not known. Such restrictions may be recommended by Internal Dosimetry and will be coordinated with the ES&H Team HP and appropriate facility or program management. The reasons for the radiological work restriction should be explained to the worker.

Although such restrictions are less formal than medical restrictions described above in Section 7.12.3, notification and removal should be made in writing to both the worker and the supervisor. Internal Dosimetry issues and manages such restrictions.

7.12.5 Completion of Follow-up and Assessment

Upon completion of appropriate follow-up, Internal Dosimetry will prepare a dose assessment as described in Chapter 9. Removal of any work restrictions will be coordinated with the ES&H Team HP and Health Services.

7.13 COMPLIANCE MANAGEMENT

7.13.1 Tracking Compliance for Routine In Vitro Monitoring

Request notices for routine bioassay samples are emailed to workers at the beginning of each month using the BLIMS Scheduler function. If the sample has not been received by BLAB before the last week of the month, a reminder notice is emailed to the worker. If the sample has not been received by the first week of the following month, the sample is considered late and compliance is tracked and managed as described in Section 7.13.3.

7.13.2 Tracking Compliance for Routine In Vivo Counts

Request notices for routine in vivo counts are emailed to workers about a week prior to the month in which they are due. The worker is requested to call the WBC Laboratory directly at 2-3154 to schedule an appointment during the upcoming month. If a count is not completed within the month it is due, the count is considered late and compliance is tracked and managed as described in Section 7.13.3.

7.13.3 Compliance Criteria and Reporting

Missed measurements and significant delays in obtaining routinely scheduled bioassay measurements will affect the detection sensitivity of the internal dose monitoring program. For workers in the Required monitoring category, missed internal dosimetry measurements may even have Authorization Basis or Price-Anderson Amendment Act (PAAA) implications. Late monitoring for workers in the Required monitoring category will result in notifications to the worker's supervisor and assurance manager, and missed Required monitoring will result in radiological work restrictions until an appropriate bioassay sample or in vivo count is completed.

For Confirmatory and Discretionary monitoring, the Internal Dosimetry Team issues late notices to workers on a monthly basis. The ES&H Team HP also receives a copy of the first late notice. In the second month after a sample was due, the supervisor is also copied on the late notice. In the third month after a sample was due, the assurance manager is also notified.

Follow-up for missed samples is managed according to a graded approach based on monitoring category and monitoring frequency as outlined in Table 7.4.

Table 7.4 Follow-up for late and missed monitoring

	Schedule Frequency		
	Monthly or one-time	**Quarterly**	**Semiannual or annual**
Month after due month	Late notice: copy to HP.	Late notice: copy to HP.	Late notice: copy to HP.
Two months after due month	Missed notice: copies to HP and supervisor.	Second late notice: copies to HP and supervisor.	Second late notice: copies to HP and supervisor.
Three months after due month	Second missed notice: copies to HP, supervisor, and assurance manager. Open investigation for Confirmatory monitoring.	Missed notice: copies to HP, supervisor, and assurance manager.	Third late notice: copies to HP, supervisor, and assurance manager
Four months after due month		Open investigation for Confirmatory monitoring.	Missed monitoring: open investigation for Confirmatory monitoring.

Exemptions to this compliance management process are considered on a case-by-case basis and may be necessary in cases of extended leave or medical treatments involving radioisotopes that interfere with routine internal dose monitoring techniques.

7.14 MONITORING UPON CHANGE OF WORK ASSIGNMENT OR TERMINATION

The Internal Dosimetry Team may be notified of workers terminating or changing work assignments by either of two methods:

(1) If the employee or supervisor notifies the ES&H Team HP of an upcoming change in employment status, the ES&H Team HP should notify Internal Dosimetry to review the need for termination monitoring.
(2) The Internal Dosimetry Team is part of the Institutional Terminations, Transfers, Leaves (exIT) program and receives email notifications of employees who are terminating or changing work assignments. This system may be used for non-LLNL employees (such as contractor employees), but this is not always done. The Internal Dosimetry Team monitors these notifications only informally.

Termination (or "closeout") bioassay monitoring is required for workers in the Required monitoring category and is recommended for workers in the Confirmatory monitoring category. Normally, a worker who has been on a routine monitoring schedule should have a similar set of analyses made prior to termination. For example, if the worker was enrolled in both urine sampling and lung counts, both analyses would typically be requested for termination monitoring. However, Internal Dosimetry may review the worker's recent monitoring history to determine if a termination in vivo count may be waived as long as an appropriate bioassay sample is submitted.

If the worker is transferring to another work area with different exposure potential, appropriate termination (for the old job) and baseline (for the new job) measurements are necessary. In particular, Internal Dosimetry and the ES&H Team HP should carefully evaluate both the old and new exposure potentials for the worker to determine the monitoring category for new job, taking into account the year-to-date internal dose from the old job. If ongoing follow-up monitoring is in progress for a confirmed intake, that monitoring should be continued to the extent practicable.

If the worker is transferring from one organization to another (e.g., contractor employee changing to LLNL employee) but will have the same exposure potential, no action needs to be taken. The

BLIMS Scheduler system recognizes such situations and automatically updates the schedule with the worker's new employee number, once it is assigned by the institutional personnel database.

In addition to the Required and Confirmatory termination monitoring described above, termination monitoring may be provided upon the request of any terminating employee expressing concern regarding their potential internal exposure. Appropriate monitoring for such discretionary requests will be determined by Internal Dosimetry and the ES&H Team HP on a case-by-case basis.

7.15 REPORTING OF MONITORING RESULTS

Internal doses, including "zero" doses, are entered in the LLNL Radiation Exposure Monitoring System (REMS) dosimetry database and reporting system, which is managed by the External Dosimetry Team. Non-tritium internal doses are entered into REMS within 90 days of completion of the dose assessment. Tritium doses are calculated and transferred to REMS on a quarterly basis.

8. WORKPLACE MONITORING

In addition to the individual internal dose monitoring programs described in Chapters 6 and 7 of this Manual, area monitoring may be necessary in order to demonstrate compliance with the requirements of 10 CFR 835 and to assure effective detection of any significant intakes. Such workplace monitoring programs typically involve air sampling or monitoring and monitoring for contamination on surfaces and personnel.

8.1 REGULATORY REQUIREMENTS AND GUIDELINES FOR AIR MONITORING

10 CFR 835.403 states:

> (a) Monitoring of airborne radioactivity shall be performed:
> (1) Where an individual is likely to receive an exposure of 40 or more DAC-hours in a year; or
> (2) As necessary to characterize the airborne radioactivity hazard where respiratory protective devices for protection against airborne radionuclides have been prescribed.
> (b) Real-time air monitoring shall be performed as necessary to detect and provide warning of airborne radioactivity concentrations that warrant immediate action to terminate inhalation of airborne radioactive material.

LLNL requirements and guidelines regarding design, operation, and review of air sampling and monitoring programs are presented in ES&H Manual Document 20.2. Additional guidelines for ES&H Team HPs are provided in the applicable Health Physics Field Operations (HP-FO) Procedures and associated technical basis documents.

8.2 SUPPLEMENTING INDIVIDUAL MONITORING PROGRAMS IN THE CASE OF A TECHNOLOGY SHORTFALL

As discussed in Section 6.6 of this Manual, in some situations, practical individual monitoring programs may not provide the degree of sensitivity necessary to detect investigation-level intakes. In such cases, the RPP Guide recommends consideration of the following actions:

- Enhance contamination and air monitoring and the use of indicators (e.g., unexpected glove or surface contamination, increase in airborne radioactive material contamination) to trigger early special radiobioassay monitoring;
- Enhance personal contamination monitoring (e.g., clothing, skin, nasal smears) to trigger special radiobioassay monitoring;
- Use the best practicable radiobioassay monitoring methods;
- Implement enhanced design, operation, controls, and personal protection equipment and procedures to minimize intakes;
- Implement supplementary air monitoring; and
- Document and justify the planned supplementary approach in the facility's internal dosimetry technical basis documentation.

The intent of such supplemental workplace monitoring is to assure that intakes that could produce doses greater than 0.1 rem CED can be detected and confirmed. Accordingly, this target level of sensitivity should be used when designing a workplace monitoring program for that purpose.

8.3 PROGRAM NOTIFICATION LEVELS FOR WORKPLACE MONITORING

Workplace samples are analyzed by the Radiological Measurements Laboratory (RML) and results are provided directly to the ES&H Team HPs. Notification levels should be established for air and surface contamination monitoring programs. For air sampling, notification levels are typically set at some fraction of the DAC for the radioactive material in question. For surface contamination monitoring, notification levels are typically analogous to the contamination levels specified in Appendix D of ES&H Manual Document 20.2.

Conservative default LLNL site-wide notification levels for particular monitoring methods and analytes are provided in HP-FO-601, *Identification and Response to Unexpected Radiological Conditions* (LLNL 2015d), and are reproduced below for convenience. (If inconsistencies exist between the values below and the current version of the procedure, the procedure prevails.)

Table 8.1 RML default swipe notification levels

Analyte	Swipes (dpm/100 cm^2)
Gross Alpha	20
Gross Beta	200
Tritium	1000
C-14	200
P-32	200

Table 8.2 RML default air sample notification levels

Analyte	Air Concentration (µCi/cm^3)
Gross Alpha	1.0 E-13
Gross Beta	1.0 E-11
Tritium	1.0 E-06
C-14	1.0 E-06
P-32	1.0 E-06

9. ASSESSMENT OF INTERNAL DOSES

This Chapter presents general guidelines for assessment of internal doses. Detailed guidelines and methods are found in the ID TBM. The normal sequence of events in the internal dose assessment process is as follows:

(1) Recognition of possible intake,
(2) Follow-up investigation,
(3) Confirmation of intake,
(4) Follow-up measurements,
(5) Assessment of intake and doses,
(6) Review of assessment, and
(7) Recording and reporting of assessed doses.

Dose assessments are performed by the Internal Dosimetry Team. The Internal Dosimetry Team Lead has the primary responsibility for assuring the accuracy and appropriateness of internal dose assessments performed by the Internal Dosimetry Team. Follow-up investigation and assessment of intakes and doses will be coordinated with the appropriate ES&H Team HP.

9.1 REGULATORY REQUIREMENTS

Implicit in the requirement of 10 CFR 835.402(d) (*"Internal dose monitoring programs implemented to demonstrate compliance with § 835.402(c) [individual monitoring requirements] shall be adequate to demonstrate compliance with the dose limits established in subpart C of this part"*) is the need for accurate assessment of internal doses received. The minimum requirements for internal doses to be assessed are specified in 10 CFR 835.702(b):

> Recording of internal dose (committed effective dose or committed equivalent dose) is not required for any monitoring result estimated to correspond to an individual receiving less than 0.01 rem (0.1 mSv) committed effective dose. The bioassay or air monitoring result used to make the estimate shall be maintained in accordance with § 835.703(b) and the unrecorded internal dose estimated for any individual in a year shall not exceed the applicable monitoring threshold at § 835.402(c) [0.1 rem for radiological workers].

9.2 GUIDELINES FOR ASSESSMENTS

9.2.1 Confirmation of Intake

A potential intake may be considered confirmed in any of the following cases, with decreasing levels of confidence:

(1) A bioassay (in vivo or in vitro) measurement exceeds the notification level, corresponds to an occupational source term, and is associated with a known incident;
(2) A routine bioassay measurement exceeds the notification level, corresponds to an occupational source term, and is followed by another measurement also exceeding the notification level;
(3) A routine bioassay measurement exceeds the notification level, corresponds to an occupational source term, and an appropriate follow-up measurement is not obtained, *but there is reasonable potential that an intake may have occurred*; or
(4) A routine bioassay measurement exceeds the notification level and follow-up measurement results cannot definitively negate that an intake took place, *but there is reasonable potential that an intake may have occurred*.

In cases (3) and (4) above, if there is reasonable potential that an intake may have occurred, the conservative approach of calculating and recording an appropriate estimate of internal dose will be taken. Evidence that negates an intake (e.g., no workplace intake potential) or definitively reduces the implied intake potential will be considered and documented in the evaluation.

9.2.2 Scope and Detail of Internal Dose Assessments

Internal dose assessments can consume a great deal of time and measurement laboratory resources. Accordingly, a graded approach should be applied to the scope and depth of follow-up and assessment efforts, based on the anticipated magnitude of the doses.

Assessments of doses at levels below 0.1 rem CED may be abbreviated and may use standard models and model parameters without further justification. For assessments of doses greater than 0.1 rem, but significantly lower than the occupational limit of 5 rem CED, consideration should be given to using person-specific models and model parameters if available.

For assessments of doses that are expected to approach or exceed a DOE dose limit (i.e., 5 rem CED or 50 rem CEqD to any organ or tissue), person-specific models and model parameters should be used to the extent practicable in order to obtain the most accurate assessment of dose possible. These guidelines are summarized in Table 9.1.

Table 9.1 Graded approach for internal dose assessments

Estimated Dose (rem CED)	Dose Evaluation	Dose Record
< 0.01	A screening assessment using standard models and parameters is sufficient.	The estimated dose is not reported as the dose of record, but is tracked by Internal Dosimetry to ensure the requirements of 10 CFR 835.702(b) are met.
0.01–0.1	A screening assessment using standard models and parameters is sufficient, although more detailed calculations may be performed at the discretion of the Internal Dosimetry Team Lead.	The estimated dose is reported as the dose of record.
0.1–0.5	Formal dose assessment is performed. Person-specific biokinetic patterns may be utilized in the dose calculation.	The estimated dose is reported as the dose of record.
≥ 0.5	Formal dose assessment is performed. Person-specific biokinetic patterns are characterized and incorporated, as appropriate, into the dose calculation.	The estimated dose is reported as the dose of record.

9.2.3 Methods of Assessing Intake and Dose

The methods used to assess intakes and doses should be appropriate to the workplace conditions and materials, and should be consistent with DOE guidelines and the recommendations of the ICRP and NCRP. In most cases, the biokinetic models used will be those presented in the ID TBM. Alternative models, consistent with ICRP or NCRP recommendations, may be applied as deemed necessary by the Internal Dosimetry Team Lead.

The tissue weighting factors of 10 CFR 835, which are consistent with those of ICRP Publication 68, are used in calculating effective doses.

In accordance with 10 CFR 835.209(b), estimation of internal dose shall be based on bioassay data rather than air concentrations unless bioassay data are:

(1) Unavailable;
(2) Inadequate; or
(3) Internal dose estimates based on air concentration values are demonstrated to be as or more accurate.

9.2.4 Quality Assurance and Review

All formal internal dose assessments will receive a technical review prior to finalization. Normally, this technical review will be performed by one of the dosimetrists in the Internal Dosimetry Team. On occasion, this review may be performed by another health physicist with appropriate experience in internal dosimetry, as determined by the Internal Dosimetry Team Lead.

9.3 INFORMATION TO BE INCLUDED IN THE ASSESSMENT

To the extent practicable, each dose assessment should be a standalone document. Each assessment should contain sufficient information to allow an internal dosimetrist to reconstruct the estimation of intake and dose. References should be made to applicable assumptions, models, and methods of the ID TBM, specifying the version number and date.

9.3.1 Identifying Information

To the extent practicable, the following identifying information should be included in the dose assessment. The individual's complete dose record is managed by External Dosimetry and will include additional identifying information (see Chapter 12 of this Manual).

- Full name,
- LLNL employee number,
- Gender,
- Job title, and
- Exposure area, facility, or program.

9.3.2 Documentation of Intake Event

The circumstances leading to the intake and subsequent follow-up actions should be documented. If an incident or investigation report or critique was generated, that report should be referenced in the assessment. If practicable, a copy of the report should be included in the personnel dose file with the dose assessment.

9.3.3 Intake-Specific Information

Sufficient information must be included to characterize the intake and allow for dose verification and possible reassessment. All of the bioassay results used to estimate intake should be presented in the dose assessment. Specific note should be made of any bioassay results excluded from use. Use of any normalization factors should be clearly noted. Assumptions should be clearly distinguished from known or measured quantities.

Such information should include:

- The magnitude of the intake (in terms of activity or mass) for each radionuclide that contributes significantly (i.e., more than about 15%) to the total dose,
- The physical and chemical forms of each radionuclide involved,
- The known or assumed material solubility type (as applicable),
- Measured or assumed isotopic ratios,
- Known or assumed particle size distribution,
- The time course of the intake (e.g., acute vs. chronic; dates of intake)
- The routes of intake, and in the case of multiple routes, the assessed partitioning of the total intake through each route,
- All bioassay information pertinent to the evaluation and assessment of the intake,
- Any workplace monitoring information pertinent to the evaluation and assessment of the intake,
- Methods, models, and assumptions used to assess intake and dose, and
- The individual's previous exposure history (e.g., indication of previous intakes).

9.3.4 Dose Values to be Assessed

Dose assessments shall include the CED resulting from the intake. The associated committed equivalent doses will be recorded for any organ contributing more than 10% to a CED greater than 0.1 rem. In cases where a mixture of radionuclides is involved (e.g., weapons-grade plutonium), separate dose contributions should be assessed and listed for each radionuclide that contributes significantly (more than about 15%) to the total CED.

Dose assessment results shall be provided in terms of rem or millirem. Weighting factors used to convert equivalent dose to effective dose shall be those listed in 10 CFR 835.

9.3.5 Projected Future Results

In some circumstances, it may be desirable to project anticipated bioassay measurement values into the future, to allow for confirmation of the model fit to longer-term bioassay results, and to assist in determining the possible impact of long-term excretion on the sensitivity of subsequent monitoring.

9.4 OTHER CONSIDERATIONS

9.4.1 Time Frame of Dose Assessments

Although the magnitude of doses can usually be estimated within a relatively short time after an intake, an accurate final assessment of doses may take months or, in some cases, years. This is particularly true in the case of assessment of doses from intakes of transuranic elements with unknown intake dates, intake pathways, or other atypical intake conditions, where the process of follow-up measurement and assessment can be long and drawn-out. Further, this situation may be exacerbated by the difficulties involved in interpreting excretion of transuranic radionuclides following chelation therapy.

These unavoidable delays present a number of problems with respect to:

- The long time frame for follow-up sampling and measurements,
- The delay in providing final assessed dose values to the individual, and
- The delay in reporting final assessed dose values to DOE.

The impact of such delays can be mitigated somewhat by ensuring that, to the extent practicable, the anticipated time frame for follow-up and assessment is understood by the individual and LLNL management.

In the absence of complicating factors, final assessments should be available within six months of the intake recognition. An estimate of the timing of the final assessment will be provided within the first few weeks after the intake is confirmed and may be revised at a later date. As necessary, interim assessments of estimated doses should be provided by Internal Dosimetry to the individual and appropriate management. Such interim assessments should include the current best estimate of the doses and an estimate of the range of uncertainties associated with those dose values, and should be clearly labeled as preliminary with an "assessment as of" date.

9.4.2 Management of Dose Information

Information related to personnel dose assessments must be managed carefully in order to protect the privacy of the individual and to meet DOE and LLNL information reporting requirements. All personnel-related bioassay and dosimetry information will be protected in accordance with ES&H Memorandum ESH-RP-2012-037, *Controls for Reports Containing Personnel Monitoring Data or Doses* (reproduced as Appendix C).

9.4.3 Consultation with Other Internal Dosimetrists

Assessment of intakes and doses can be extremely complex, especially in the case of assessment of doses from intakes of transuranics. When necessary or desirable, Internal Dosimetry may consult with other recognized experts (e.g., within the DOE community) in order to take advantage of their specialized expertise and peer review. Such consultation is typically informal. However, as necessary, formal arrangements for such consultation will be made by RPFA.

Documents to be transmitted off-site must adhere to the LLNL Information Management (IM) Policy[1], which typically involves an IM review. In addition, it is a good practice to obtain the individual's consent before transmitting bioassay data off-site, even if such data will not include identifying information.

9.4.4 Review and Revision of Dose Assessments

In cases of significant intakes of long-retained, long-lived radionuclides (e.g., plutonium), it may be desirable to perform extended follow-up monitoring to determine whether the models used in the assessment accurately reflect the long-term clearance of material from the body. If a significant departure from the projected excretion pattern is observed, an evaluation should be performed to determine whether the assumptions and models used in the assessment should be revised.

Historical dose assessments are not routinely reevaluated or revised. However, if the need arises for such a reevaluation, guidance provided in RCTP 2004-01, *Guidance on the Revision of Internal Radiation Dose Estimates in Response to Updated Internal Dosimetry Methodologies* (DOE 2004), and its references will be followed.

[1] Available at https://im-int.llnl.gov/guides/html

10. INTERNAL DOSE MANAGEMENT

10.1 REGULATORY REQUIREMENTS

The primary objective of an internal dose monitoring program is to ensure that the occupational dose limits of 10 CFR 835.202 are not exceeded. Accordingly, internal dose monitoring and evaluation programs must be adequate to ascertain the internal dose status of workers and to assure and demonstrate compliance with the occupational dose limits.

10.2 SUMMATION OF INTERNAL AND EXTERNAL DOSE

The Total Effective Dose (TED) received during a calendar year shall be calculated by summing the effective dose from external exposures and the committed effective dose (CED) from any internal exposures. It is this TED value that is compared to the occupational limit of 5 rem for radiological workers.

The dose received by any organ or tissue during a calendar year is calculated by summing the equivalent dose received by that organ or tissue from any external exposures and the committed equivalent dose received by that organ or tissue from any internal exposures. This value is not given a specific name in 10 CFR 835, but is referred to as the Total Organ Equivalent Dose (TOED) in the LLNL Radiation Exposure Monitoring System (REMS) database and the Total Organ Dose (TOD) in the DOE Radiation Exposure Monitoring System. It is this value that is compared to the occupational limit of 50 rem for radiological workers.

10.3 MANAGEMENT OF DOSE FOR NEWLY HIRED OR TRANSFERRED EMPLOYEES

For new workers who fall under the Required monitoring category (i.e., they are likely to receive a committed effective dose of 0.1 rem from all occupational radionuclide intakes in a year), reasonable efforts shall be made to obtain complete records of prior years occupational internal and external doses before the worker begins work.

Internal Dosimetry, in conjunction with the ES&H Team HP, will determine whether or not baseline monitoring is necessary in accordance with Section 7.3 of this Manual. If deemed necessary, Internal Dosimetry and the ES&H Team HP may recommend to program or facility management that the employee be restricted from radiation work until their internal dose status can be accurately determined.

10.4 MANAGEMENT OF DOSE FROM PREVIOUS YEARS' INTAKES

The DOE occupational internal dose limits are based on committed (50-year) equivalent and effective dose values that are assigned to the year of intake. The intent of the occupational dose limits is to control the risk accrued, not the dose actually received, during a calendar year of occupational exposure.

In cases of long-retained radionuclides such as transuranics, the risk is assumed to be proportional to the total dose received, and that total dose is distributed throughout many years after the intake. The total risk from an internal intake is assumed to be best represented by the total dose received over a 50-year period after the intake, or the committed effective dose.

Once the committed effective and committed equivalent dose values have been assessed and assigned to the year of intake, they have no impact on dose limitations for that worker for subsequent years. The sole exception is in cases of dose exceeding the dose limits which would impact any Planned Special Exposures for that individual. Such a situation would be highly unlikely.

10.5 MANAGEMENT OF DOSE AFTER SUSPECTED INTAKE INCIDENTS

10.5.1 Medical Restrictions

After a suspected or confirmed intake of radioactive materials in a recognized incident, the affected worker should be restricted from further radiological work involving any internal or external radiation exposure until a preliminary assessment of intake is conducted. This early restriction is necessary until it can be determined with reasonable assurance that occupational dose limits will not be exceeded.

All workers who are identified as likely to have been exposed to internal contamination (see Section 11.3 of this Manual) should be included in this initial temporary restriction. Accordingly, such workers should not participate in immediate incident cleanup or recovery operations, unless imperative and overriding factors such as rescue or prevention of serious facility or programmatic damage exist. In most cases, the potential for a significant internal exposure approaching dose limits can be evaluated relatively quickly, typically within several hours. In such cases, no written restriction would be issued and the restriction may be verbally removed by the ES&H Team HP or Internal Dosimetry.

In cases where dose limits have been or are likely to be exceeded, a formal medical restriction will be issued in accordance with Section 7.12.3 of this Manual to minimize the likelihood that the worker will receive any further radiation dose from either internal or external exposures. The decision to issue a medical restriction will be carefully considered and made in consultation with program or facility management, the Radiological Control Manager, the ES&H Team HP, Internal Dosimetry, and Health Services staff. Factors to be considered in such a determination include:

- The magnitude of dose indicated by the bioassay result,
- The results of the work history review and workplace monitoring, and
- The judgment of the ES&H Team HP and Internal Dosimetry regarding the likelihood of the implied intake.

Further information on medical restrictions is detailed in ES&H Manual Document 10.1, *Occupational Medical Program*.

10.5.2 Concerns about Transfer of Internal Contamination

Internal contamination incidents are unusual in that the potential exists, in some circumstances, for internal contamination (and therefore dose) to be transferred from the affected worker to others. The mechanism for this transfer is chiefly through transfer of contaminated body fluids. The ES&H Team HP needs to be aware of such situations and should evaluate the potential for transfer of contamination presented by the circumstances of each situation. Accordingly, after an incident involving suspected or confirmed intakes of radioactive materials, the ES&H Team HP, in consultation with Internal Dosimetry, should evaluate the potential for:

- Transfer of contamination to an embryo or fetus,
- Direct irradiation (from the mother's internal contamination) of an embryo or fetus,
- Transfer of contamination (via nursing) to a child, and
- Transfer of contamination (via other body fluids) to others.

Perhaps the most common such situation would be the potential transfer of tritium-contaminated body fluids from a worker to others. Any body fluid would be expected to contain tritium at about the same concentration as that found in the worker's body water. Thus, a female worker with measureable levels of tritium in urine (and, by implication, in her body water) who is nursing a child would be transferring some quantity of activity to the child. In a similar manner, tritium-

contaminated sweat could be washed off in the household washing machine, thereby cross-contaminating other clothes.

Another similar situation may arise in the case of individuals receiving chelation therapy for significant intakes of transuranics (americium, plutonium, or curium). The package inserts for Ca-DTPA and Zn-DTPA state:

> In individuals with recent internal contamination with plutonium, americium, or curium, Ca-DTPA [or Zn-DTPA] treatment increases excretion of radioactivity in the urine. Appropriate safety measures should be taken to minimize contamination of others. When possible, a toilet should be used instead of a urinal, and it should be flushed several times after each use. Spilled urine or feces should be cleaned up completely and patients should wash their hands thoroughly. If blood or urine comes in contact with clothing or linens, they should be washed separately…. If patients are coughing, any expectorant should be disposed of carefully. Swallowing the expectorant should be avoided if possible…. Nursing mothers should take extra precaution in disposing of breast milk.

While such situations would rarely, if ever, result in the transfer of any significant doses, there is the potential for great concern or misunderstanding on the part of the worker and their family. Accordingly, such situations warrant evaluation to assure that significant dose transfer does not occur, and that the affected worker is informed of the potential (or lack thereof) for such dose transfer. Upon becoming aware of such a situation, the ES&H Team HP should consult with Internal Dosimetry for assistance in evaluating any dose transfer potential. The worker should be encouraged to consult with Health Services and Internal Dosimetry with any questions about such matters. Guidance documents such as ICRP Publication 95, *Doses to Infants from Ingestion of Radionuclides in Mothers' Milk* (ICRP 2004), may be used as necessary.

10.6 MANAGEMENT OF DOSE TO THE EMBRYO OR FETUS OF A DECLARED PREGNANT WORKER

10.6.1 Regulatory Requirements

10 CFR 835.206 requires:

> (a) The equivalent dose limit for the embryo/fetus from the period of conception to birth, as a result of occupational exposure of a declared pregnant worker, is 0.5 rem (0.005 Sv).
> (b) Substantial variation above a uniform exposure rate that would satisfy the limits provided in § 835.206(a) shall be avoided.
> (c) If the equivalent dose to the embryo/fetus is determined to have already exceeded 0.5 rem (0.005 Sv) by the time a worker declares her pregnancy, the declared pregnant worker shall not be assigned to tasks where additional occupational exposure is likely during the remaining gestation period.

10.6.2 Implementation at LLNL

Section 3.2.4 and Appendix C of ES&H Manual Document 20.1 provide detailed procedures for evaluation and control of doses to the embryo/fetus of a declared pregnant worker. Particular attention should be paid to situations involving more soluble radioactive materials such as tritium, iodine, and cesium. The nature of the potential radiological hazard, including possible routes of transfer of activity from the mother to the embryo/fetus, should be clearly presented to the declared pregnant worker.

Management of internal radiation doses to the embryo/fetus of a declared pregnant worker can present a number of challenges, not the least of which is interpretation of the regulations with respect to internal doses. The primary issue is the determination of the dose quantity to be compared to the 0.5 rem limit. The intent of the 0.5 rem limit and the implied 0.05 rem monthly

limit is to prevent the occurrence of deterministic effects in the embryo/fetus during particularly radiosensitive stages of the gestation period. Thus, the applicable dose quantity is the *equivalent dose* actually received *during the gestation period*, not the committed equivalent dose that would be received over an extended period of the child's lifetime.

Another issue is related to the nature of the equivalent dose to be calculated. In the relatively simple case of uniform irradiation of the embryo/fetus (e.g., from transferred tritium contamination, or perhaps ^{137}Cs contamination in the declared pregnant worker), the "effective" dose received by the embryo/fetus can be assumed to be the same as the equivalent dose, since these nuclides are assumed to distribute uniformly throughout the embryo/fetus.

This may not be the case if the radionuclides transferred are distributed non-uniformly within the body of the embryo/fetus (e.g., with nuclides such as ^{131}I or ^{90}Sr). Estimates of intakes and doses in such cases are not straightforward and must be dealt with on a case-by-case basis by Internal Dosimetry. However, as a first approximation, an "effective" dose may be used to evaluate the magnitude of the appropriate dose quantity to be compared to the limit of 0.5 rem equivalent dose to the embryo/fetus.

Because of these issues, it is recommended that any potential for internal exposure by declared pregnant workers be minimized to the extent practicable. Further guidance for estimation of doses to the embryo/fetus may be found in ICRP Publication 88, *Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother* (ICRP 2001).

11. RESPONSE TO INTERNAL CONTAMINATION INCIDENTS

The response to an incident involving potential intakes of radioactive material will vary depending on the nature of the potential hazards and the magnitude of the suspected intakes. In general, the response will fall into the following categories:

(1) Immediate incident response,
(2) Initial ES&H Team response,
(3) Health Services response, as necessary,
(4) Internal Dosimetry response and assessment, and
(5) Administrative follow-up and notifications.

The following general guidelines should be used by the ES&H Team HP and the H&S Technician responding to such incidents. Detailed H&S Technician response information is included in the Radiological Control Technician (RCT) qualification program.

11.1 RECOGNITION OF POSSIBLE INTAKES

It is essential that possible intakes of radioactive materials be recognized so confirmation and prompt follow-up actions may be taken. **Although significant intakes are often preceded or accompanied by obvious workplace indications, occasionally the indications of possible intakes are more subtle.** Workers must report any suspected intake of radioactive materials, however minor, to the appropriate H&S Technician or HP. H&S Technicians and HPs should be aware of indicators of possible intakes, including:

- Continuous air monitor (CAM) alarms (see HP-DAP Instruction #HP-17 and HP-FO-600, both titled *CAM Alarm Response*),
- Removable contamination discovered on personnel or work surfaces,
- Breaks in the skin that occur while working with radioactive materials,
- Skin contact with solutions containing radioactive materials,
- Ventilation system failures or upsets,
- Fires, explosions, or other energetic events that could disperse radioactive materials,
- Difficulties with respiratory protection equipment while working in contaminated areas,
- Contamination observed on the inside of respirators after use, or
- Skin contamination observed on or near the face and head.

If any of these indicators are observed, the first person at the scene should notify the appropriate H&S Technician immediately. The H&S Technician or the HP should notify Internal Dosimetry as soon as possible.

In general, a conservative approach should be used in evaluating the circumstances of possible intakes of radioactive materials. Follow-up should be performed for any indication of a possible intake.

11.2 IMMEDIATE INCIDENT RESPONSE

In an accident or incident resulting in potential intakes of radioactive materials, the first priority is to assure the physical safety of the people involved by administering first aid as necessary and preventing further injury. The priorities for immediate incident response are to:

(1) Notify emergency response personnel as necessary (dial 911 or 2-7595 from an LLNL phone or (925) 447-6880 from a cell phone),
(2) Give life support and first aid as necessary,
(3) Prevent further injuries, intakes, and contamination to personnel,
(4) Request additional ES&H Team assistance as necessary, and
(5) Stabilize the scene of the incident.

NOTE

Concerns about radiological contamination never take precedence over life-saving or basic life-support measures.

Although reasonable contamination control procedures should be followed if time permits, such procedures and concerns should not be allowed to delay urgent medical care. Good health physics judgment must be exercised when considering the possible trade-off between contamination control measures and their possible negative impacts on medical care.

11.3 INITIAL HEALTH PHYSICS RESPONSE

In general, the priorities of the Health Physicist on the scene should be to:

(1) Assure appropriate care for injured and contaminated people,
(2) Prevent further exposures,
(3) Request assistance, as described below,
(4) Identify and detain (as necessary) personnel involved,
(5) Make appropriate notifications,
(6) Collect information to assist with assessment of intakes,
(7) Assess the magnitude of the intake and resulting doses, and
(8) Preserve the incident scene.

11.3.1 Prioritization and Segregation of Health Physics Response Tasks

The multitude of tasks and responsibilities involved in responding to and following up on significant contamination incidents can be overwhelming. Additional Health Physics support, if necessary, should be requested as soon as possible, and the responsibility for these tasks should be divided into the following areas:

(1) On-scene recovery, access, and contamination control,
(2) Internal dose care and follow-up for injured or contaminated people, and
(3) Access and contamination control at Health Services (or off-site medical facility).

The following segregation and assignment of tasks is suggested:

The **ES&H Team Health Physicist** is responsible for providing health physics coverage at the incident scene, including:

- Establishing access and contamination control points, as appropriate,
- Requesting additional HP and ES&H Technician assistance on-scene,
- Notifying Internal Dosimetry and Health Services,
- Identifying all potentially exposed personnel,
- Performing initial characterization of radioactive materials involved,
- Obtaining and providing information to Internal Dosimetry and Health Services regarding the circumstances of the intake, and
- Notifying and coordinating with the ES&H Team Leader and program or facility management.

The **Internal Dosimetry Team** is responsible for:

- Notifying the necessary ASI laboratories,
- Notifying Health Services, even if the ES&H Team HP may already have done so,
- Notifying the ES&H Team HP assigned to the Health Services building (B663),
- Providing guidance to Health Services or hospital staff regarding care and treatment of contaminated individuals,
- Advocating for the patient and ensuring necessary medical treatment is not impeded because of radiological concerns,
- Assuring appropriate internal dosimetry follow-up of contaminated individuals, and
- Providing information to the ES&H Team HP, Health Services, and ES&H management regarding estimates of possible intakes and doses.

The **ES&H Team HP assigned to the Health Services building** is responsible for:

- Coordinating the radiological aspects of the Health Services response,
- Assuring access and contamination control at Health Services (or the off-site hospital),
- Assisting (as necessary) in evaluating the contamination status of the patients,
- Providing guidance to responding Health Services staff regarding appropriate PPE and procedures,
- Requesting additional H&S Technician support at Health Services as necessary, and
- In consultation with the ES&H Team Environmental Analyst, providing guidance for handling and management of contaminated medical waste.

The recommended scheme above is intended as a general guideline. The circumstances and magnitude of the incident and availability of personnel will play a major role in the assignment and division of these tasks.

11.3.2 Prevention of Further Exposures

The ES&H Team HP and H&S Technician should minimize or prevent additional internal exposures by:

(1) Evacuating the area as necessary,
(2) Restricting access to contaminated areas,
(3) Assuring appropriate contamination control, and
(4) Assuring adequate and appropriate ventilation control.

No re-entry into the affected room or area should be made (unless for rescue purposes) until the scene is sufficiently stabilized and the radiological conditions within the affected area are adequately assessed. Personnel should remain as far away and upwind of any potential airborne contamination as practicable.

Ventilation control of the incident scene should be evaluated to assure that contamination is not being inadvertently transferred to occupied areas inside or outside of the facility. In some circumstances, it may be desirable to deactivate the ventilation system or modify the airflow patterns. Any such ventilation system changes must be coordinated with appropriate Facility Management personnel.

Initial re-entry efforts should be made cautiously, with adequate personal protective equipment to deal with expected “worst case” conditions. Efforts to decontaminate the room or area should be deferred until adequate incident and dosimetry assessment and follow-up have been completed.

11.3.3 Requesting and Managing Additional Assistance

As soon as possible, the ES&H Team HP on the scene should request as much additional HP and H&S Technician assistance as he or she thinks necessary. The number of additional personnel needed depends on the circumstances of the incident, but in general, it is far better to have too much assistance than too little.

To the extent practicable, each on-scene ES&H responder should be assigned a specific task or area of responsibility. For example, one person might be in charge of the "hot line," while another person would be in charge of identifying and surveying contaminated individuals.

NOTE

Any time a contaminated or potentially contaminated individual is sent to a medical facility (either on-site or off-site), an ES&H Team H&S Technician or HP should accompany or meet that person at the medical facility to provide assistance.

In a major accident, one HP should remain somewhat "detached" from the hands-on response to provide health physics oversight and management of the entire event.

11.3.4 Identification of Affected Personnel

In any accident involving actual or potential internal contamination, it is extremely important to identify workers or bystanders who may have been exposed. Such personnel include:

- Any people in the affected room or area,
- Any people who were in the affected room or area who might have been exposed before the incident was recognized,
- All people who entered the room or area as part of the accident response,
- All emergency response personnel (including ES&H personnel),
- People who may have been "downwind" of airborne contamination (either inside or outside the facility),
- People who may have come into contact with equipment or material contaminated during the event (e.g., Health Services personnel), and
- Any security staff who may have been in or near the area.

Identification of these individuals should include the person's full name, employee identification number, lab phone, and lab (or contractor) supervisor's name. All personnel who may have been exposed during the incident or response to the incident should be detained, unless prompt medical treatment is necessary, until appropriate sampling, measurements, and information gathering can be completed. Normally, release of these personnel should be cleared through the ES&H Team HP.

If practicable, emergency response personnel (e.g., firefighters) who were involved in transporting contaminated or potentially contaminated patients to Health Services or other medical facilities should be released to return to duty only after evaluation (and contamination survey, if necessary) by the HP responsible for on-scene contamination control at Health Services.

The ES&H Team HP should assure, to the extent practicable, that people who may have been involved in the incident and who may have been exposed (or who may *believe* they have been exposed) are briefed with respect to the nature of the incident and their potential for exposure.

11.3.5 Notifications

As soon as possible, the following entities should be notified, as necessary, regarding the potential internal contamination incident:

- Health Services,
- The Radiological Control Manager,
- The appropriate ES&H Team Leader,
- Internal Dosimetry, and
- Appropriate program or facility management.

Typically, the ES&H Team HP notifies the ES&H Team Leader, Internal Dosimetry, and program or facility management. Internal Dosimetry typically notifies Health Services and the Radiological Control Manager.

11.3.6 Incident Response During Off-Shift Hours

Response to incidents or accidents that occur during off-shift hours (i.e., nights, weekends, and holidays) is managed by the on-site Alameda County Fire Department. In the event of a serious accident or injury, the Alameda County Regional Emergency Communication Center (ACRECC, historically called "Fire Dispatch") should be immediately contacted by dialing 911 or 2-7595 from an LLNL phone or by calling (925) 447-6880 from a cell phone.

ACRECC will respond with appropriate resources and coordinate necessary communications, depending upon the circumstances and severity of the incident. Typically, in any event involving contamination or exposure to radiation, the ES&H Team HP would be notified. If significant injury has occurred, or medical intervention appears warranted, the responding HP should request that ACRECC notify a Health Services physician.

During off-shift hours, patients who are injured and contaminated will be transported to one of the medical facilities with which LLNL maintains a Memorandum of Understanding (MOU): ValleyCare Medical Center in Pleasanton, Eden Medical Center in Castro Valley, or Sutter Tracy Community Hospital in Tracy.

If a contaminated injured worker is transported to an off-site medical facility, it is important that LLNL provide ES&H Team HP and H&S Technician support to that facility as soon as possible. If practicable, an H&S Technician should accompany the patient to the medical facility. As soon as possible, ACRECC should contact appropriate ES&H resources (e.g., the ES&H Team HP and Internal Dosimetry staff) to alert them of the response. Similarly, ACRECC should notify the LLNL Health Services Department of the transport.

11.3.7 Health Physics Response at Health Services

To the extent practicable, health physics support to Health Services (or to off-site medical facilities) should be segregated as described above in Section 11.3.1. The number of Health Physics, Internal Dosimetry, and H&S Technician personnel present in the treatment room should be kept to a minimum to avoid impacting medical operations and to preserve the patient's privacy. Non-essential personnel (e.g., program or facility management) should be kept out of the treatment area.

11.4 PROMPT MONITORING AND INFORMATION NEEDS

11.4.1 General Guidelines

Once the scene has been stabilized and the affected individuals identified and treated, the next priority for the responding HP is to obtain information that may be necessary to assess the

magnitude of possible intakes and resulting doses. In order to assess the severity of the intake, the following information is necessary:

- The radionuclides involved,
- The quantities and concentrations of radioactive material involved,
- The physical and chemical forms of the material,
- The nature of the operations being performed at the time of the incident,
- The circumstances of the incident, and
- Suspected and possible routes of intake.

The HP should obtain any information that might bear on the magnitude of the intake and the nature of the radioactive materials involved. Such information may include:

- Nasal swabs (in cases of suspected inhalation),
- Head, facial, neck, and hair contamination levels,
- Contamination levels observed at the workplace,
- Contamination levels on the outside and inside of respirators (if worn),
- Contamination levels around wounds and associated bandages (in cases of suspected wound intakes),
- Air sampler filters,
- CAM alarm results, and
- Any delay in recognition of a contaminated work environment.

11.4.2 Identification of Radionuclides Involved

One of the first actions should be to identify or confirm the radionuclide, or mix of radionuclides, involved in the incident. This information is necessary to assure the appropriate analyses and measurements are performed. Radionuclide information may be available from:

- On-scene program or facility personnel,
- The ES&H Team HP,
- The H&S Technician, or
- On-scene samples such as contamination swipes, air monitoring and sampling filters, or nasal swabs.

If practicable, information or assumptions about the nature of the material should be verified by direct measurement of on-scene samples. Such verification may include gamma scans or rapid alpha spectroscopy analyses of swipe or filter samples.

11.4.3 General Guidelines for Suspected Inhalation Intakes

Perform personnel surveys of affected personnel to determine the degree and extent of contamination. Particular attention should be paid to the face, mouth, nose, head/hair, hands, forearms, and front torso of the individual. Record the results of these surveys on an appropriate personnel survey form (e.g., the HP-FO-120 Survey Form, LLNL 2015c).

Nasal swabs (also called “nasal smears,” “nasal swipes,” or “nose swabs”) taken from the anterior nasal passages of each nostril may provide an indication of the quantity of radioactivity inhaled. Nasal swabs should be collected as soon as possible from all potentially exposed personnel (e.g., if contamination is identified on the face, neck area, or on respirator inner surfaces, or if airborne radioactivity is suspected). Table 11.1 provides default guidelines for collection of nasal swabs in the absence of documented facility-specific criteria.

Instructions for obtaining nasal swabs are contained in standard “nasal swab kits” issued to selected facilities and available from Internal Dosimetry. Nasal swab results can be affected by

many factors (e.g., time delays between the intake and collection of nasal swabs greater than about 30 minutes, nose blowing, sniffling, showering, or mouth-breathing), and any of these circumstances should be noted.

It is imperative to understand that while significant activity detected on nasal swabs *may* indicate that an inhalation intake occurred, **the absence of significant activity on nasal swabs is not definitive evidence that an intake did not occur**.

The possibility of an ingestion intake, either instead of or in addition to the suspected inhalation intake, should also be reviewed. Much of the activity from an ingestion intake would be expected to be excreted in the feces. If the fecal activity were interpreted as resulting solely from inhalation, the estimate of intake would be erroneously high.

Table 11.1 General guidelines for collection of nasal swabs in plutonium facilities

Location of Contamination or Condition	Level[1] (cpm α)	Comments
Personnel or PPE Contamination		
Above the shoulders (face, head, neck, hair)	> background	
Between shoulders and hips (lab coat sleeves, coveralls, pockets, PPE gloves, hands)	> 1,000	If found quickly[2]
Below hips (lab coat below pockets, pants, shoe covers, booties, shoes)	> 10,000	If found quickly[2]
Personnel contamination detected more than 10 minutes after completion of work	> 500	Includes lab coat, clothing, gloves, hands, etc.
Personnel contamination involving "americium-poor" mixtures of Pu or high specific activity materials (^{238}Pu)	> 500	Includes lab coat, clothing, gloves, hands, etc.
Inside respirator after use	> background	
Workplace Contamination or Other Conditions		
Area – General (large area, widespread, or general surface contamination)	> 1,000	If found quickly[2]
Area – Spotty (small area, localized or spotty surface contamination)	> 10,000	If found quickly[2]
CAM alarm (non-radon)		Get swabs from anyone in room at time of alarm
Glovebox overpressure		As determined by HP
Breach in glovebox containment		As determined by HP

[1] Counts per minute above background as measured by "blue alpha" survey instrument; assumes 50% dpm/cpm calibration factor.

[2] A delay in recognition of a contamination event may significantly increase the likelihood of intakes. Accordingly, a given level of contamination discovered hours or days after the event may be much more significant than the same level of contamination discovered immediately after the event. A lower threshold may be appropriate if there has been a significant delay between the event and its recognition.

If respirators were worn, carefully take separate swipe surveys of both the outside and the inside of the respirator. Label all swipes and document the identity of the respirators and cartridges (who wore which respirator).

Perform work area surveys to determine the degree and extent of area contamination, but surface contamination may not be representative of the inhaled activity. For example, the radioactivity on a swipe of pre-existing contamination may have little to do with the contamination that may have been inhaled.

In cases of delayed discovery of personnel or area contamination, it is important to determine how long the people were working in the contaminated environment before they discovered the contamination. As appropriate and practicable, filters from area CAMs or passive air samples should be collected and counted as soon as possible.

In cases where a more easily-detectable radionuclide is used as a marker for the presence of a less readily-detectable radionuclide (e.g., ^{241}Am for plutonium mixes), it is critically important to obtain as much information as possible about the actual or assumed activity ratios. If practicable, samples of the actual contamination should be obtained and submitted for rush analysis to determine the activity ratio. Any other workplace information that would confirm such activity ratios should also be sought.

11.4.4 General Guidelines for Contaminated Wounds or Breaks in the Skin

Appropriate medical management of contaminated wounds should be the first priority in all cases. Severe trauma should prompt immediate transport to the hospital, and in other cases, the first priority is to establish hemostasis (stopping any blood loss). Simple contamination control measures may be taken, but only if they do not delay required medical treatment. In most cases, personal protective equipment used for standard or universal precautions is sufficient to control the spread of radioactive contamination. Once the patient is stabilized, attention may be directed toward the radiological aspects of the wound.

Contaminated wounds can usually be segregated into one of two categories:

- Wounds involving plutonium, americium, curium, or other transuranics which are potentially radiologically serious, or
- Wounds involving uranium, tritium, or almost any other radioactive materials which are seldom radiologically serious.

Normally, efforts should be made to clean the wound and remove any material or contamination that may be imbedded in the wound. Any solids or fragments removed from the wound should be retained for later analysis. If practicable, fluids used to rinse the wound should be collected for appropriate disposal.

To the extent practicable, identify and retain the object or surface that caused the wound. Assess the possibility for contaminated debris to be embedded in the wound. If possible, obtain a contamination swipe from the object or surface that caused the wounds. Interview appropriate program or facility personnel to determine the nature of the radioactive material expected to be present on the object in question.

CAUTION

If the object or surface has sharp edges or points, exercise great care to avoid being injured while obtaining the swipe sample.

CAUTION

Shards or pieces of highly radioactive beta-gamma sources (e.g., ^{137}Cs) may emit intense local radiation fields. If such a beta-gamma source is possible, the wound site and the rest of the body should be surveyed prior to proceeding.

DO NOT manually handle any shards or pieces of such material.

Use remote tools (e.g., forceps) to handle any such material.

11.5 INTERACTION WITH HEALTH SERVICES

11.5.1 Notification

Effective communication with Health Services is important in cases of contaminated injured individuals and/or potential internal contamination. Depending on the circumstances, the on-scene ES&H Team HP may notify Health Services or request that Health Services be notified by Internal Dosimetry. Notification should be made initially to the Treatment Area Coordinator (2-7459) and then to the clinician who is currently on duty. The checklist in Figure 11.1 on the following page may be used to assure that Health Services is provided with the necessary information to respond appropriately to the incident.

Health Services must be notified promptly if any of the following conditions exist:

- Any time a contaminated or potentially contaminated person is being transported to Health Services or off-site for treatment,
- Any wound, burn, or break in the skin that is potentially contaminated with plutonium or another transuranic element, or
- Preliminary indications of an intake of radioactive materials that could result in a CED in excess of 2 rem or a committed equivalent dose to an organ in excess of 20 rem.

11.5.2 Internal Dosimetry and Health Physics Support to Health Services

In the event of significant or serious internal contamination events, an internal dosimetrist or health physicist with internal dosimetry experience should report to Health Services to provide guidance to Health Services staff as part of the treatment team. This dosimetrist or health physicist will assist Health Services staff in acquiring information needed for treatment decisions, interpreting radiological measurements, and assessing whether medical intervention should be recommended to the patient.

One of the most important duties of the HP and Internal Dosimetrist is to help medical staff put the radiological aspects of the incident into perspective. **Do not assume that the medical staff is familiar with the radiological aspects of the incident.** Be sure to review available information with them (e.g., what radioactive material is involved, types of radiation emitted, suspected routes of intake, and other radiological concerns). Let the attending medical staff know what *your* perspective is on the potential seriousness of the intake (e.g., "trivial," "may just warrant follow-up bioassay," "may be serious enough to consider medical intervention," etc.).

Figure 11.1 Information checklist for notification of Internal Dosimetry and Health Services of suspected internal contamination incidents

General Information:

- ☐ Caller's name and identification (e.g., Team 2 Health Physicist)
- ☐ Nature of incident (spill, release, fire, etc.)
- ☐ Location of incident (Building, Room)
- ☐ Nature of contamination (internal, external, both?)
- ☐ Number of people involved
- ☐ Names and ID numbers of people involved
- ☐ Number of people being transported to Health Services
- ☐ Caller's phone number (for call-backs)

Status and Condition of Affected Persons:

- ☐ Medical condition (wounds, consciousness, etc.)
- ☐ Radiological condition (externally contaminated? clean? showered? deconned?)
- ☐ Is person being transported to Decon Facility at Health Services?
- ☐ Has lung count or wound count been performed?

Nature of Suspected Intake:

- ☐ Inhalation
- ☐ Wound (specify: cut, abrasion, puncture, burn, etc.)
- ☐ Absorption through skin?
- ☐ Skin contamination only?
- ☐ Ingestion

Materials Involved:

- ☐ Radionuclides, isotopic ratios
- ☐ Type of radiation emitted (alpha, beta, gamma, mixed)
- ☐ Quantities and concentrations involved
- ☐ Physical and chemical forms
- ☐ Concomitant exposure to non-radioactive chemicals or toxins

Indications of Intake and Samples Taken:

- ☐ CAM alarm?
- ☐ Nasal/facial/body contamination? (specify location and levels)
- ☐ Area contamination? (specify location and levels)

Health Physics Recommendations:

- ☐ Treat affected person(s) in Decon Facility?
- ☐ What anti-C precautions should medical responders use (anti-Cs, respirators)?
- ☐ Should affected person(s) shower at Decon Facility?
- ☐ Prepare for possible chelation or excision?
- ☐ Stand by for results of wound count, lung count, nose swabs?

11.6 OVERVIEW OF MEDICAL INTERVENTION

11.6.1 General Guidelines for Medical Intervention

In cases of suspected or confirmed serious intakes of some radioactive materials (e.g., transuranics), medical intervention may be warranted. The intent of such intervention is to prevent the uptake of radioactive materials by the body, or to enhance the excretion of radioactive materials from the body, thereby reducing the retention time and the dose received. Such intervention may include administration of chelating or blocking agents, enhancing excretion of radioactive materials from the body by increased fluid intake, or physical intervention such as excision of contaminated wound tissue.

Once radioactive materials cross cell membranes, they are said to be incorporated. Incorporation is a time-dependent physiological phenomenon related to both the physical and chemical natures of the contaminant. Incorporation can be quite rapid, occurring in minutes, or it can take days to months. Thus, time can be critical and prevention of uptake is urgent. The Health Services physician managing treatment should consider consultation with the Radiation Emergency Assistance Center/Training Site (REAC/TS) depending on individual case specifics before initiating a treatment plan. Expert guidance is available from REAC/TS through the 24-hour emergency number, (865) 576-1005 (ask for REAC/TS).

Guidelines for medical intervention are specific to each type of radioactive material. Specific intervention methods for plutonium and other transuranics, uranium, and tritium are presented in this Manual. Guidelines for radioactive materials not covered in this Manual may be found in the ID TBM or in NCRP Report No. 161, *Management of Persons Contaminated with Radionuclides: Handbook* (NCRP 2008).

There are risks associated with medical intervention, and there are also risks associated with the decision not to accept such intervention. LLNL's goal is to provide the highest standard of care in the event of intakes of radionuclides. Decisions regarding possible medical intervention or treatment must balance the risks associated with projected internal doses and any risks that may be associated with medical intervention for the purpose of dose reduction. The decision to use any medical intervention must be a joint decision between **the patient and the Health Services physician**. Internal dosimetry is responsible for providing guidance about the dose reductions that might be achieved by medical intervention.

Most of the guidelines below are directed at intakes of plutonium or other transuranic materials. Intakes of other radioactive materials present at LLNL are far less likely to produce doses that warrant medical intervention.

The ES&H Team HP should review each facility or operation to evaluate the possibility of serious accidental intakes of radioactive materials. If such intakes are evaluated to be credible, the ES&H Team HP should review the appropriate intervention guidelines presented in the ID TBM and ensure that facility or program management and the workers are aware of those guidelines.

Workers who are at risk for accidental intakes that may warrant medical intervention should receive training and information about the treatments that may be recommended in the event of serious intakes. Such pre-incident training is essential in allowing the worker to make an informed decision regarding such treatment.

11.6.2 Recommended Dose Thresholds for Medical Interventions

The decision to use any medical intervention must be a joint decision between **the patient and the Health Services physician**. Internal Dosimetry is responsible for providing guidance to both the patient and to the Health Services physician about the dose reductions that might be achieved by medical intervention.

Table 11.2 summarizes reference intervention levels used at LLNL. The bases for these reference intervention levels are the guidelines set forth in the CEC/DOE *Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers* (CEC/DOE 1992). These intervention levels are slightly more conservative than, but generally consistent with, the 25 rem CED value used as a basis for the Clinical Decision Guides of NCRP Report No. 161 (NCRP 2008).

This table predicts *additional* risk of fatal cancer due to radiation doses above those to an unexposed population. The lifetime risk of fatal cancer for an unexposed population is about one in five.

Table 11.2 Reference intervention levels

Estimated Dose Range Based on Early Information (rem CED)	Approximate Risk of Fatal Cancer[3]	Intervention
≥ 20	≥ 1 in 100	Recommended
≥ 2 but < 20	≥ 1 in 1000 but < 1 in 100	Should be considered[4]
< 2	< 1 in 1000	Probably not warranted

This relatively low 2-rem threshold for consideration of intervention is based on the assumption that there may be great uncertainties (e.g., factors of 10 or more) associated with the early estimates of dose, and that risks associated with most medical interventions are minimal. The intent of medical intervention is to minimize risks associated with possible *significant* radiation doses, and the 2-rem guideline for consideration of intervention has not been selected merely to remain below an administrative or regulatory dose limit.

Dose limits are established to represent acceptable levels of risk that may be incurred during continual occupational exposure to radiation, year after year. Since significant intakes are unplanned rare events, the fact that a dose from such an intake might slightly exceed a dose limit is not sufficient justification, in and of itself, to warrant medical intervention.

11.6.3 Chelation Therapy for Transuranics

Chelating agents are drugs that bind to transuranic elements (e.g., plutonium, americium, curium, berkelium, and californium) in the bloodstream and enhance the body's ability to excrete these elements via the urine. The chelating agents currently recommended for use with plutonium, americium, and curium are pentetate calcium trisodium and pentetate zinc trisodium, also known as trisodium calcium and trisodium zinc diethylenetriaminepentaacetate (Ca-DTPA and Zn-DTPA). The drug effectively exchanges calcium or zinc for the plutonium, americium, or curium and carries it to the kidneys where it is excreted into the urine (NCRP 2008).

DTPA is approved by the Food and Drug Administration (FDA) for treatment of individuals with *known or suspected* internal depositions of plutonium, americium, or curium to increase the rates of elimination (NCRP 2008). By inference, it is assumed that DTPA may be effective for intakes of other transuranic elements, but use of DTPA for indications other than plutonium, americium, or curium intakes must be considered "off-label" (NCRP 2008). **DTPA may not be effective for neptunium and is <u>contraindicated</u> (should not be used) for uranium.**

[3] Using a risk factor of 0.05% per rem from ICRP Publication 103 (ICRP 2007).
[4] Unless risks of intervention are judged to outweigh potential benefits after consideration of the patient's health status.

Normally, DTPA is administered intravenously, although other methods of administration are available. Since DTPA is now an FDA-approved new drug application (NDA), it is no longer provided to LLNL by REAC/TS. LLNL Health Services maintains a supply of DTPA both in the Health Services facility (Building 663) and on ambulances maintained by ACRECC.

NOTE

Ca-DTPA is about ten times more effective than Zn-DTPA for initial chelation of transuranics within 24 hours of contamination. Accordingly, unless contraindicated (such as for pregnant patients), Ca-DTPA is the form of choice for initial treatment.

DTPA can dramatically increase the rate of elimination of plutonium from the body, thereby significantly lowering the total dose received. The effectiveness of DTPA treatment depends greatly upon the route of intake, the chemical and physical form of the plutonium, and the time and duration of the DTPA treatment. DTPA can reduce dose by 80% for soluble forms of plutonium, americium, or curium if given within 24 hours, but the dose reduction may be less than 25% for insoluble compounds (NCRP 2008).

The effectiveness of DTPA depends, in part, on the solubility of the intake material. Since the exact solubility of the material involved is unlikely to be known with any certainty, and since many plutonium-contaminated workplaces have a mixture of physical and chemical forms of material, it is prudent to assume that some fraction of the material may be soluble. There have been cases where the material was thought to be "highly insoluble" in which DTPA was very successful in enhancing excretion and reducing dose. Accordingly, assumptions about the "insolubility" of the plutonium involved should not preclude the use of DTPA.

The chelating efficacy in reducing dose is greatest immediately or within one hour of exposure, when the greatest amount of the radionuclide is circulating in, or available to, the tissue fluids and plasma. This early administration allows the DTPA to work while the maximum concentration of material is still in the bloodstream. Since such a time frame leaves little time for decision-making, preparation for such treatment should be performed in advance of any incidents and should include:

- Providing training and information about chelation therapy to applicable workers as part of their normal required training,
- Establishing decision criteria to assist physicians and HPs in evaluating the need for chelation,
- Maintaining adequate supplies of DTPA and associated items needed for administration, and
- Establishing Health Services procedures for administration, including "informed consent" forms.

A post-exposure interval greater than one hour does not preclude the administration of and effective action of DTPA.

DTPA has been used successfully on over six hundred people in the last 40 years throughout the DOE complex. Since 2004, DTPA has been approved by the Food and Drug Administration (FDA) for treatment of individuals with known or suspected internal depositions of plutonium, americium, or curium to increase the rates of elimination (NCRP 2008).

11.6.4 Possible Side Effects and Risks of Chelation

Administration of DTPA is not expected to cause any serious side effects or risks. Of 310 recipients of DTPA for whom the presence or absence of side effects was recorded, 19 recipients (6.1%) reported at least one adverse event. Adverse events included headache, lightheadedness,

chest pain, allergic reaction, dermatitis, metallic taste, nausea, diarrhea, and injection site reactions (NCRP 2008). The normal route of administration of DTPA is via intravenous injection, and there can be some pain and discomfort associated with such injections.

As with any drug, there may be special considerations, particularly in the case of pregnant or nursing women. NCRP Report No. 65 describes that pregnant mice receiving five daily injections of 20–80 times the normal dose of Ca-DTPA during gestation demonstrated severe fetal injury and fetal death, though daily doses about 10 times the daily human dose produced no harmful effects (NCRP 1980). NCRP Report No. 161 recommends that because animal studies are not always predictive of human response, DTPA should be used during pregnancy only if clearly needed. NCRP Report No. 161 also recommends that women with known or suspected internal depositions of radionuclides should not breastfeed, whether or not they are receiving chelation therapy (NCRP 2008).

WARNING

Ca-DTPA is FDA Pregnancy Category C, while Zn-DTPA is Pregnancy Category B.
Treatment of pregnant patients should begin and continue with Zn-DTPA, if available.

In addition to risks that may be associated with the DTPA itself, there are small risks associated with the method of administration. The risk of an air bubble embolism, which can lead to serious side effects, is estimated to be about 1 in 20,000 (Wood 2000).

If intravenous administration is not possible and the only contamination was by inhalation, DTPA may be administered by nebulized inhalation. Nebulized chelation therapy may be associated with exacerbation of asthma. Two individuals experienced cough and/or wheezing with nebulized Ca-DTPA therapy, but there have been no reports of such incidents with nebulized Zn-DTPA (NCRP 2008).

No serious long-term effects of DTPA have been observed in humans, other than the depletion of zinc, which can be avoided by switching to Zn-DTPA for longer-term therapy. The largest number of Zn-DTPA doses given to a single individual was 574 doses delivered over 3.5 years (NCRP 2008).

The decision to use chelation therapy must be a joint decision between the **patient and the Health Services physician**. Internal Dosimetry is responsible for providing guidance to both the patient and to the Health Services physician to assist them in making this decision. A signed "informed consent" form is required prior to treatment.

11.6.5 Excision for Transuranic-Contaminated Wounds

Debridement or surgical removal (local excision) of contaminated tissue can be a simple and very effective method of medical intervention, particularly in wounds contaminated by transuranic materials. In the event of a contaminated wound, a significant amount of contamination may be present locally at the wound site. At LLNL, excision has been used in past incidents, with one case resulting in an estimated dose reduction by a factor of 40.

Decisions about performing such excision should be based on the physical circumstances of the incident, results of wound counting measurements (if available), the projected doses, and the location, extent, and nature of the tissue to be excised. Almost without exception, a wound count should be performed to determine the amount and location of contamination prior to making any decisions about excision. A wound count will take at least 30 minutes (including equipment setup time, a 10-minute background count, and a 10-minute wound count). Therefore, if a wound involving transuranic nuclides is known to meet any of the immediate chelation criteria listed in

Figure 11.3 on page 86, *the decision to accept or reject chelation therapy should be made as soon as possible, even before a wound count is requested*.

If the patient decides to accept excision, in addition to the wound count, a radiograph (x-ray) may also be useful in assessing the presence and location of dense material in the wound.

NOTE

The excision procedure may actually "loosen" contamination at the wound site and make it more readily available for absorption into the bloodstream. Accordingly, if chelation therapy is also accepted by the patient, it should be administered before excision procedures begin.

11.6.6 Possible Side Effects and Risks of Excision

The risks of tissue excision depend greatly on the site of the wound and the nature and quantity of tissue involved. Most excisions involve relatively small amounts of tissue. In all cases, the risk of disfigurement or loss of function must be carefully weighed against the potential radiation doses averted. The Health Services physician should consider timely referral to a hand or plastic surgeon if the nature of the wound poses significant cosmetic or functional risks.

The decision to excise tissue must be a joint decision between the **patient and the Health Services physician**. Internal Dosimetry is responsible for providing guidance to both the patient and to the Health Services physician to assist them in making this decision. A signed "informed consent" form is required prior to treatment.

11.6.7 Medical Intervention for Ingestion Intakes

In cases of significant inhalation (and obviously, ingestion), a large fraction of the intake may reside in or be translocated to the gastrointestinal (GI) tract in the first few days after the intake. Accordingly, it may be desirable to reduce the residence time of such material in the GI tract to minimize any direct radiation of the GI tract walls and to minimize absorption from the GI tract to the bloodstream. The use of purgatives (laxatives) may be considered in such cases, under the direction of Health Services.

11.6.8 Decontamination of Intact Skin

While not strictly related to internal dosimetry, general information for decontamination of intact skin is provided here since improper techniques could result in an internal exposure. Detailed procedures for skin decontamination are found in Appendix C of ES&H Manual Document 20.2 and summarized here for convenience:

- Perform a careful survey to establish a baseline level of contamination.
- Obtain the worker's consent before continuing with each step of the process.
- Begin decontamination using the mildest methods (e.g., water only), progressing to stronger methods as necessary (e.g., water and mild detergent, very light scrubbing).
- Use appropriate techniques (body positioning, trays, absorbent material) to minimize the spread of contamination during decontamination.
- Re-survey as necessary to assess the effectiveness of the decontamination efforts.
- **DO NOT** redden or break the skin, as this could increase the absorption of contamination into the bloodstream.
- **DO NOT** use chemicals other than mild detergent unless specific approval is granted by Health Services, since some chemicals may be absorbed readily through the skin and can carry a contaminant directly to the bloodstream.

11.7 MEDICAL INTERVENTION FOR PLUTONIUM AND TRANSURANICS

Intakes involving plutonium or similar transuranic elements (e.g., americium, curium) are more likely to result in significant doses than intakes from other nuclides. As with many heavy metals, plutonium is chemically toxic, but its chemical toxicity is dwarfed by its radiological toxicity. Most of the plutonium handled at LLNL is "weapons grade" plutonium, a mixture of plutonium and americium isotopes. In the event of a plutonium wound, it is important to verify the expected mix of radionuclides—initially from process knowledge, and as necessary by analysis.

The most commonly encountered other transuranic radionuclides at LLNL are americium (^{241}Am), curium (^{244}Cm), and neptunium (^{237}Np). Response to and treatment for americium and curium are similar to those for plutonium. However, the chemical properties of neptunium are different from those of plutonium, and for that reason **chelation therapy for suspected intakes of ^{237}Np is not recommended unless advised by REAC/TS**.

11.7.1 Suspected Inhalation Intakes of Plutonium and Transuranics

Since the decision to chelate should be made as soon as possible after a suspected intake, decision criteria must be based on early and possibly uncertain indicators of the magnitude of intake. Internal Dosimetry is responsible for providing guidance to both the patient and to the Health Services physician to assist them in making the decision to chelate in cases where the anticipated internal doses warrant such treatment.

Table 11.3 lists decision thresholds for early intervention with DTPA in the event of inhalation of plutonium, curium, or americium. The primary purpose of this table is to assist in determining whether chelation should be considered before a lung count is performed to prevent the hour-long delay that a lung count would cause.

Nasal swabs may provide some indication of the magnitude of intake. Although there is a great deal of uncertainty associated with such results, a "rule of thumb" is that 1 dpm on the nasal swabs is indicative of a dose of about 2 mrem CED (e.g., 1000 dpm may imply a dose of 2 rem). The accuracy of nasal swab results can be affected by many factors; accordingly, the absence of significant activity on nasal swabs **is not** definitive evidence that no intake has occurred.

Table 11.3 Guidelines for chelation before initial lung count for suspected inhalation of plutonium, americium, or curium

Threshold (possible dose implied)	Sum of nasal swabs (dpm α)	Contamination inside respirator (dpm α/100 cm^2)	Facial contamination (dpm α)	Head and Neck Contamination (dpm α)	Other
RECOMMEND intervention **before** lung count (CED ≥ 20 rem)	10,000	50,000	100,000	500,000	
CONSIDER intervention **before** lung count (CED ≥ 2 rem)	1,000	5,000	10,000	50,000	
Get lung count **SAME DAY** (CED ≥ 0.2 rem)	100	500	1,000	5,000	Fire or explosion

Following the lung count, the projected dose based on the lung count results should be compared to Figure 11.2. Since the count is a direct measure of activity present in the lungs, more confidence may be placed on such estimates, which will likely be more accurate than estimates based on early indicators such as nasal swabs or facial contamination.

Figure 11.2 Guidelines for chelation after initial lung count for suspected inhalation of plutonium, americium, or curium

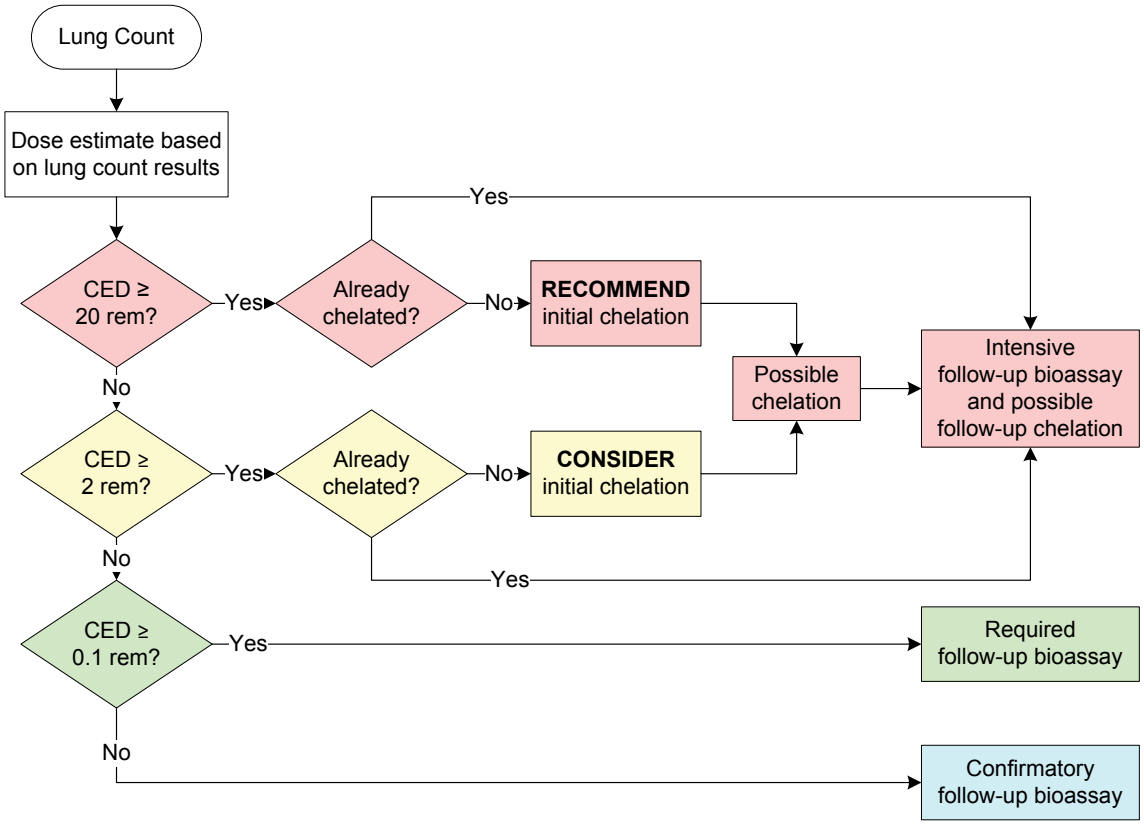


Table 11.4 provides lung count results roughly corresponding to the reference intervention levels. These values assume the lung count was completed within 24 hours of the suspected intake.

Table 11.4 Prompt[5] lung count results corresponding to intervention dose thresholds for transuranics

Dose (CED)	15-year-old Weapons Grade Plutonium (^{241}Am activity, nCi)		"Pure" Plutonium[6] (^{238}Pu, ^{239}Pu, or ^{242}Pu activity, nCi)		Most Other Transuranics (Cm, Am, or Np activity, nCi)
	Type M	Type S	Type M	Type S	All Forms
20 rem	1.1	4.5	10	33	12
2 rem	0.11	0.45	1	3.3	1.2

[5] Assumes lung count performed within 24 hours of suspected intake.
[6] These values are far below the typical minimum detectable activity of the lung counter.

Table 11.5 lists recommended follow-up bioassay regimes for suspected inhalation intakes of plutonium or other transuranics. These recommendations reflect a graded approach depending on the initial estimated dose based on early indicators. The recommendations for urine sampling may also be used for follow-up of wound intakes of transuranics.

If the worker chooses to accept chelation treatment, a pre-chelation urine sample should be collected before the initial treatment is administered. Urine and fecal samples collected after DTPA administration must be appropriately marked for the Bioassay Laboratory, since sample processing is modified for these samples.

Table 11.5 Recommended follow-up bioassay regimes for suspected inhalation of transuranics

Follow-up Category	Suspected Dose (rem CED)	Lung Counts	Urine Samples	Fecal Samples
Intensive	≥ 20	Initial lung count ASAP; repeat lung count next day	Pre-DTPA urine if applicable; begin 24-hr urine sampling immediately with 24-hr urine samples on days 1, 3, 5	Collect all feces on days 2 through 10 (separate samples)
Intensive	≥ 2	Initial lung count ASAP; repeat lung count next day	Pre-DTPA urine if applicable; begin 24-hr urine sampling immediately with 24-hr urine samples on days 1, 3, 5	Collect all feces on days 2 through 10 (separate samples)
Required	≥ 0.1	Initial lung count same day; repeat lung count next day if initial count positive	Collect 24-hr urine samples on days 1, 3, 5	Collect feces on days 2 and 3 (separate samples); consider sample day 10
Confirmatory	≥ 0.01	Repeat lung count within 1 week if initial count positive	Collect simulated 24-hr urine sample beginning day 1; repeat simulated 24-hr samples as necessary	Consider sample on day 2 or 3
Discretionary	< 0.01	At discretion of Internal Dosimetry	Collect simulated 24-hr urine sample beginning day 1	At discretion of Internal Dosimetry

11.7.2 Suspected Wound Intakes of Plutonium or Transuranics

For suspected wound intakes of plutonium or transuranics, initial recommendations about medical intervention will be based on early information such as gross contamination measurements. Internal Dosimetry will provide guidance to the patient and the Health Services physician on the dose reduction that might be achieved, but the decision to accept medical intervention is a joint decision by the patient and the physician.

The health physics guidelines for chelation and excision are similar in the event of a plutonium-contaminated wound. If any of the chelation/excision criteria listed in Figure 11.3 on page 86 are present, chelation should be recommended and given **before** any attempts at excision. Since the excision process can result in further transfer of activity from the wound site to the bloodstream, it is important to assure that there is DTPA in the bloodstream before excision begins.

Almost without exception, a wound count should be made prior to making any decisions about excision. In the case of plutonium, curium, americium, and most other transuranics, a wound count result of about 1 nCi of alpha activity implies a committed effective dose of about 2 rem. Thus, excision should be considered if the total plutonium or transuranic activity in the wound is greater than 1 nCi, or if wound survey results are greater than 2,200 dpm after initial external decontamination.

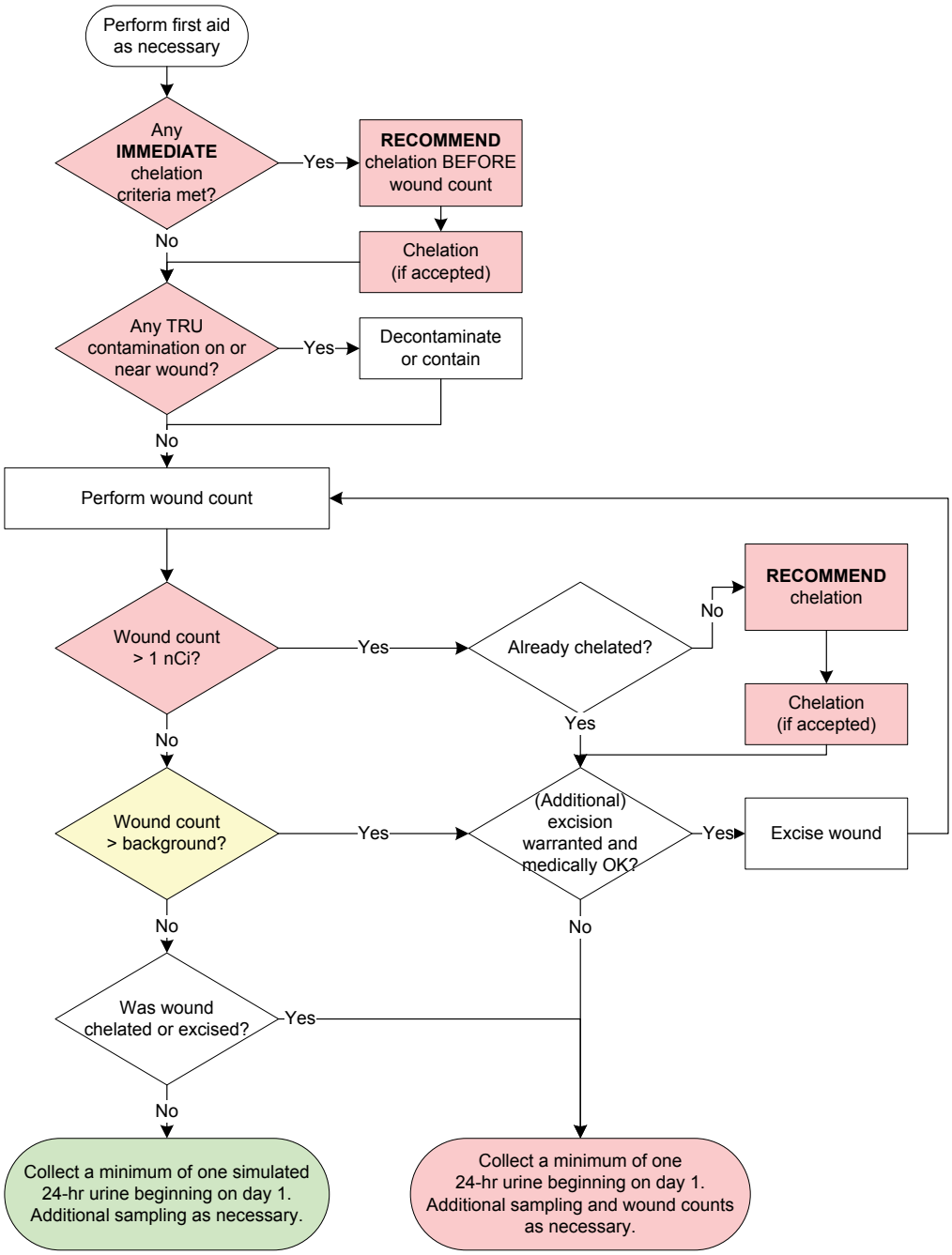
The flowchart in Figure 11.3 on the following page should be used to guide decisions in treating wounds that are contaminated with plutonium, americium, or curium.

Table 11.6 provides plutonium and other transuranic wound count results that would roughly correspond to the reference intervention levels.

Table 11.6 Wound count results corresponding to intervention dose thresholds for transuranics

Dose (CED)	Weapons Grade Plutonium (nCi, ^{241}Am)	Weapons Grade Plutonium (nCi, total α)	Pure Plutonium (^{238}Pu, ^{239}Pu, ^{242}Pu) (nCi, total α)	Most Other Transuranics (Cm, Am, Np) (nCi, total α)
20 rem	1.8	11	12	20
2 rem	0.18	1.1	1.2	2

Figure 11.3 Guidelines for medical intervention for wounds contaminated with plutonium, americium, or curium



IMMEDIATE chelation criteria for transuranic-contaminated wounds

- Wound caused by direct contact with plutonium or other transuranic element
- Wound caused by transuranic-contaminated needle or sharp
- Transuranic contamination detectable in or around wound
- Observed or suspected transuranic fragments or particles in wound
- Chemical burn from solution containing transuranic radionuclides

11.8 MEDICAL INTERVENTION FOR URANIUM

Incidents involving minor levels of uranium contamination are not uncommon; however, it is unlikely such incidents would result in any serious radiological consequences. As with many heavy metals, uranium is chemically as well as radiologically toxic and is listed by the ACGIH® as a human carcinogen. Uranium's chemical toxicity may be the dominant hazard in cases of readily or moderately soluble compounds of depleted, natural, and low-enriched uranium. Accordingly, **assessment of possible intakes of uranium should consider both the radiological and chemical toxicity hazards**.

It is unlikely that an accidental intake of uranium would be large enough to warrant medical intervention for radiological reasons. However, it is possible that medical intervention would be considered due to the potential chemical toxicity to the kidneys. In such cases, oral or intravenous administrations of sodium bicarbonate may be warranted. Sodium bicarbonate forms a compound with the uranium that is less toxic to the kidneys. Any such administration would be performed under the direction of Health Services.

WARNING

Chelating agents such as DTPA should NOT be used for uranium intakes. Such agents may cause concentration of uranium in the kidneys and increase the chemical toxicity effect of uranium on the kidneys.

11.8.1 Suspected Inhalation Intakes of Uranium

Accidental intakes of uranium are likely to be far less radiologically serious than those of plutonium. Exposures to depleted or natural uranium are seldom radiologically serious due to the low specific activity of these materials, and even for highly enriched uranium the inhalation dose consequence in terms of dose per mass inhaled is 1,000 times less than that of plutonium.

As with plutonium, nasal swabs should be collected in cases of suspected inhalation of uranium. Recall that there is always a great deal of uncertainty about the accuracy of nasal swabs. For the worst case of insoluble uranium, small particle size, and poor collection efficiency, a rough "rule of thumb" is that 1 dpm alpha activity on nasal swabs may be roughly equivalent to 0.5 mrem CED. This rule of thumb may be applied to depleted, natural, or enriched uranium.

Lung counts may be useful for suspected large inhalation intakes of uranium. Table 11.7 provides uranium lung count results that would roughly correspond to the reference intervention levels. These threshold values assume the lung count was completed within 24 hours of the suspected inhalation intake.

Table 11.7 Prompt[7] lung count results corresponding to intervention dose thresholds for uranium

Dose (CED)	Depleted Uranium (^{234}Th result, nCi)		Natural Uranium (^{234}Th result, nCi)		Highly Enriched Uranium (^{235}U result, nCi)	
	Type M	Type S	Type M	Type S	Type M	Type S
20 rem	150	50	80	25	4.5	1.5
2 rem	15	5	8	2.5	0.45	0.15

[7] Assumes lung count performed within 24 hours of suspected intake.

11.8.2 Suspected Wound Intakes of Uranium

Uranium-contaminated wounds are usually far less serious than wounds contaminated with plutonium or other transuranic materials, and are generally not expected to result in serious radiation doses. Such wounds are not uncommon in facilities in which bulk quantities of natural or depleted uranium are handled. These wounds sometimes involve pricks or punctures caused by contact with sharp edges or points of uranium metal, and sometimes involve fragments of uranium metal. Such wounds are rarely serious from a radiological standpoint due primarily to the low specific activity of uranium. However, uranium-contaminated wounds should always be evaluated for both radiological and chemical toxicity concerns.

Initial assessment of a uranium-contaminated wound will focus on the nature of the wound and the early indicators (surface and area surveys) of possible contamination. A wound count is recommended if contamination is detected near the wound, if the wound is deep or a puncture wound, or if an imbedded fragment is suspected. Since the dose consequences of uranium-contaminated wounds are not expected to be serious, there is usually no urgency about performing the wound count except for the medical considerations of wound management, location, and subsequent healing.

In a contaminated wound, a significant amount of contamination may be present locally at the wound site. Normal wound cleaning and debridement can be effective means of removing a significant portion of any uranium contamination. Decisions about performing further debridement or tissue excision should be based on results of wound counting measurements, the projected doses, the potential for uranium chemical toxicity, and the location, extent, and nature of the tissue to be treated.

Table 11.8 provides uranium wound count results that would roughly correspond to the reference intervention levels.

Table 11.8 Wound count results corresponding to intervention dose thresholds for uranium

Dose (CED)	Depleted Uranium (nCi ^{234}Th)	Natural Uranium (nCi ^{234}Th)	Low Enriched Uranium (3.5%) (nCi ^{235}U)	Highly Enriched Uranium (93.5%) (nCi ^{235}U)
20 rem	2,600	2,600	2,400	2,400
2 rem	260	260	240	240

11.9 MEDICAL INTERVENTION FOR TRITIUM

The forms of tritium to which LLNL workers might be exposed are elemental tritium (HT or T_2 gas), tritiated water (HTO), organically labeled tritium compounds, or tritiated particulates (Special Tritium Compounds, or STCs). Incidents involving tritium are rarely serious because a very large quantity of tritium activity would have to be inhaled, absorbed, or ingested in order for any significant doses to occur.

11.9.1 Suspected Inhalation or Absorption Intakes of Tritium

Exposure to airborne tritium (elemental gas, HTO, or particulates) is unlikely to result in any serious radiation doses. If significant doses from tritium are expected, internal doses can be significantly reduced by simply increasing the intake (and therefore turnover) of fluids. Dose reduction factors of 2 to 3 can be readily achieved by such treatment. The Health Services physician should consult with REAC/TS to discuss fluid treatment regimens given case specifics. As with other forms of medical intervention, the decision to increase fluid intake is a joint decision between the patient and the Health Services physician.

Despite the prevalent folk wisdom, alcoholic beverages are *not* recommended for the purpose of increasing fluid intake.

11.9.2 Suspected Wound Intakes of Tritium

Wounds contaminated with tritium are unlikely to present a significant radiological hazard. Tritiated water (HTO) is absorbed rapidly through even intact skin, so a break in the skin makes little difference in cases of skin contamination with HTO.

An exception to the above generalization might be a wound contaminated with particulate tritium contamination (STCs). In such cases, the particulates residing in the wound may act as a reservoir of tritium activity that will, in time, be absorbed into the bloodstream. However, such retention of tritium at the wound site would actually lower the whole body dose, so the dose from an STC-contaminated wound would almost never be as high as a wound or intact skin contaminated with HTO.

In either case, the treatment would consist of irrigation of the wound to reduce uptake from the wound. It is very unlikely that any excision would be necessary for dose reduction purposes.

11.10 WORK RESTRICTIONS

As soon as practicable after an incident involving potential internal doses, Internal Dosimetry will consider the possibility of issuing radiological work restrictions, which may be in the form of a medical restriction through Health Services or a radiological work restriction for bioassay follow-up requested through Internal Dosimetry and the ES&H Team HP. The purpose of a medical restriction is to minimize the likelihood of exceeding any applicable DOE dose limits. The purpose of a radiological work restriction for bioassay follow-up is to minimize the likelihood of perturbing follow-up bioassay results. See Sections 7.12.3 and 7.12.4 for details on issuance of work restrictions.

11.11 INTERACTION WITH AFFECTED WORKERS

11.11.1 Keeping the Worker Informed

It is important that affected workers be kept informed throughout the entire process of incident response, health physics and internal dosimetry response, medical diagnosis and treatment, and follow-up evaluation. Workers should be counseled promptly on the medical and radiological implications resulting from potential intakes by health physics and medical professionals. Workers should be involved in decisions made about their evaluation, diagnosis, and treatment. Decisions regarding medical interventions must be a joint decision between the worker and the physician.

Care should be taken to explain the reasoning behind treatment guidelines and recommendations to the affected workers. The workers should be given opportunities to ask questions about their treatment and follow-up. It is recommended that, in addition to verbally informing the workers, written summaries be periodically provided. These written summaries document the information given to the workers and give them the opportunity to review what they have been told.

The workers' spouses or families may also have questions and concerns about their condition, treatment, and follow-up. *With the worker's permission*, arrangements should be made to answer these questions. For example, a joint meeting with the worker, their spouse, the attending Health Services physician, and the attending Internal Dosimetrist might be held to discuss the course of treatment or follow-up.

If an Occurrence Reporting and Processing System (ORPS) report to DOE is required and includes information on an individual's exposure to radiation, LLNL is required by

10 CFR 835.801(e) to provide the same information to the individual *prior to, or at the same time* the information is transmitted to DOE.

In some circumstances (e.g., intakes of transuranic elements) the follow-up and evaluation period after an intake may take many months. During this time period, care should be taken to keep the worker informed of bioassay results and the status of the evaluation and assessment. Periodic written summaries are recommended for evaluation periods lasting more than a few months.

11.11.2 Protecting the Worker's Privacy

While an individual's radiation dose or bioassay measurement results are not considered medical records, most of the details and aspects of the treatment and follow-up in internal contamination cases should be treated as Official Use Only information under Exemption 6, Personal Privacy. To the extent practicable, the worker should be kept informed of what sort of information is being released to the DOE, or to the news media, regarding their status or treatment.

Detailed guidelines for control of radiation dose or bioassay measurement data are outlined in ES&H Memorandum ESH-RP-2012-037, *Controls for Reports Containing Personnel Monitoring Data or Doses* (reproduced as Appendix C).

11.11.3 Counseling for Workers

Involvement in suspected or actual internal contamination incidents can be very stressful for the workers involved. This stress can be produced by concerns about:

- Health effects (e.g., cancer) from the radiation exposure,
- Health effects from chemical exposure,
- Effects on reproductive health (sterility, virility) or subsequent offspring,
- Spread of contamination to family members,
- Reaction of family members and friends,
- Reaction of coworkers,
- Information appearing in the news media,
- Being "to blame" for the incident, and
- Possible disciplinary action.

These stresses can be exacerbated by the high degree of management attention (e.g., notifications, investigations, bioassay follow-up, temporary work restrictions) that often accompany even trivial intakes. Internal Dosimetry, Health Physics, and Health Services personnel who interact with the affected workers should keep these potential concerns in mind. In addition, appropriate (radiological, medical, psychological, or emotional) counseling should be made available to assure that workers involved in such incidents receive the information and support necessary to alleviate or resolve these stresses. Program and facility management and ES&H staff should also be aware of and sensitive to such stresses.

11.11.4 Concerns about Transfer of Internal Contamination

Refer to Section 10.5.2 for information on evaluating the potential for transfer of internal contamination from the affected individual to others (e.g., through transfer of contaminated body fluids).

If chelating agents were administered for significant intakes of transuranics (americium, plutonium, or curium), the following information from the package inserts for Ca-DTPA and Zn-DTPA should be provided to the individual:

> In individuals with recent internal contamination with plutonium, americium, or curium, Ca-DTPA [or Zn-DTPA] treatment increases excretion of radioactivity in the urine. Appropriate safety measures should be taken to minimize contamination of others. When possible, a toilet should be used instead of a urinal, and it should be flushed several times after each use. Spilled urine or feces should be cleaned up completely and patients should wash their hands thoroughly. If blood or urine comes in contact with clothing or linens, they should be washed separately…. If patients are coughing, any expectorant should be disposed of carefully. Swallowing the expectorant should be avoided if possible…. Nursing mothers should take extra precaution in disposing of breast milk.

11.12 NOTIFICATION AND REPORTING REQUIREMENTS

In addition to the emergency response-related communications discussed above, LLNL and the DOE have requirements for notification and reporting of radiological incidents. Guidelines for implementing these procedures at LLNL are found in PRO-0082, *Reporting Occurrences to DOE* (LLNL 2014c). As outlined in PRO-0082, occurrence reporting to the DOE Occurrence Reporting and Processing System (ORPS) is conducted through the appropriate Assurance Manager.

If an ORPS report to DOE is required and involves an individual's exposure to radiation, LLNL is required by 10 CFR 835.801(e) to provide the same information to the individual *prior to, or at the same time* the information is transmitted to DOE.

The Radiation Protection Functional Area has established a "sub-ORPS" tracking and reporting process in HP-FO-601, *Identification and Response to Unexpected Radiological Conditions* (LLNL 2015d). Incidents that do not meet the reporting thresholds of PRO-0082 should be evaluated to determine if they should be reported through the HP-FO-601 process.

11.13 FOLLOW-UP BIOASSAY MEASUREMENTS

11.13.1 Determination of Follow-up Bioassay Needs

Follow-up (sometimes referred to as "special" or "for-cause") monitoring is performed in response to workplace intake indicators as a means of detecting and assessing unplanned intakes. Recommendations for follow-up bioassay regimes for intakes of plutonium or other transuranics are presented above in Table 11.5. Follow-up monitoring may be tailored for other materials and circumstances, as determined necessary by Internal Dosimetry and the ES&H Team HP.

The ES&H Team HP should discuss with affected workers the reasons for, and the schedule and nature of, recommended follow-up measurements. Written summaries of the follow-up sampling schedule and any special instructions should be provided to the worker by Internal Dosimetry or the ES&H Team HP when it is known in advance that more than one bioassay sample or in vivo count will be requested.

Factors to be considered when planning the nature of and schedule for follow-up measurements are:

- The magnitude of the anticipated dose,
- The complexity and uncertainty involved in the case,
- Any measurements made to rule out possibilities,
- The biological elimination pattern (route and time frame) of the radionuclides of interest,
- The inconvenience to the worker, and
- The costs of analysis, particularly if non-routine methods are used.

Default conditions warranting follow-up monitoring are presented below:

- Contamination detected near a wound,
- Contamination detected inside a respirator surveyed immediately upon removal, or when cross-contamination is not a consideration,
- Contamination detected around the nose or mouth,
- Contamination above 500 dpm α or 5,000 dpm β/γ detected on the head, heck, or hair,
- Contamination above 2,000 dpm α or 20,000 dpm β/γ detected on skin elsewhere,
- Removable contamination above 10,000 dpm/100 cm^2 α or 100,000 dpm/100 cm^2 β/γ detected widespread around the work area, or on personal protective equipment when no respiratory protection was worn,
- Positive nasal swab results above 10 dpm α or 25 dpm β,
- Greater than 40 DAC-hr of exposure to airborne contamination after correcting for respiratory protection,
- Greater than 0.1 rem CED suspected based on any combination of workplace intake indicators and process knowledge, or
- Greater than 0.1 rem CED implied by routine bioassay results.

Follow-up sampling initiated for any of the conditions above is considered Required monitoring, since these conditions may indicate a potential CED of 0.1 rem. Radiological work restrictions will be imposed on workers failing to complete follow-up sampling initiated for any of the conditions listed above.

11.13.2 Analysis of "Non-Standard" Radionuclides by ASI Laboratories

In cases where analytical measurements for radionuclides involved in an incident have not been established, the ASI laboratories will work in conjunction with Internal Dosimetry and the ES&H Team HP to develop and verify special procedures that are applicable and appropriate for those radionuclides. Considerations in this development should include:

- Type and energy of emitted radiations,
- Chemical properties of the material involved,
- Appropriate analytical chemistry and processing procedures, and
- Appropriate counting procedures, including any necessary corrections for radiation type and energy, yield, counting system efficiency, and counting system backgrounds.

Any such special procedures should be prepared in writing and reviewed and verified by the appropriate ASI Laboratory Group Leader and Internal Dosimetry.

11.14 DOCUMENTATION OF SUSPECTED INTAKES

For a variety of reasons, decisions and follow-up actions taken in response to internal contamination cases must be well-documented. The level of documentation needed should be tailored to the severity of the case. In most cases, if the initiating event is known or identified in the workplace, the HP-FO-601 reporting process will be used for the initial documentation of the incident. If the initiating event is unknown and the first indication of a suspected intake is by routine bioassay results, Internal Dosimetry will maintain the investigation files and subsequent documentation for follow-up information.

12. DATA MANAGEMENT, RECORDING, AND DOSE REPORTING

12.1 GENERAL REQUIREMENTS

The regulatory requirements for dose recordkeeping are specified in Subpart H of 10 CFR 835. In summary, these requirements specify that:

- Records shall be maintained to document compliance with [10 CFR 835],
- Unless otherwise specified in [Subpart H], records shall be retained until final disposition is authorized by DOE,
- Records shall include both individual monitoring and workplace monitoring results,
- Individual records shall contain the data specified in section § 835.702, and
- Data necessary to allow future verification or reassessment of the recorded doses shall be recorded.

ES&H Manual Document 20.1 provides further details of the records management program in Section 3.3, Section 8, and Appendix F.

12.2 PROTECTION OF PERSONAL OR SENSITIVE INFORMATION

The Privacy Act of 1974 applies to bioassay data and dosimetry reports associated with an individual. The Privacy Act applies when protected information is provided to someone *other* than the person to whom the record pertains (e.g., supervisor or coworkers). However, the Privacy Act does not apply to data and reports provided *only* to the monitored individual.

The Privacy Act also does not apply to data and reports utilized within the Radiation Safety Program, where access to the information is controlled and made available only to individuals who have a business need for the information.

Because the Privacy Act applies to bioassay data and dosimetry reports associated with an individual, Exemption 6 (Personal Privacy) of the Freedom of Information Act (FOIA) also applies, and this information must be protected as Official Use Only (OUO).

Personally Identifiable Information (PII) controls apply to databases (e.g., BLIMS and REMS), but do not apply to individual letters or reports, as given in Appendix C.

Bioassay data and dosimetry reports are not medical records, so the Health Insurance Portability and Accountability Act (HIPAA) does not apply.

Further information is outlined in ES&H Memorandum ESH-RP-2012-037, *Controls for Reports Containing Personnel Monitoring Data or Doses*, which is reproduced as Appendix C.

12.3 INDIVIDUAL RECORDS

12.3.1 Bioassay Data Records

In vitro measurement records are maintained by the Bioassay Laboratory (BLAB). In vitro results and sample information from 1996 to the present are documented in the BLIMS database, which is managed by the Bioassay Team and maintained by the LLNL institutional Information and Communication Services (ICS) group. Hard copy data packages, including measurement results provided by the Spectroscopy and Radiological Measurements Laboratories, comprise the full Bioassay Laboratory analysis records and are stored in the BLAB/RML Records Storage Area in B253. Earlier results (prior to 1996) are stored in the MAPPER and Symphony databases, which are accessible through BLIMS. Bioassay Laboratory records are described in further detail in procedure RP-BLAB-001, *Bioassay Laboratory Administration*.

In vivo measurement records consist of the WBC Count Information Form and the measurement analysis report. The raw spectrum files and report files are stored on the WBC system. Hard copy data packages are stored in each individual's Personnel Dosimetry File located in the records storage area maintained by External Dosimetry in B253W.

12.3.2 Internal Dosimetry Investigation Information

Internal Dosimetry investigation and result follow-up information is electronically documented and stored in the Bioassay Investigation Tracking System (BITS) database, which is managed by the Internal Dosimetry Team and maintained by ICS. This database includes workplace information, potential exposure information, and internal dosimetry analysis of elevated or anomalous bioassay results. The BITS database serves as a repository for field and workplace information that puts the bioassay result records and final dose record into context.

12.3.3 Individual Dose Records

Dosimetry records must contain identifying information that ensures that the records are correctly associated with the individual. Final doses are stored in the LLNL Radiation Exposure Monitoring System (REMS) database, which is managed by the External Dosimetry Team and maintained by ICS. The REMS database stores and maintains the following information for each individual's dose records:

- Full name (and former names, if any),
- Social Security Number (or passport number and country),
- LLNL employee number (and former numbers, if any),
- Date of birth,
- Gender,
- Employment status,
- Job title or occupation code, and
- Organization code.

The REMS database is used for both internal and external dose records, and provides the following total dose records for each individual required by 10 CFR 835:

- The total effective dose in a year,
- For any organ or tissue assigned an internal dose during the year, the sum of the equivalent dose to the whole body from external exposures and the committed equivalent dose to that organ or tissue, and
- Cumulative total effective dose[1].

In addition to the information in the REMS database, hard copy personnel dosimetry files are maintained in the External Dosimetry Laboratory in B253. Personnel dosimetry files are separate for each individual and consist of documentation generated for dose investigations and assessments for both internal and external exposures.

12.3.4 Individual Internal Dose Records

For any individuals with assessed internal doses, the following information is also included in the REMS dose records as required by 10 CFR 835:

- The committed effective dose,
- The committed equivalent dose to any organ or tissue of concern, and
- The identity of radionuclides.

[1] LLNL includes all *known* dose values in the reported cumulative total effective dose, including those received prior to January 1, 1989.

In addition to this information required above, data necessary to allow for verification or reassessment of the recorded doses is also recorded as required by 10 CFR 835. Such additional information is described in Section 9.3.3 of this Manual and is contained in the dose assessment report stored in the individual's personnel dosimetry file.

12.4 DOSE REPORTS

12.4.1 Annual Reports to Individuals

10 CFR 835.801(c) requires that monitored individuals be provided with an annual radiation dose report. Such annual reports are generated automatically from the REMS database by External Dosimetry and include both external and internal doses.

12.4.2 Termination Reports

10 CFR 835.801(b) requires:

> Upon the request from an individual terminating employment, records of exposure shall be provided to that individual as soon as the data are available, but not later than 90 days after termination. A written estimate of the radiation dose received by that employee based on available information shall be provided at the time of termination, if requested.

This requirement may place great constraints on the accuracy of assessments of internal doses for terminating individuals, particularly in the cases of transuranic materials that are still being assessed at the time of termination. In such cases, Internal Dosimetry will provide a best estimate of the dose to the terminating employee.

12.4.3 Special Reports to Individuals

Individuals for whom internal dose assessments are prepared are provided with copies of the reports by Internal Dosimetry. Also, in accordance with 10 CFR 835.801(d), detailed information concerning an individual's exposure shall be made available to the individual upon request of that individual, consistent with the provisions of the Privacy Act (5 U.S.C. 552a). Such detailed reports will be prepared by Internal Dosimetry.

12.4.4 Occurrence Reporting

10 CFR 835.801(e) requires:

> When a DOE contractor is required to report to the Department, pursuant to Departmental requirements for occurrence reporting and processing, any exposure of an individual to radiation and/or radioactive material, or planned special exposure in accordance with § 835.204(e), the contractor shall also provide that individual with a report on his or her exposure data included therein. Such report shall be transmitted at a time not later than the transmittal to the Department.

If an occurrence report to DOE includes specific dose information on an individual, the worker shall be provided the same information *prior to, or at the same time* as the report to DOE. In general, it is a good practice to contact individuals first if possible.

12.4.5 Annual Reports to the Department of Energy

On an annual basis, LLNL is required to prepare and transmit summary dose reports to the Department of Energy. The External Dosimetry Team produces these reports. The Internal Dosimetry Team is responsible for providing internal doses, including zero doses, to REMS.

12.5 RECORDS STORAGE

12.5.1 Records Storage Guidelines

Internal dosimetry records are stored in accordance with the guidelines of Section 8.2.4 of ES&H Manual Document 20.1. Hard copy records such as original dose assessments and investigation reports are stored in the individual personnel dosimetry files, which are stored in fire-resistant repositories. Electronic records such as working files of assessments are stored on institutionally-managed servers, not on individual hard drives.

12.5.2 Records Retention Requirements

Specific records retention requirements and responsibilities are detailed in Appendix F of ES&H Manual Document 20.1. Table 12.1 summarizes and clarifies the responsibilities with respect to the Internal Dosimetry Program.

Table 12.1 Radiological records retention list for internal dosimetry records

Type of Record	Responsible Individual or Organization
Internal Dosimetry Technical Basis Manual	Internal Dosimetry
Internal Dosimetry Program Manual	Internal Dosimetry
Procedures (Internal Dosimetry)	Internal Dosimetry
Procedures (bioassay and counting laboratories)	Applicable ASI Laboratory
Results of in vivo measurements	WBC Laboratory
Results of in vitro measurements	Bioassay Laboratory
Records of dose assessments	Internal Dosimetry
Records of bioassay programs	Internal Dosimetry
QA records (Internal Dosimetry)	Internal Dosimetry
QA records (bioassay and counting laboratories)	Applicable ASI Laboratory
Medical evaluations and treatment performed in support of the radiological protection program	Health Services Department
Records of declarations of pregnancy and retractions	Health Services Department
Medical restrictions	Health Services Department
Radiological work restrictions	Internal Dosimetry

13. QUALITY ASSURANCE

13.1 GENERAL GUIDANCE

General guidelines for appropriate quality assurance (QA) for internal dosimetry programs are contained in Section 11 of the Internal Dosimetry Standard (DOE 2008).

13.2 QA OF ANALYTICAL MEASUREMENTS

Quality assurance and quality control (QC) procedures for the Analytical Services and Instrumentation (ASI) laboratories that support the Internal Dosimetry Program are detailed in the Radiation Protection Functional Area (RPFA) QA Plan (LLNL 2014e).

13.3 QA OF INTERNAL DOSE ASSESSMENTS

13.3.1 Procedure Documentation

General methods and models used to assess intakes and doses are documented in the ID TBM. If modifications to the standard methods and models are used, they will be documented in the dose assessment. Specific details of processes related to the implementation of this Manual are documented in Internal Dosimetry Program Procedures and Instructions.

13.3.2 Dosimetrist Qualifications

Personnel with the responsibility for internal dose evaluation should have the necessary expertise and experience, based on appropriate education and training in conjunction with practical experience, to perform their assigned duties. In general, the minimum requirements should be a master's degree in health physics (or related field) and formal additional professional-level education or experience in internal dosimetry.

13.3.3 Dose Assessment Reviews

All formal assessments of internal dose will be technically reviewed by a second internal dosimetrist or qualified health physicist prior to final recording in REMS. When considered necessary or desirable by the Internal Dosimetry Team Lead or RPFA management, an independent review of dose assessments will be obtained. Such an independent review may be conducted by LLNL or non-LLNL personnel, but should be conducted by a person with recognized internal dosimetry expertise for the radioactive materials of interest.

The evaluation and assessment of internal doses can be complex, and often involves a good deal of individual professional judgment. As noted in the Internal Dosimetry Standard, "Agreement within a factor of two among experienced dose assessors is probably the best that can be hoped for in difficult cases such as transuranic intakes with subsequent chelation."

13.4 QA OF COMPUTER PROGRAMS AND WORKSHEETS USED FOR INTERNAL DOSIMETRY

13.4.1 General Considerations

A variety of computer software and spreadsheets are used at LLNL for internal dose evaluation. These evaluation tools may include programs developed and maintained by other DOE organizations (e.g., Oak Ridge National Laboratory), "in-house" developed computer programs and databases, and custom-developed spreadsheets implemented using commercially available software such as Excel or Mathcad. These applications are used for both intake and dose evaluation and data management.

Internal dose calculation software is not considered 830 Software under the LLNL Institutional Software Quality Assurance Program (ISQAP)[1]. Internal dose calculation is a type of consequence assessment and is always a retrospective process. Internal dose calculations are not used to analyze potential hazards, nor are they used to develop administrative controls affecting safety. Consequently, internal dose calculation software was removed from the LLNL 830 Software list in 2012 and now falls under non-830 Software requirements as described in the ISQAP.

13.4.2 Configuration Management

Dosimetry codes and worksheets should be subject to configuration management. Configuration management records should include:

- An identifying version number and applicable date,
- A copy of the code or worksheet,
- Instructions for running the code or worksheet,
- Instructions for the scope of use and any limitations, and
- Acceptance or validation records.

13.4.3 Verification and Validation

Computer programs and worksheets used for internal dose evaluation should undergo a verification and validation process as acceptance testing before their routine use for dosimetry. As described in the Internal Dosimetry Standard,

> *Verification* involves determining program requirements, range of program results that may be considered valid, or criteria to be used in evaluating the validity of results. *Validation* is the process of testing a computer program under a specific computing system and evaluating the results to ensure the compliance with specified requirements. Part of the testing should include running selected "benchmark" cases for comparison against an independent solution process (e.g., hand calculations, published tabulations of reference man dose, results from other verified code, etc.).

Additional guidelines on verification and validation are presented in the Internal Dosimetry Standard.

13.4.4 Software Security

Backup copies of internal dosimetry software and data should be kept in a secure location. A second copy should be kept in a different location for purposes of disaster recovery. Documentation of the procedure to install the software should be included with the backup copies.

13.5 PROGRAM AUDITS

10 CFR 835 requires that internal audits of all functional elements of the radiation protection program be conducted at least every 36 months. The Health Physics Field Operations group within RPFA schedules and manages such audits according to Appendix B of ES&H Manual Document 20.1.

These audits should include a review of program documentation, program implementation, dose assessment procedures, data management, recording and reporting, qualifications of personnel, adequacy of staffing and resources, and other key elements of an internal dose monitoring program, as necessary, to assure that the program maintains the capability to provide quality

[1] https://isqa-int.llnl.gov/

radiation protection to LLNL workers and to stay abreast of scientific developments in internal dosimetry.

The Internal Dosimetry team should perform periodic informal reviews of facility- or operation-specific individual monitoring programs to assure that the hazard characterization, program design rationale, and program operational procedures are consistent with the guidelines of this Manual.

13.6 LEADING INDICATORS AND COMPLIANCE REPORTING

Internal Dosimetry will track and report programmatic leading indicators related to the implementation of and compliance with this Manual and the overall Internal Dosimetry Program in accordance with guidance from RPFA management. Examples of ID programmatic leading indicators include:

- ES&H Team HP positive/anomalous result notification time
- Number of internal dose investigations
- Bioassay result follow-up and closure time
- Dose assessment completion time
- Worker sampling compliance

Use of such leading indicator tracking is intended to address any chronic issues potentially impacting Internal Dosimetry Program health and general compliance with the internal dosimetry monitoring program.

14. CONTINGENCY PLAN

14.1 OVERVIEW

This Chapter presents the technical contingency plan for the internal dosimetry monitoring program in the absence of operable ASI bioassay or in vivo systems. Detailed contingency guidance is presented across multiple LLNL documents and memoranda of understanding (MOUs), but is summarized and enhanced here to aid in programmatic understanding and decision making.

14.2 NOTIFICATION OF CONTINGENCY PLAN IMPLEMENTATION

Internal Dosimetry staff will notify the ES&H Team HPs, and RPFA management when unplanned downtime of ASI bioassay processing, bioassay analysis, or in vivo systems occurs or is anticipated such that LLNL's ability to perform incident follow-up internal dosimetry monitoring is impacted, or routine monitoring will not be available for more than 10 working days. The notification system established in HP-FO-601, *Identification and Response to Unexpected Radiological Conditions*, will be used.

Internal Dosimetry will include in such notifications the following information:

- Systems affected,
- Anticipated duration of downtime,
- Impact on routine and incident response capabilities, and
- Any implementation of contingency plans, as appropriate.

Notification of the absence of an operational in vitro or in vivo system capability is not meant to imply a work stoppage or hold. The notifications are made to the ES&H Teams so that information may be communicated to programs and facilities to ensure that appropriate operational reviews are conducted (e.g., to consider if higher-risk activities need to be rescheduled), and determinations made of any impact to facility Authorization Basis requirements.

14.3 CONTINGENCY PLANS

Internal dose monitoring and analysis contingency plans may be invoked under two general conditions:

(1) Temporary absence of in vivo or in vitro capabilities, particularly impacting ability to perform incident response monitoring, and
(2) Extended inability to respond to incident and routine monitoring needs.

Contingency plans are summarized below regarding specific ASI laboratory short- and long-term backup capabilities, as well as Internal Dosimetry programmatic guidance criteria and decision-making changes that may occur as a result of invoking the contingency plans for incident and routine monitoring purposes.

14.3.1 In Vivo Contingency Plans

(a) Whole Body Scans

The LLNL whole body scanning system in Building 253 is used to measure high-energy gamma radiation emitted from within the body. It quantifies internal activity for isotopes such as ^{22}Na, ^{40}K, ^{60}Co, and ^{137}Cs. This system can be utilized for transuranic radionuclide measurements only for extremely large intakes. In the case that the whole body scanner is not available for incident or

time-sensitive routine monitoring, the LLNL B378 Masse Chair system may be utilized to ensure workers are monitored in a timely manner. The B378 system is of comparable performance to the B253 system and would be operated by the ASI WBC personnel in such cases.

(b) Lung Counts

The LLNL lung counting system in Building 253 is used to measure low-energy gamma and x-ray radiation emitted from within the body. It quantifies internal activity for isotopes such as ^{235}U, ^{238}U (via ^{234}Th), ^{238}Pu, ^{239}Pu, and ^{241}Am. In the case that the lung counter is not available, the LLNL B378 Masse Chair system may be utilized as a backup system for emergency counting. However, detection limits for transuranics will be about an order of magnitude higher than the B253 system.

(c) Wound and Thyroid Counts

Two independent systems are used by ASI for wound and thyroid counting, the portable thin crystal NaI detector system and the ACT-II high-purity germanium detectors normally associated with the lung counting system. In the event that both systems are simultaneously incapacitated and a thyroid count is needed on an emergency basis, the B378 Masse Chair system may be used for emergency thyroid counts if a significant radioiodine intake is suspected.

14.3.2 In Vitro Contingency Plans

(a) Bioassay Sample Processing

The LANL MOU supports bioassay sample processing and analysis for plutonium, americium, uranium, and thorium in urine and feces, and tritium in urine. This MOU is intended for emergency use such as follow-up of suspected significant intakes, not routine monitoring.

(b) Bioassay Sample Analysis

In the event that in vitro sample analysis cannot be performed, screening analyses may be performed at another LLNL analysis facility, such as one of the Physical and Life Sciences (PLS) laboratories. However, no formal MOU is established with these laboratories. In the event that Radiological Measurements Laboratory (RML) capabilities are not available for the performance of nasal swab analysis, alternate detectors or alternate facilities may be utilized.

If possible, samples will be recounted or reanalyzed by a DOELAP-accredited facility before being considered the final result of record or used for any final internal dose assessments.

14.4 CONTINGENCY PLAN IMPLEMENTATION GUIDELINES

14.4.1 Internal Dosimetry Programmatic Impacts

The need to invoke contingency plans for internal dose monitoring will be made jointly by the affected ASI Laboratory Group Leader, Internal Dosimetry, and their respective management on a case-by-case basis. The decision to implement a contingency plan will be driven by the nature and expected duration of the capability downtime, potential dose consequences (for incident follow-up monitoring), number of samples or individuals potentially impacted, number and types of operations impacted, impact on backup facilities and personnel, regulatory consequence, and cost.

14.4.2 Impacts on Post-Incident Decision Making

Incident follow-up decision and monitoring guidelines are described in Section 11 of this Manual. Through the remaining discussions of this Section, focus is placed on contingency planning for responses to transuranic events given the significant internal dose consequence. Response to non-transuranic material events will be managed as needed on a case-by-case basis.

The basis for the early medical intervention guidelines (i.e., administering chelating agents before lung counting) in Table 11.3 on page 82 correspond to the implied CED based on early indicators such as nasal swab results and observed contamination levels. If the "RECOMMEND" or "CONSIDER" thresholds are exceeded, the potential intake is generally deemed large enough to warrant initiation of prompt chelation even before a lung count or bioassay is performed. Thus, the absence of lung counting or bioassay analysis capability would not affect such a decision. When "RECOMMEND" and "CONSIDER" thresholds are exceeded, use of the contingency plans for processing and analysis of bioassay results will be pursued when capability downtimes are expected to exceed 10 days. Other scenarios will be considered on a case-by-case basis.

At lower levels, lung counts are recommended before any decisions are made about medical intervention. Early indicators at the "SAME DAY" thresholds generally warrant a lung count as soon as possible, and the decision to recommend medical intervention is typically made after the lung count is completed if the results indicate a potential CED greater than 2 rem.

The fastest intake-to-LANL monitoring time would likely be greater than 6 hours, greater than what is typically considered "as soon as possible." Reliance on the LANL counting facility would not satisfy the guidelines of this Manual for incident follow-up when field monitoring indicates the potential for a significant intake.

Typically, lung counts are used to provide relatively rapid information about the potential magnitude of the intake. The "SAME DAY" lung count threshold is based primarily on nasal swab results, in conjunction with any facial, head, neck, and respirator contamination levels. Although field area and air monitoring results are taken into consideration, the lung count is typically performed even in the absence of significant field intake indicators, as it provides the more reassuring upper bound of potential internal dose consequence.

In the absence of the LLNL lung counting capability, the following more aggressive decision criteria and follow-up guidelines will be practiced to ensure that timely and conservative internal dose mitigation actions are considered:

- Prompt chelation should be considered when "SAME DAY" lung count criteria, *in combination with other personnel and field contamination conditions*, indicate a credible intake potential approaching or exceeding 2 rem CED.
- Implied CED may be calculated based on available air data, early indicators such as nasal swab results, or resuspension/transfer of personnel or area contamination.

If the worker chooses to accept chelation treatment, a pre-chelation urine sample should be collected and initial treatment administered. Following initial administration, the contingency plans described above will be implemented.

When "RECOMMEND" and "CONSIDER" thresholds are exceeded, use of the contingency plans for processing and analysis of bioassay results will be pursued when capability downtimes are expected to exceed 10 days. Other scenarios will be considered on a case-by-case basis.

These compensatory measures will provide for appropriate and conservative response and follow-up to suspected inhalation events during temporary unavailability of lung counting capability at LLNL.

14.4.3 Impacts on Routine Monitoring Expectations

Significant impact on the routine internal dose monitoring program is not expected from temporary in vivo or in vitro measurement capability downtimes of less than 10 working days. Impacted in vivo appointments will be rescheduled, and bioassay processing schedules will be adjusted in attempt to meet the expectations described in Chapter 7 of this Manual.

However, implementation of ASI laboratory contingency plans in response to extended capability downtimes (e.g., due to significant facility failure or a catastrophic event, such as an earthquake), or system overload (e.g., due to simultaneous response to a major radiological event), would impact LLNL's ability to effectively sustain the routine monitoring program. It is impractical to project and document the variety of scenarios and their associated contingency plans in any detail in this Manual. Expectations for issues such as:

- Detection sensitivity,
- Incident follow-up monitoring guidelines,
- Sample processing times,
- Number and priority of individuals monitored,
- Number and priority of samples processed, or
- Limiting operations with required internal dose monitoring programs,

will need to be evaluated and adjusted as determined appropriate by Internal Dosimetry, ASI Laboratory Group Leaders, ES&H Team HPs, their respective management, and program and facility management on a case-by-case basis.

Appendix A: Definitions

Term	Definition	Reference
Absorbed dose (D)	The average energy imparted by ionizing radiation to the matter in a volume element per unit mass of irradiated material. The absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 gray).	10 CFR 835
Airborne radioactivity area	Any area, accessible to individuals, where: (1) The concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the derived air concentration (DAC) values listed in appendix A or appendix C of 10 CFR 835; or (2) An individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week.	10 CFR 835
Air monitoring (generic)	Actions to detect and quantify airborne radiological conditions by the collection of an air sample and subsequent analysis, either in real-time or offline laboratory analysis, of the amount and type of radioactive material present in the atmosphere.	DOE 2011
Air monitoring (specific)	In this Manual, denotes continuous sampling and measurement of the levels of airborne radioactive materials on a "real-time" basis, usually with alarm capabilities at pre-set levels. Also referred to as a real-time air monitor.	
Air sampling	A form of air monitoring in which an air sample is collected and analyzed at a later time, sometimes referred to as retrospective air monitoring. *In this Manual, used specifically to denote passive air sampling methods (e.g., passive air samplers), where filters are periodically collected and submitted for laboratory analysis.*	DOE 2011
ALARA	"As Low As Reasonably Achievable," which is the approach to radiation protection to manage and control exposures (both individual and collective) to the work force and to the general public to as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. ALARA is not a dose limit but a process which has the objective of attaining doses as far below the applicable limits of 10 CFR 835 as is reasonably achievable.	10 CFR 835
Activity Median Aerodynamic Diameter (AMAD)	A particle size in an aerosol where fifty percent of the activity in the aerosol is associated with particles of aerodynamic diameter greater than the AMAD.	10 CFR 835

Term	Definition	Reference
Annual limit on intake (ALI)	The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man (ICRP Publication 23) that would result in a committed effective dose of 5 rems (0.05 sieverts (Sv)) (1 rem = 0.01 Sv) or a committed equivalent dose of 50 rems (0.5 Sv) to any individual organ or tissue. ALI values for intake by ingestion and inhalation of selected radionuclides are based on International Commission on Radiological Protection Publication 68, *Dose Coefficients for Intakes of Radionuclides by Workers*, published July, 1994.	10 CFR 835
Analyte	The particular radionuclide to be determined in a sample of interest.	DOE 2011
Background	Radiation from: (1) Naturally occurring radioactive materials which have not been technologically enhanced; (2) Cosmic sources; (3) Global fallout as it exists in the environment (such as from the testing of nuclear explosive devices); (4) Radon and its progeny in concentrations or levels existing in buildings or the environment which have not been elevated as a result of current or prior activities; and (5) Consumer products containing nominal amounts of radioactive material or producing nominal amounts of radiation.	10 CFR 835
Bioassay	The determination of kinds, quantities, or concentrations, and, in some cases, locations of radioactive material in the human body, whether by direct measurement or by analysis and evaluation of radioactive materials excreted or removed from the human body.	10 CFR 835
Committed effective dose (CED or E_{50})	The sum of the committed equivalent doses to various tissues or organs in the body ($H_{T,50}$), each multiplied by the appropriate tissue weighting factor (w_T) – that is, $E_{50} = \Sigma w_T H_{T,50} + w_{Remainder} H_{Remainder,50}$. Where $w_{Remainder}$ is the tissue weighting factor assigned to the remainder organs and tissues and $H_{Remainder,50}$ is the committed equivalent dose to the remainder organs and tissues. Committed effective dose is expressed in units of rem (or Sv).	10 CFR 835
Committed equivalent dose (CEqD or $H_{T,50}$)	The equivalent dose calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed equivalent dose is expressed in units of rem (or Sv).	10 CFR 835

Term	Definition	Reference
Cumulative total effective dose	The sum of all total effective dose values recorded for an individual plus, for occupational exposures received before the implementation date of this amendment [June 8, 2007], the cumulative total effective dose equivalent (as defined in the November 4, 1998 amendment to this rule) values recorded for an individual, where available, for each year occupational dose was received, beginning January 1, 1989. *Note that 10 CFR 835 begins this summation on January 1, 1989, but LLNL includes all known dose values including those received prior to 1989 in the reported value.*	10 CFR 835
Decision Level (L_C)	The number of counts measured at or above which a decision is made that the analyte is definitely present.	ANSI/HPS N13.30-2011
Derived air concentration (DAC)	The airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 m^3).	10 CFR 835
Derived air concentration-hour (DAC-hour)	The product of the concentration of radioactive material in air (expressed as a fraction or multiple of the DAC for each radionuclide) and the time of exposure to that radionuclide, in hours.	10 CFR 835
Derived investigation level (DIL)	A value of a radiobioassay or air monitoring measurement that indicates an intake resulting in a dose exceeding an Investigation Level (IL).	DOE 2011
Deterministic effects *(nonstochastic effects)*	Effects due to radiation exposure for which the severity varies with the dose and for which a threshold normally exists (*e.g.*, radiation-induced opacities within the lens of the eye).	10 CFR 835
Discipline Action Plan (DAP)	An LLNL document establishing routine tasks and survey/monitoring requirements (e.g., contamination surveys) to be performed routinely by the ES&H Team H&S Technician for the specific facility or operation.	LLNL 2012
Dispersible radioactive material	Radioactive liquids, powders, fines, solids with oxidized surfaces, and other forms that can be easily transferred to another surface or medium. Dispersible radioactive material includes surface contamination in excess of the removable contamination thresholds in Appendix D of ES&H Manual Document 20.2 and Sealed Radioactive Sources that fail their leak test.	ES&H Manual Document 20.2
Dose	A general term for absorbed dose, equivalent dose, effective dose, committed equivalent dose, committed effective dose, or total effective dose as defined in 10 CFR 835.	10 CFR 835
Effective dose (E)	The summation of the products of the equivalent dose received by specified tissues or organs of the body (H_T) and the appropriate tissue weighting factor (w_T) – that is, $E = \Sigma w_T H_T$. It includes the dose from radiation sources internal and/or external to the body. For purposes of compliance with 10 CFR 835, equivalent dose to the whole body may be used as effective dose for external exposures. The effective dose is expressed in units of rem (or Sv).	10 CFR 835

Appendix A: Definitions

Term	Definition	Reference
Equivalent dose (H_T)	The product of average absorbed dose ($D_{T,R}$) in rad (or gray) in a tissue or organ (T) and a radiation (R) weighting factor (w_R). Equivalent dose is expressed in units of rem (or Sv).	10 CFR 835
External dose or exposure	That portion of the equivalent dose received from radiation sources outside the body (*i.e.*, "external sources").	10 CFR 835
General employee	An individual who is either a DOE or DOE contractor employee; an employee of a subcontractor to a DOE contractor; or an individual who performs work for or in conjunction with DOE or utilizes DOE facilities.	10 CFR 835
Intake	Activity that enters the respiratory or gastrointestinal tract from the environment. (See *Uptake*.)	ICRP Publication 119
Intake retention fraction (IRF)	The fraction of the initial intake activity that is expected to be present in the measured organ, tissue, or compartment at a specified time after intake.	
Intake excretion fraction (IEF)	The fraction of the initial intake that is expected to be collected in an incremental (e.g., "24-hour") urine or fecal sample collected at a specified day after intake.	
Internal dose or exposure	That portion of the equivalent dose received from radioactive material taken into the body (*i.e.*, "internal sources").	10 CFR 835
Investigation Level	The value of the committed effective dose from an intake(s) of radioactive material by a worker at or above which, for regulatory purposes, is regarded as sufficiently important to justify further investigation. *LLNL uses an Investigation Level of 0.1 rem CED.*	DOE 2011
Nonstochastic effects	See *deterministic effects*.	
Notification Level	In this Manual, the activity or concentration in a routine monitoring result at which the ES&H Team HP or Internal Dosimetry is promptly notified by the processing laboratory.	
Radiation weighting factor (w_R)	The modifying factor used to calculate the equivalent dose from the average tissue or organ absorbed dose; the absorbed dose (expressed in rad or gray) is multiplied by the appropriate radiation weighting factor. *With respect to internal dosimetry, the following radiation weighting factors are used:* *Photons:* $w_R = 1$ *Beta particles:* $w_R = 1$ *Alpha particles:* $w_R = 20$	10 CFR 835
Radiological area	Any area within a controlled area defined in 10 CFR 835 as a "radiation area," "high radiation area," "very high radiation area," "contamination area," "high contamination area," or "airborne radioactivity area."	10 CFR 835
Radiological worker	A general employee whose job assignment involves operation of radiation producing devices or working with radioactive materials, or who is likely to be routinely occupationally exposed above 0.1 rem (0.001 Sv) per year total effective dose.	10 CFR 835

Term	Definition	Reference
Real-time air monitoring	Measurement of the concentrations or quantities of airborne radioactive materials on a continuous basis. *See definition for air monitoring (specific).*	10 CFR 835
Remainder	The following additional tissues and organs and their masses, in grams, following parenthetically: adrenals (14), brain (1400), extrathoracic airways (15), small intestine (640), kidneys (310), muscle (28,000), pancreas (100), spleen (180), thymus (20), and uterus (80). The equivalent dose to the remainder tissues ($H_{remainder}$) is normally calculated as the mass-weighted mean dose to the preceding ten organs and tissues. In those cases in which the most highly irradiated remainder tissue or organ receives the highest equivalent dose of all the organs, a weighting factor of 0.025 (half of remainder) is applied to that tissue or organ and 0.025 (half of remainder) to the mass-weighted equivalent dose in the rest of the remainder tissues and organs to give the remainder equivalent dose.	10 CFR 835; *Remainder calculation details in ICRP Publication 68*
Safety plan (SP)	A management-approved safety document that describes the safety and environmental hazards and the applicable controls for a particular work activity.	ES&H Manual Document 20.2
Specific effective energy (SEE or $SEE(T \leftarrow S)_R$)	The energy, suitably modified for radiation weighting factor, imparted per unit mass of a target tissue, T, as a consequence of the emission of a specified radiation, R, from a transformation occurring in source region S expressed as Sv $(Bq\ s)^{-1}$.	ICRP Publication 68
Shall	A mandatory requirement from 10 CFR 835.	ES&H Manual Document 20.1
Should	A recommended practice. Can also indicate a desirable or best management practice. Written justification for declining to implement a "should" statement is not required.	ES&H Manual Document 20.1
Source region	An anatomical region within the reference phantom body which contains the radionuclide following its intake. The region may be an organ, a tissue, the contents of the gastrointestinal tract or urinary bladder, or the surfaces of tissues as in the skeleton, the alimentary tract, and the respiratory tract.	ICRP Publication 103
Special tritium compound (STC)	Any compound, except for H_2O, that contains tritium, either intentionally (e.g., by synthesis) or inadvertently (e.g., by contamination mechanisms).	ES&H Manual Document 20.2
Stochastic effects	Malignant and hereditary diseases for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose without a threshold, for radiation protection purposes.	10 CFR 835
Target region	Anatomical region within the body (reference phantom) in which radiation is absorbed. The region may be an organ or a specified tissue as in the gastrointestinal tract, urinary bladder, skeleton, and respiratory tract.	ICRP Publication 103
Technology shortfall	Exists when the Derived Investigation Level for a "reasonable and practical" routine bioassay program is less than the achievable Minimum Detectable Activity (or Concentration).	DOE 2011

Term	Definition	Reference
Tissue weighting factor (w_T)	The fraction of the overall health risk, resulting from uniform, whole body irradiation, attributable to specific tissue (T). The equivalent dose to tissue, (H_T), is multiplied by the appropriate tissue weighting factor to obtain the effective dose (E) contribution from that tissue. The tissue weighting factors are as follows:	10 CFR 835

ORGANS OR TISSUES, T:	TISSUE WEIGHTING FACTOR, W_T
Gonads	0.20
Red bone marrow	0.12
Colon	0.12
Lungs	0.12
Stomach	0.12
Bladder	0.05
Breast	0.05
Liver	0.05
Esophagus	0.05
Thyroid	0.05
Skin	0.01
Bone surfaces	0.01
Remainder [a]	0.05
Whole body	1.00

[a] See above crystal clear definition of the *Remainder*.

Total effective dose (TED)	The sum of the effective dose (for external exposures) and the committed effective dose.	10 CFR 835
Total organ equivalent dose (TOED)	In this Manual, the sum of the organ equivalent dose estimated to be received from external exposures and the committed equivalent dose received from internal exposures.	
Total organ dose (TOD)	The sum of the effective dose from external radiation and the committed effective dose to the maximally exposed organ or tissue other than the skin or the lens of the eye.	DOE 2014
Type I workplace	A workplace that provides minimal contamination control and does not provide a barrier between the worker and the material (e.g., a laboratory benchtop). Such workplaces are only appropriate for low-hazard operations where it is unlikely that a worker would incur an internal uptake.	ES&H Manual Document 20.2
Type II workplace	A workplace that provides one barrier between the worker and the material (e.g., a chemical fume hood). Such workplaces are appropriate for moderate-hazard operations where, without the proper controls, workers could incur a low-to-moderate internal uptake (e.g., up to a few rem CED).	ES&H Manual Document 20.2
Type III workplace	A workplace that provides two barriers between the worker and the material (e.g., a HEPA-filtered glovebox). Such workplaces are appropriate for high-hazard operations where, without the proper controls, workers could incur a significant internal uptake (i.e., a dose greater than the legal limits).	ES&H Manual Document 20.2
Uptake	Activity that enters the body fluids from the respiratory tract, gastrointestinal tract, or through the skin. (See *Intake*.)	ICRP Publication 119

Appendix B: Summary of Internal Dosimetry Factors for Selected Radionuclides

B.1 Introduction

The tables of this appendix summarize internal dosimetry factors that may be used to establish the technical basis for the type and frequency of internal dose monitoring. Models and assumptions used to generate these values are discussed in the ID TBM and summarized below.

B.1.1 Biokinetic Models

Bioassay factors and dose conversion factors were calculated with IMBA Professional Plus (Version 4.1.55) using the following biokinetic models:

Table B.1
Default Biokinetic Models

System or Element	Reference
Respiratory Tract Model	ICRP 66
Gastrointestinal Tract Model	ICRP 30
Americium	ICRP 67/78
Cesium	ICRP 67
Hydrogen	ICRP 67
Iodine	ICRP 67/78
Neptunium	ICRP 67/78
Plutonium	ICRP 67/78
Uranium	ICRP 69/78

B.1.2 Assumptions

The following assumptions were used in the derivation of these factors:

- Acute intake
- Particle size distribution: 5 μm AMAD
- f_1 values as specified in ICRP 68
- Receptor is an adult male worker (ICRP Publication 89)

B.1.3 Derivation of ALIs and DACs

The ALI values listed in the tables below are based on the more limiting of either the committed effective dose (stochastic ALI, or *SALI*) or the highest committed equivalent dose to an organ or tissue (non-stochastic ALI, or *NALI*). DAC values are reproduced from 10 CFR 835, Appendix A.

B.1.4 List of Radionuclides

The radionuclides included in this Appendix are the major radionuclides of concern at LLNL that are included in the Conditions of DOELAP Accreditation, effective October 30, 2014.

CONDITIONS OF DOELAP ACCREDITATION

Lawrence Livermore National Laboratory
(Lawrence Livermore National Security, LLC)

Effective until August 31, 2017, the indirect (*in vitro*) and direct (*in vivo*) radiobioassay systems described below, used at the Lawrence Livermore National Laboratory, are hereby granted DOELAP accreditation:

	DOELAP Indirect Categories:	Urine	Fecal
I	Beta Activity: Avg. Energy <100 keV		
	Hydrogen-3	☑	☐
	Carbon-14	☐	☐
	Sulfur-35	☐	☐
	Radium-228	☐	☐
II	Beta Activity: Avg. Energy ≥100 keV		
	Phosphorus-32	☐	☐
	Strontium-89/90	☐	☐
	or Strontium-90	☐	☐
III	Alpha Activity, isotopic analysis		
	Thorium-228/232	☐	☐
	or Thorium-230	☐	☐
	Uranium-234/238	☐	☐
	Neptunium-237	☐	☐
	Plutonium-238	☑	☑
	or Plutonium-239/240	☑	☑
	Americium-241	☑	☑
IV	Elemental (mass/volume)		
	Uranium-Total	☑	☐
	Uranium-235	☑	☐
	Neptunium-237	☑	☐
	Uranium-238	☑	☐
V	Gamma (photon) activity		
	Cobalt-60	☑	☑
	Iodine-125	☑	☑
	Cesium-137	☑	☑

	DOELAP Direct Categories:	Type	ACT-II	Scanning Bed
I	Transuranium elements via L x-rays	Lung	☑	☐
II	Americium-241	Lung	☑	☐
III	Thorium-234 in equilibrium with Uranium-238	Lung	☑	☐
IV	Uranium-235	Lung	☑	☐
V	Fission and activation products	Lung		
	Manganese-54		☐	☑
	Cobalt-58		☐	☑
	Cobalt-60		☐	☑
	Cerium-144		☐	☑
VI	Fission and activation products	Total body		
	Cesium-134		☐	☑
	Cesium-137		☐	☑
VII	Radionuclides in the thyroid	Thyroid		
	Iodine-125		☑	☐
	Iodine-131		☑	☐

Accreditation is for these radiobioassay systems only, and is contingent upon maintaining a radiobioassay program that is consistent with the application(s) submitted, the methodologies used during DOELAP performance testing, and any corrective actions made in response to the onsite assessment. Accreditation of these radiobioassay systems will be necessary every three years as required by 10 CFR 835.402(d) and as discussed in the DOE Technical Standard DOE-STD-1112-98, *Laboratory Accreditation Program for Radiobioassay*.

B.2 Americium

Table B.2
Summary of bioassay factors for ^{241}Am

Typical monitoring techniques and MDAs			
Lung Count		0.15 nCi	Assuming 4 cm CWT
Urine		0.02 dpm/sample	MDDs assume a 24-hour sample
Feces		0.02 dpm/sample	MDDs assume a 24-hour sample
Reference values			
DAC	Type M	5E-12 µCi/mL	
ALI	Type M	0.012 µCi	NALI; Bone Surface (BS) is the limiting tissue
SALI	Type M	0.05 µCi	*For reference only; NALI is limiting*
Dose conversion factors			
Inhalation	Type M	100 rem CED/µCi	4100 rem BS/µCi

Table B.3
Summary of minimum detectable doses (rem CED) for inhalation of ^{241}Am (Type M)

Days Post-Intake	Lung	Urine	Feces
1	2.60E-01	5.08E-04	8.31E-06
2	2.68E-01	3.88E-03	5.82E-06
3	2.73E-01	6.89E-03	1.13E-05
7	2.89E-01	1.56E-02	3.90E-04
15	3.24E-01	2.29E-02	2.13E-03
30	3.91E-01	3.44E-02	3.22E-03
90	6.88E-01	5.75E-02	1.37E-02
180	1.26E+00	8.21E-02	5.36E-02
365	3.76E+00	1.29E-01	1.62E-01

B.3 Cesium

Table B.4
Summary of bioassay factors for ^{137}Cs

Typical monitoring techniques and MDAs			
Whole Body Scan		1 nCi	NL = 5 nCi unless monitoring for Marshall Islands work
Urine		0.5 nCi	Reference MDA for gamma scan of urine samples
Feces		0.5 nCi	Reference MDA for gamma scan of fecal samples
Reference values			
DAC	Type F	8E-08 µCi/mL	
ALI	Type F	202 µCi	
Dose Conversion Factors			
Inhalation		Type F	0.0248 rem CED/µCi

Table B.5
Summary of minimum detectable doses (rem CED) for inhalation of ^{137}Cs (Type F)

Days Post-Intake	Whole Body	Urine	Feces
1	4.15E-05	7.84E-07	2.59E-05
2	4.89E-05	5.00E-07	4.26E-06
3	5.31E-05	6.23E-07	2.71E-06
7	5.87E-05	1.46E-06	4.35E-06
15	6.26E-05	2.65E-06	1.01E-05
30	6.90E-05	3.08E-06	1.22E-05
90	1.01E-04	4.51E-06	1.79E-05
180	1.79E-04	7.99E-06	3.17E-05
365	5.82E-04	2.60E-05	1.03E-04

B.4 Hydrogen

Table B.6
Summary of bioassay factors for ^{3}H

Typical monitoring techniques and MDAs			
Urine		0.01 µCi/mL	Spot sample (single void) is sufficient
Personal air sampling		20 dpm/sample	Personal air sampling to monitor for potential STC intakes
Reference values			
DAC	HTO	2E-05 µCi/mL	
	HT or T_2	2E-01 µCi/mL	
	STC	--	See ID TBM, Appendix C
ALI	HTO	74 mCi	
	HT or T_2	740 Ci	
Dose conversion factors			
Inhalation	HTO	6.76E-05 rem CED/µCi	
	OBT	1.5E-04 rem CED/µCi	
	HT or T_2	6.76E-09 rem CED/µCi	
	STC	--	See ID TBM, Appendix C

Table B.7
Summary of minimum detectable doses (rem CED) for inhalation of HTO

Days Post-Intake	Urine
1	3.00E-05
2	3.21E-05
3	3.43E-05
7	4.49E-05
15	7.65E-05
30	2.01E-04
90	3.42E-03

B.5 Iodine

Table B.8
Summary of bioassay factors for ^{125}I

Typical monitoring techniques and MDAs			
Thyroid Count		0.3 nCi	
Urine		0.002 µCi/L	LSC screening analysis (thyroid counts are preferred)
Reference values			
DAC	Methyl	2E-08 µCi/mL	
	Vapor	2E-08 µCi/mL	
	Type F	3E-08 µCi/mL	
ALI	Methyl	63.6 µCi	NALI; Thyroid (T) is the limiting organ
	Vapor	49.5 µCi	NALI; Thyroid (T) is the limiting organ
	Type F	92.6 µCi	NALI; Thyroid (T) is the limiting organ
SALI	Methyl	127 µCi	*For reference only; NALI is limiting*
	Vapor	98.6 µCi	*For reference only; NALI is limiting*
	Type F	184 µCi	*For reference only; NALI is limiting*

Dose conversion factors			
Inhalation	Methyl (CH_3I)	0.0394 rem CED/µCi	0.786 rem T/µCi
	Vapor (I_2)	0.0507 rem CED/µCi	1.01 rem T/µCi
	Particulate (Type F)	0.0271 rem CED/µCi	0.54 rem T/µCi

Table B.9
Summary of minimum detectable doses (rem CED) for inhalation of ^{125}I

Days Post-Intake	Methyl Iodide ($CH_3{}^{125}I$)		Elemental Iodine ($^{125}I_2$)		Particulate ^{125}I (Type F)	
	Thyroid	Urine	Thyroid	Urine	Thyroid	Urine
1	6.11E-05	2.83E-04	6.23E-05	2.90E-04	6.31E-05	2.95E-04
2	5.86E-05	3.45E-03	5.87E-05	2.73E-03	5.88E-05	2.38E-03
3	5.96E-05	5.38E-02	5.96E-05	4.23E-02	5.96E-05	3.69E-02
7	6.45E-05	4.92E-01	6.45E-05	4.96E-01	6.45E-05	4.99E-01
15	7.52E-05	2.87E-01	7.52E-05	2.88E-01	7.52E-05	2.88E-01
30	9.94E-05	2.48E-01	9.95E-05	2.49E-01	9.95E-05	2.49E-01
90	2.93E-04	5.75E-01	2.93E-04	5.75E-01	2.93E-04	5.75E-01
180	1.46E-03	2.84E+00	1.46E-03	2.84E+00	1.46E-03	2.84E+00
365	3.97E-02	7.72E+01	3.97E-02	7.72E+01	3.97E-02	7.72E+01

Table B.10
Summary of bioassay factors for ^{131}I

Typical monitoring techniques and MDAs			
Thyroid Count		0.04 nCi	
Urine		0.002 µCi/L	LSC screening analysis (thyroid counts are preferred)
Reference values			
DAC	Methyl	1E-08 µCi/mL	
	Vapor	1E-08 µCi/mL	
	Type F	2E-08 µCi/mL	
ALI	Methyl	44.2 µCi	NALI; Thyroid (T) is the limiting organ
	Vapor	34.5 µCi	NALI; Thyroid (T) is the limiting organ
	Type F	64.7 µCi	NALI; Thyroid (T) is the limiting organ
SALI	Methyl	87.9 µCi	*For reference only; NALI is limiting*
	Vapor	68.4 µCi	*For reference only; NALI is limiting*
	Type F	129 µCi	*For reference only; NALI is limiting*

Dose conversion factors			
Inhalation	Methyl (CH_3I)	0.0569 rem CED/µCi	1.13 rem T/µCi
	Vapor (I_2)	0.0731 rem CED/µCi	1.45 rem T/µCi
	Particulate (Type F)	0.0389 rem CED/µCi	0.773 rem T/µCi

Table B.11
Summary of minimum detectable doses (rem CED) for inhalation of ^{131}I

Days Post-Intake	Methyl Iodide ($CH_3{}^{131}I$)		Elemental Iodine ($^{131}I_2$)		Particulate ^{131}I (Type F)	
	Thyroid	Urine	Thyroid	Urine	Thyroid	Urine
1	1.27E-05	4.41E-04	1.29E-05	4.51E-04	1.30E-05	4.57E-04
2	1.31E-05	5.79E-03	1.31E-05	4.57E-03	1.31E-05	3.97E-03
3	1.44E-05	9.71E-02	1.43E-05	7.63E-02	1.43E-05	6.62E-02
7	2.09E-05	1.20E+00	2.09E-05	1.21E+00	2.08E-05	1.21E+00
15	4.44E-05	1.27E+00	4.43E-05	1.27E+00	4.41E-05	1.27E+00
30	1.80E-04	3.37E+00	1.80E-04	3.37E+00	1.79E-04	3.36E+00
90	4.68E-02	6.89E+02	4.68E-02	6.89E+02	4.65E-02	6.85E+02

B.6 Neptunium

Table B.12
Summary of bioassay factors for ^{237}Np

Typical monitoring techniques and MDAs			
Lung Count		0.4 nCi	Assuming 4 cm CWT
Whole Body Count		2 nCi ^{233}Pa	Assuming secular equilibrium with ^{237}Np
Urine		0.032 ng/L	Spot sample is sufficient for ICP-MS analysis
		0.35 dpm/sample	Worst-case MDA for screening analysis with a 24-hour sample processed by Pu-239 and Gross Alpha techniques
Reference values			
DAC	Type M	8E-12 µCi/mL	
ALI	Type M	0.020 µCi	NALI; Bone Surface (BS) is the limiting tissue
SALI	Type M	0.093 µCi	*For reference only; NALI is limiting*
Dose conversion factors			
Inhalation	Type M	54 rem CED/µCi	2470 rem BS/µCi

Table B.13
Summary of minimum detectable doses (rem CED) for inhalation of ^{237}Np (Type M)

Days Post-Intake	Lung	Whole Body (^{233}Pa)	Urine (ICP-MS)	Urine (Alpha screen)
1	3.75E-01	2.20E-01	3.13E-04	1.37E-03
2	3.86E-01	4.21E-01	1.46E-03	6.37E-03
3	3.93E-01	7.35E-01	2.79E-03	1.22E-02
7	4.17E-01	1.44E+00	9.58E-03	4.19E-02
15	4.66E-01	1.57E+00	2.00E-02	8.73E-02
30	5.63E-01	1.73E+00	2.53E-02	1.11E-01
90	9.90E-01	2.14E+00	4.38E-02	1.92E-01
180	1.81E+00	2.42E+00	7.23E-02	3.16E-01
365	5.41E+00	2.71E+00	1.54E-01	6.75E-01

B.7 Plutonium

Table B.14
Summary of bioassay factors for weapons grade plutonium (WGPu)

Typical monitoring techniques and MDAs

Lung Count	0.15 nCi ^{241}Am	Assuming aged WGPu and 4 cm CWT
Urine	0.01 dpm/sample	$^{239+240}$Pu result; MDDs assume a 24-hour sample
Feces	0.01 dpm/sample	$^{239+240}$Pu result; MDDs assume a 24-hour sample

Inhalation dose conversion factors

Age (years)	Solubility Type	rem/nCi ^{241}Am	rem/dpm $^{239+240}$Pu
0	Type M	N/A	6.70E-05
	Type S	N/A	1.68E-05
15	Type M	1.08E+00	6.86E-05
	Type S	2.83E-01	1.81E-05
30	Type M	7.41E-01	6.91E-05
	Type S	1.99E-01	1.85E-05
50	Type M	6.36E-01	6.89E-05
	Type S	1.72E-01	1.87E-05

Table B.15
Reference mixture of weapons grade plutonium, 0 years after initial separation

Isotope	Mass %	Alpha activity (Ci) per gram mix	Total activity (Ci) per gram mix	Total activity relative to ^{241}Am	Total activity relative to $^{239+240}$Pu	Total activity relative to total alpha
^{238}Pu	0.0400	6.85E-03	6.85E-03	N/A	9.58E-02	8.74E-02
^{239}Pu	93.3400	5.79E-02	5.79E-02	N/A	8.10E-01	7.39E-01
^{240}Pu	6.0000	1.36E-02	1.36E-02	N/A	1.90E-01	1.74E-01
^{241}Pu	0.5800	1.47E-05	6.00E-01	N/A	8.38E+00	7.65E+00
^{242}Pu	0.0400	1.58E-06	1.58E-06	N/A	2.20E-05	2.01E-05
^{241}Am	0.0000	0.00E+00	0.00E+00	N/A	0.00E+00	0.00E+00
Total		**7.84E-02**	**6.78E-01**			

Table B.16
Reference mixture of weapons grade plutonium, 15 years after initial separation

Isotope	Mass %	Alpha activity (Ci) per gram mix	Total activity (Ci) per gram mix	Total activity relative to ^{241}Am	Total activity relative to $^{239+240}$Pu	Total activity relative to total alpha
^{238}Pu	0.0355	6.08E-03	6.08E-03	6.01E-01	8.51E-02	6.94E-02
^{239}Pu	93.2998	5.78E-02	5.79E-02	5.72E+00	8.10E-01	6.60E-01
^{240}Pu	5.9905	1.36E-02	1.36E-02	1.34E+00	1.90E-01	1.55E-01
^{241}Pu	0.2810	7.12E-06	2.91E-01	2.87E+01	4.06E+00	3.31E+00
^{242}Pu	0.0400	1.58E-06	1.58E-06	1.56E-04	2.20E-05	1.80E-05
^{241}Am	0.2950	1.01E-02	1.01E-02	1.00E+00	1.42E-01	1.15E-01
Total		**8.77E-02**	**3.78E-01**			

Table B.17
Reference mixture of weapons grade plutonium, 30 years after initial separation

Isotope	Mass %	Alpha activity (Ci) per gram mix	Total activity (Ci) per gram mix	Total activity relative to ^{241}Am	Total activity relative to $^{239+240}$Pu	Total activity relative to total alpha
^{238}Pu	0.0316	5.40E-03	5.40E-03	3.65E-01	7.57E-02	5.90E-02
^{239}Pu	93.2595	5.78E-02	5.79E-02	3.91E+00	8.10E-01	6.32E-01
^{240}Pu	5.9810	1.36E-02	1.36E-02	9.18E-01	1.90E-01	1.48E-01
^{241}Pu	0.1362	3.45E-06	1.41E-01	9.52E+00	1.97E+00	1.54E+00
^{242}Pu	0.0400	1.58E-06	1.58E-06	1.07E-04	2.21E-05	1.72E-05
^{241}Am	0.4309	1.48E-02	1.48E-02	1.00E+00	2.07E-01	1.61E-01
Total		**9.16E-02**	**2.32E-01**			

Table B.18
Reference mixture of weapons grade plutonium, 50 years after initial separation

Isotope	Mass %	Alpha activity (Ci) per gram mix	Total activity (Ci) per gram mix	Total activity relative to ^{241}Am	Total activity relative to $^{239+240}$Pu	Total activity relative to total alpha
^{238}Pu	0.0269	4.61E-03	4.61E-03	2.69E-01	6.47E-02	4.96E-02
^{239}Pu	93.2059	5.78E-02	5.78E-02	3.37E+00	8.10E-01	6.21E-01
^{240}Pu	5.9684	1.35E-02	1.35E-02	7.89E-01	1.90E-01	1.45E-01
^{241}Pu	0.0518	1.31E-06	5.36E-02	3.12E+00	7.51E-01	5.75E-01
^{242}Pu	0.0400	1.58E-06	1.58E-06	9.18E-05	2.21E-05	1.69E-05
^{241}Am	0.5001	1.72E-02	1.72E-02	1.00E+00	2.40E-01	1.84E-01
Total		**9.31E-02**	**1.47E-01**			

Table B.19
Summary of minimum detectable doses (rem CED) for inhalation of 15-year-old WGPu

Days Post-Intake	Type M			Type S		
	Lung	Urine	Feces	Lung	Urine	Feces
1	2.80E+00	2.97E-03	6.34E-06	6.61E-01	7.71E-02	1.58E-06
2	2.89E+00	5.26E-03	4.44E-06	6.78E-01	1.33E-01	1.11E-06
3	2.94E+00	8.83E-03	8.61E-06	6.86E-01	2.17E-01	2.15E-06
7	3.11E+00	2.82E-02	2.94E-04	7.14E-01	5.80E-01	7.31E-05
15	3.48E+00	6.12E-02	1.61E-03	7.67E-01	9.74E-01	3.66E-04
30	4.20E+00	7.22E-02	2.44E-03	8.61E-01	1.05E+00	5.15E-04
90	7.40E+00	9.64E-02	1.03E-02	1.13E+00	1.12E+00	1.69E-03
180	1.35E+01	1.28E-01	4.03E-02	1.33E+00	1.13E+00	4.84E-03
365	4.04E+01	1.78E-01	1.26E-01	1.60E+00	1.08E+00	8.13E-03

Table B.20
Summary of minimum detectable doses (rem CED) for inhalation of 30-year-old WGPu

Days Post-Intake	Type M			Type S		
	Lung	Urine	Feces	Lung	Urine	Feces
1	1.93E+00	2.98E-03	6.38E-06	4.64E-01	7.91E-02	1.63E-06
2	1.99E+00	5.29E-03	4.47E-06	4.76E-01	1.37E-01	1.14E-06
3	2.02E+00	8.88E-03	8.67E-06	4.82E-01	2.22E-01	2.21E-06
7	2.14E+00	2.84E-02	2.96E-04	5.01E-01	5.95E-01	7.50E-05
15	2.40E+00	6.16E-02	1.62E-03	5.39E-01	9.99E-01	3.76E-04
30	2.89E+00	7.27E-02	2.46E-03	6.04E-01	1.08E+00	5.29E-04
90	5.09E+00	9.70E-02	1.04E-02	7.92E-01	1.15E+00	1.73E-03
180	9.32E+00	1.29E-01	4.05E-02	9.33E-01	1.16E+00	4.96E-03
365	2.78E+01	1.79E-01	1.27E-01	1.13E+00	1.10E+00	8.35E-03

Table B.21
Summary of minimum detectable doses (rem CED) for inhalation of 50-year-old WGPu

Days Post-Intake	Type M			Type S		
	Lung	Urine	Feces	Lung	Urine	Feces
1	1.65E+00	2.97E-03	6.36E-06	4.02E-01	7.96E-02	1.64E-06
2	1.70E+00	5.27E-03	4.45E-06	4.12E-01	1.38E-01	1.14E-06
3	1.73E+00	8.85E-03	8.64E-06	4.17E-01	2.24E-01	2.22E-06
7	1.84E+00	2.83E-02	2.95E-04	4.34E-01	5.99E-01	7.54E-05
15	2.06E+00	6.14E-02	1.62E-03	4.66E-01	1.01E+00	3.78E-04
30	2.48E+00	7.24E-02	2.45E-03	5.23E-01	1.08E+00	5.32E-04
90	4.37E+00	9.67E-02	1.04E-02	6.86E-01	1.16E+00	1.74E-03
180	7.99E+00	1.28E-01	4.04E-02	8.08E-01	1.17E+00	4.99E-03
365	2.39E+01	1.78E-01	1.27E-01	9.75E-01	1.11E+00	8.40E-03

Table B.22
Summary of bioassay factors for ^{238}Pu

Typical monitoring techniques and MDAs		
Lung Count	140 nCi	Assuming 4 cm CWT
Urine	0.01 dpm/sample	MDDs assume a 24-hour sample
Feces	0.01 dpm/sample	MDDs assume a 24-hour sample

Reference values			
DAC	Type M	6E-12 µCi/mL	
	Type S	5E-11 µCi/mL	
ALI	Type M	0.015 µCi	NALI; Bone Surface (BS) is the limiting tissue
	Type S	0.128 µCi	SALI
SALI	Type M	0.045 µCi	*For reference only; NALI is limiting for Type M ^{238}Pu*

Dose conversion factors			
Inhalation	Type M	111 rem CED/µCi	3350 rem BS/µCi
	Type S	39.2 rem CED/µCi	

Table B.23
Summary of minimum detectable doses (rem CED) for inhalation of ^{238}Pu

Days Post-Intake	Type M			Type S		
	Lung	Urine	Feces	Lung	Urine	Feces
1	2.70E+02	2.16E-03	4.62E-06	8.54E+01	7.53E-02	1.55E-06
2	2.78E+02	3.83E-03	3.23E-06	8.75E+01	1.30E-01	1.08E-06
3	2.83E+02	6.43E-03	6.27E-06	8.86E+01	2.12E-01	2.10E-06
7	3.00E+02	2.05E-02	2.14E-04	9.22E+01	5.66E-01	7.14E-05
15	3.35E+02	4.46E-02	1.18E-03	9.91E+01	9.51E-01	3.58E-04
30	4.05E+02	5.26E-02	1.78E-03	1.11E+02	1.03E+00	5.04E-04
90	7.14E+02	7.03E-02	7.53E-03	1.46E+02	1.10E+00	1.65E-03
180	1.31E+03	9.33E-02	2.94E-02	1.72E+02	1.11E+00	4.74E-03
365	3.92E+03	1.30E-01	9.28E-02	2.09E+02	1.06E+00	8.01E-03

Table B.24
Summary of bioassay factors for ^{239}Pu

Typical monitoring techniques and MDAs			
Lung Count		215 nCi	Assuming 4 cm CWT
Urine		0.01 dpm/sample	Result is for $^{239+240}$Pu; MDDs assume a 24-hour sample
Feces		0.01 dpm/sample	Result is for $^{239+240}$Pu; MDDs assume a 24-hour sample
Reference values			
DAC	Type M	5E-12 µCi/mL	
	Type S	6E-11 µCi/mL	
ALI	Type M	0.013 µCi	NALI; Bone Surface (BS) is the limiting tissue
	Type S	0.149 µCi	NALI; BS is the limiting tissue
SALI	Type M	0.042 µCi	*For reference only; NALI is limiting*
	Type S	0.161 µCi	*For reference only; NALI is limiting*
Dose conversion factors			
Inhalation	Type M	120 rem CED/µCi	3730 rem BS/µCi
	Type S	31 rem CED/µCi	336 rem BS/µCi

Table B.25
Summary of minimum detectable doses (rem CED) for inhalation of ^{239}Pu

Days Post-Intake	Type M			Type S		
	Lung	Urine	Feces	Lung	Urine	Feces
1	4.48E+02	2.33E-03	4.99E-06	1.04E+02	5.95E-02	1.22E-06
2	4.61E+02	4.14E-03	3.49E-06	1.06E+02	1.03E-01	8.56E-07
3	4.69E+02	6.95E-03	6.78E-06	1.08E+02	1.67E-01	1.66E-06
7	4.98E+02	2.22E-02	2.31E-04	1.12E+02	4.48E-01	5.64E-05
15	5.57E+02	4.82E-02	1.27E-03	1.20E+02	7.52E-01	2.83E-04
30	6.72E+02	5.68E-02	1.92E-03	1.35E+02	8.11E-01	3.98E-04
90	1.18E+03	7.59E-02	8.12E-03	1.77E+02	8.68E-01	1.30E-03
180	2.16E+03	1.01E-01	3.17E-02	2.08E+02	8.73E-01	3.74E-03
365	6.46E+03	1.40E-01	9.95E-02	2.52E+02	8.31E-01	6.28E-03

Table B.26
Summary of bioassay factors for ^{242}Pu

Typical monitoring techniques and MDAs

Lung Count	200 nCi	Assuming 4 cm CWT
Urine	0.01 dpm/sample	MDDs assume a 24-hour sample
Feces	0.01 dpm/sample	MDDs assume a 24-hour sample

Reference values

DAC	Type M	5E-12 µCi	
	Type S	6E-11 µCi	
ALI	Type M	0.014 µCi	NALI; Bone Surface (BS) is the limiting tissue
	Type S	0.157 µCi	NALI; BS is the limiting tissue
SALI	Type M	0.044 µCi	*For reference only; NALI is limiting*
	Type S	0.174 µCi	*For reference only; NALI is limiting*

Dose conversion factors

Inhalation	Type M	114 rem CED/µCi	3550 rem BS/µCi
	Type S	28.8 rem CED/µCi	319 rem BS/µCi

Table B.27
Summary of minimum detectable doses (rem CED) for inhalation of ^{242}Pu

Days Post-Intake	Type M			Type S		
	Lung	Urine	Feces	Lung	Urine	Feces
1	3.96E+02	2.22E-03	4.74E-06	8.96E+01	5.53E-02	1.14E-06
2	4.08E+02	3.93E-03	3.32E-06	9.19E+01	9.56E-02	7.95E-07
3	4.15E+02	6.60E-03	6.44E-06	9.30E+01	1.55E-01	1.54E-06
7	4.40E+02	2.11E-02	2.20E-04	9.68E+01	4.16E-01	5.24E-05
15	4.92E+02	4.58E-02	1.21E-03	1.04E+02	6.99E-01	2.63E-04
30	5.94E+02	5.40E-02	1.83E-03	1.17E+02	7.54E-01	3.70E-04
90	1.04E+03	7.21E-02	7.72E-03	1.53E+02	8.06E-01	1.21E-03
180	1.91E+03	9.55E-02	3.01E-02	1.80E+02	8.11E-01	3.47E-03
365	5.71E+03	1.33E-01	9.46E-02	2.17E+02	7.72E-01	5.84E-03

B.8 Uranium

Table B.28
Summary of bioassay factors for depleted uranium

Reference isotopic mix for depleted uranium (DU)				
	^{234}U	^{235}U	^{236}U	^{238}U
Activity fraction	1.55E-01	1.07E-02	5.00E-04	8.34E-01
Mass fraction	1.00E-05	1.99E-03	3.11E-06	9.98E-01

Typical monitoring techniques and MDAs		
Lung Count	0.8 nCi ^{234}Th	Assumes secular equilibrium with ^{238}U and 4 cm CWT
Urine	3.3E-03 µg ^{238}U/L	Spot (single void) sample is sufficient for ICP-MS analysis

Reference values			
DAC	Type F	5.6E-10 µCi/mL	Compare to 5E-10 µCi/mL DAC for ^{238}U
	Type M	3.3E-10 µCi/mL	Compare to 3E-10 µCi/mL DAC for ^{238}U
	Type S	8.5E-11 µCi/mL	Compare to 8E-11 µCi/mL DAC for ^{238}U
ALI	Type F	1.34 µCi DU	NALI; Bone Surface (BS) is the limiting tissue
	Type M	0.782 µCi DU	
	Type S	0.203 µCi DU	NALI; Extrathoracic airways (ET) are the limiting tissue
SALI	Type F	2.27 µCi DU	*For reference only; NALI is limiting*
	Type S	0.229 µCi DU	*For reference only; NALI is limiting*

Dose conversion factors			
Inhalation	Type F	2.20 rem CED/µCi DU	37.4 rem BS/µCi DU
	Type M	6.39 rem CED/µCi DU	
	Type S	21.8 rem CED/µCi DU	246 rem ET/µCi DU

Table B.29
Summary of minimum detectable doses (rem CED) for inhalation of depleted uranium

Days Post-Intake	Type F	Type M		Type S	
	Urine	Lung	Urine	Lung	Urine
1	2.55E-08	1.06E-01	5.85E-07	3.25E-01	6.59E-05
2	7.34E-07	1.10E-01	1.21E-05	3.33E-01	1.05E-03
3	9.11E-07	1.11E-01	1.59E-05	3.38E-01	1.78E-03
7	1.34E-06	1.18E-01	2.11E-05	3.51E-01	2.42E-03
15	2.60E-06	1.32E-01	3.18E-05	3.78E-01	3.72E-03
30	6.87E-06	1.60E-01	5.12E-05	4.24E-01	6.01E-03
90	3.91E-05	2.81E-01	1.09E-04	5.55E-01	1.08E-02
180	1.50E-04	5.14E-01	2.08E-04	6.54E-01	1.41E-02
365	8.46E-04	1.54E+00	6.23E-04	7.89E-01	1.76E-02

Table B.30
Summary of bioassay factors for natural uranium

Reference isotopic mix for natural uranium (Nat U)

	^{234}U	^{235}U	^{236}U	^{238}U
Activity fraction	4.89E-01	2.28E-02	0.00E+00	4.89E-01
Mass fraction	5.37E-02	7.20E-03	0.00E+00	9.93E-01

Typical monitoring techniques and MDAs

Lung Count	0.8 nCi ^{234}Th	Assumes secular equilibrium with ^{238}U and 4 cm CWT
Urine	0.04 µg ^{238}U/L	Spot (single void) sample is sufficient for ICP-MS analysis; assumes background value of 0.01 µg ^{238}U/L

Reference values

DAC	Type F	5E-10 µCi/mL	Same as 10 CFR 835 DAC for ^{238}U
	Type M	3E-10 µCi/mL	Same as 10 CFR 835 DAC for ^{238}U
	Type S	8E-11 µCi/mL	Same as 10 CFR 835 DAC for ^{238}U
ALI	Type F	1.28 µCi Nat U	NALI; Bone Surface (BS) is the limiting tissue
	Type M	0.718 µCi Nat U	
	Type S	0.193 µCi Nat U	NALI; Extrathoracic airways (ET) are the limiting tissue
SALI	Type F	2.19 µCi Nat U	*For reference only; NALI is limiting*
	Type S	0.216 µCi Nat U	*For reference only; NALI is limiting*

Dose conversion factors

Inhalation	Type F	2.28 rem CED/µCi Nat U	39 rem BS/µCi Nat U
	Type M	6.96 rem CED/µCi Nat U	
	Type S	23.2 rem CED/µCi Nat U	259 rem ET/µCi Nat U

Table B.31
Summary of minimum detectable doses (rem CED) for inhalation of natural uranium

Days Post-Intake	Type F	Type M		Type S	
	Urine	Lung	Urine	Lung	Urine
1	5.46E-07	1.98E-01	1.32E-05	5.91E-01	1.45E-03
2	1.57E-05	2.04E-01	2.73E-04	6.06E-01	2.32E-02
3	1.95E-05	2.07E-01	3.59E-04	6.13E-01	3.93E-02
7	2.87E-05	2.20E-01	4.75E-04	6.38E-01	5.33E-02
15	5.58E-05	2.46E-01	7.16E-04	6.86E-01	8.18E-02
30	1.47E-04	2.97E-01	1.15E-03	7.70E-01	1.32E-01
90	8.38E-04	5.22E-01	2.46E-03	1.01E+00	2.39E-01
180	3.22E-03	9.56E-01	4.69E-03	1.19E+00	3.10E-01
365	1.81E-02	2.85E+00	1.40E-02	1.43E+00	3.87E-01

Table B.32
Summary of bioassay factors for low-enriched uranium (3.5% ^{235}U by mass)

Reference isotopic mix for low-enriched uranium (LEU)

	^{234}U	^{235}U	^{236}U	^{238}U
Activity fraction	8.18E-01	3.44E-02	0.00E+00	1.47E-01
Mass fraction	2.90E-04	3.50E-02	0.00E+00	9.65E-01

Typical monitoring techniques and MDAs

Lung Count	0.09 nCi ^{235}U	Assumes 4 cm CWT
Urine	1.3E-05 µg ^{235}U/L	Spot (single void) sample is sufficient for ICP-MS analysis

Reference values

DAC	Type F	5E-10 µCi/mL	Same as 10 CFR 835 DAC values for ^{238}U
	Type M	2.8E-10 µCi/mL	Compare to 3E-10 µCi/mL DAC for ^{238}U
	Type S	7.7E-11 µCi/mL	Compare to 8E-11 µCi/mL DAC for ^{238}U
ALI	Type F	1.24 µCi LEU	NALI; Bone Surface (BS) is the limiting tissue
	Type M	0.665 µCi LEU	
	Type S	0.184 µCi LEU	NALI; Extrathoracic airways (ET) are the limiting tissue
SALI	Type F	2.11 µCi LEU	*For reference only; NALI is limiting*
	Type S	0.203 µCi LEU	*For reference only; NALI is limiting*

Dose conversion factors

Inhalation	Type F	2.37 rem CED/µCi LEU	40.4 rem BS/µCi LEU
	Type M	7.52 rem CED/µCi LEU	
	Type S	24.6 rem CED/µCi LEU	272 rem ET/µCi LEU

Table B.33
Summary of minimum detectable doses (rem CED) for inhalation of low-enriched uranium

Days Post-Intake	Type F	Type M		Type S	
	Urine	Lung	Urine	Lung	Urine
1	1.69E-08	3.42E-01	4.24E-07	1.00E+00	4.57E-05
2	4.86E-07	3.52E-01	8.75E-06	1.03E+00	7.30E-04
3	6.04E-07	3.58E-01	1.15E-05	1.04E+00	1.24E-03
7	8.87E-07	3.80E-01	1.52E-05	1.08E+00	1.68E-03
15	1.72E-06	4.24E-01	2.30E-05	1.16E+00	2.58E-03
30	4.55E-06	5.13E-01	3.71E-05	1.31E+00	4.17E-03
90	2.59E-05	9.02E-01	7.90E-05	1.71E+00	7.52E-03
180	9.94E-05	1.65E+00	1.51E-04	2.02E+00	9.78E-03
365	5.60E-04	4.93E+00	4.51E-04	2.43E+00	1.22E-02

Table B.34
Summary of bioassay factors for highly enriched uranium (93.5% ^{235}U by mass)

Reference isotopic mix for highly enriched uranium (HEU)

	^{234}U	^{235}U	^{236}U	^{238}U
Activity fraction	9.68E-01	2.97E-02	1.97E-03	2.60E-04
Mass fraction	1.06E-02	9.35E-01	2.08E-03	5.27E-02

Typical monitoring techniques and MDAs

Lung Count	0.09 nCi ^{235}U	Assumes 4 cm CWT
Urine	1.3E-05 µg ^{235}U/L	Spot (single void) sample is sufficient for ICP-MS analysis

Reference values

DAC	Type F	5E-10 µCi/mL	Same as 10 CFR 835 DAC values for ^{234}U
	Type M	2.7E-10 µCi/mL	Compare to 2E-10 µCi/mL DAC for ^{234}U
	Type S	7.5E-11 µCi/mL	Compare to 7E-11 µCi/mL DAC for ^{234}U
ALI	Type F	1.22 µCi HEU	NALI; Bone Surface (BS) is the limiting tissue
	Type M	0.644 µCi HEU	
	Type S	0.181 µCi HEU	NALI; Extrathoracic airways (ET) are the limiting tissue
SALI	Type F	2.08 µCi HEU	*For reference only; NALI is limiting*
	Type S	0.198 µCi HEU	*For reference only; NALI is limiting*

Dose conversion factors

Inhalation	Type F	2.4 rem CED/µCi HEU	41.1 rem BS/µCi HEU
	Type M	7.77 rem CED/µCi HEU	
	Type S	25.2 rem CED/µCi HEU	277 rem ET/µCi HEU

Table B.35
Summary of minimum detectable doses (rem CED) for inhalation of highly enriched uranium

Days Post-Intake	Type F	Type M		Type S	
	Urine	Lung	Urine	Lung	Urine
1	1.98E-08	4.09E-01	5.07E-07	1.19E+00	5.42E-05
2	5.70E-07	4.22E-01	1.05E-05	1.22E+00	8.66E-04
3	7.08E-07	4.29E-01	1.38E-05	1.23E+00	1.47E-03
7	1.04E-06	4.55E-01	1.82E-05	1.28E+00	1.99E-03
15	2.02E-06	5.09E-01	2.75E-05	1.38E+00	3.06E-03
30	5.34E-06	6.14E-01	4.43E-05	1.55E+00	4.95E-03
90	3.03E-05	1.08E+00	9.45E-05	2.03E+00	8.92E-03
180	1.17E-04	1.98E+00	1.80E-04	2.39E+00	1.16E-02
365	6.57E-04	5.91E+00	5.39E-04	2.89E+00	1.45E-02

Appendix B: Summary of Internal Dosimetry Factors for Selected Radionuclides

Appendix C: Controls for Reports Containing Personnel Monitoring Data or Doses

Interdepartmental Letter
Environment, Safety & Health
Radiation Protection Functional Area

Mail Station L-384

Extension 2-5172

May 9, 2012
ESH-RP-2012-037

MEMORANDUM

To: Distribution

From: Kathleen L. Shingleton

Subject: *Controls for Reports Containing Personnel Monitoring Data or Doses*

A number of federal Acts and Orders apply to the protection of personal and medical information. The purpose of this memo is to clarify which Acts and Orders apply to reports that contain an individual's name and radiation dose or bioassay measurement result, and the required markings and transmittal controls.

LLNL's Classifications Office (Dave Brown) and Legal Department (Peter Murray) have reviewed this memo and its attachments. Radiation Safety Program staff (including the Radiation Protection Functional Area [RPFA] and ES&H Teams) working under the authority of the Radiological Control Manager must handle OUO documents in accordance with this memo.

Applicability

- The Privacy Act of 1974 *does* apply to bioassay data and dosimetry reports associated with an individual. Because the Privacy Act applies, the Freedom of Information Act (FOIA) applies (specifically, Exemption 6). These Acts are implemented via DOE Order 471.3, *Identifying and Protecting Official Use Only Information*.

  The Privacy Act applies when protected information is provided to someone *other* than the person to whom the record pertains, such as:

  - The worker's supervisor.
  - Co-workers in the same work group.

  The Privacy Act applies does NOT apply to:

  - Data and reports provided only to the monitored individual.
  - Data and reports utilized within the Radiation Safety Program, where access to the information is controlled and made available only to individuals who have a business need for the information.

- Personally Identifiable Information (PII) controls apply to **databases and any large sets of data taken offsite** that contains personally-identifiable information (i.e., information that could be useful in identity theft), but does not apply to individual letters/reports.
- The Health Insurance Portability and Accountability Act (HIPAA) does not apply, as bioassay data and dosimetry reports are not medical records.

Lawrence Livermore National Laboratory

Marking and Unmarking Documents

The person who transmits or releases OUO information is responsible for ensuring it is properly marked.

Attachment 1 contains a properly marked RPFA OUO memo template suitable for transmitting dosimetry information; the template may be modified for ES&H Team use as well. Note:

- It is permissible to mark the monitored person's report as 'OUO'.
- Historically used markings (e.g., 'In Strict Confidence', 'Privacy Protected Information') should *not* be used.
- For electronic files containing names and doses, the Footer must include the words, 'For Official Use Only' (or, OUO if space is limited); the file name should start with 'OUO'. For example, the Excel file containing the year-to-date dose information should be entitled, 'OUO-CY12 Positive Doses' (or words to that effect).
- Reports transmitted on-site, outside of the Radiation Safety Program (e.g., monthly ALARA reports provided to the Authorizing Program) must have the 'admonishment' (i.e., the official box containing FOIA information) on the cover sheet, but subsequent data sheets need to be marked only with 'Official Use Only' (or 'OUO' if space is limited).

OUO markings should be removed when the document is no longer OUO. For example, if an individual's name and ID number is removed from the document, it is no longer protected under FOIA Exemption 6, Personal Information, and no longer warrants the OUO marking.

Disposing of OUO Documents

Documents that are marked 'OUO' must be disposed of as follows.

- By shredding, using a strip-cut shredder that produces strips no more than 1/4 inch wide or by any other means that provides a similar level of destruction, or
- By placing it in the 'Unclassified Sensitive Materials Only' waste containers (currently, in the External Dosimetry Team area and the B253 Rm 1526 (Lektriever room).

Do NOT dispose of OUO in the 'Unclassified **Non**-Sensitive Materials' waste container (e.g., the grey container in the B253 copy room). The 'Unclassified Sensitive/Non-Sensitive Materials' containers are prominently marked—be sure to use the correct container.

Examples

1. If a hard-copy report containing the monitored person's name, dose, and social security number (SSN) is sent to the monitored individual's home and work address, the report does not require any specific markings or transmittal controls (although it is permissible to mark the individual's report as 'OUO'). That is, the monitored person doesn't have to be warned about protecting their own information. If the report is e-mailed to the monitored individual, it should be Entrusted, if possible. However, the same report, if sent to the monitored individual's supervisor or to a future employer *does* require specific OUO markings and transmittal controls. That is, the recipient *does* have to be warned about protecting someone else's information. If the report is e-mailed, it should be Entrusted, if possible.

2. If the monthly ALARA graphs are provided to program personnel, they should be transmitted using the memo format shown in Attachment 1 (modified as appropriate to replace RPFA with ES&H Team 1 or 2), or with a cover sheet containing the FOIA admonishment. Individual graphs each must be marked 'Official Use Only'.
3. A binder of ALARA graphs should have a first page displaying the FOIA admonishment.

Attachments

Enclosure 1, Tables 1 and 2 summarize the applicability of the various privacy-related Acts depending on the type of information contained in the report and the recipient of the report. Table 3 specifies the transmittal controls, if the Act applies.

Attachment 1 provides an RPFA memo template for an appropriately marked memo containing a person's name, identification number (employee number or SSN) and radiation dose.

Please feel free to contact me if you have questions regarding the appropriate marking of dosimetry reports.

Kathleen L. Shingleton
Radiation Safety Technical Leader
Radiation Protection Functional Area

Enclosure: Applicability of Federal Acts to Radiation Dose Reports

Attachment: Example of an appropriately marked memo containing dosimetry information.

Copy:

Brown, Dave	L-302	Simpson, Tracey	L-509
Carl, Bill	L-384	Sundsmo, Michele	L-384
Fisher, Sandi	L-383	Tai, Lydia	L-384
Glass, Al	L-787	Thompson, Kaylie	L-384
Hickman, Dave	L-383	Topper, Jack	L-787
Lobaugh, Megan	L-384	Wong, Carolyn	L-384
McGuff, Paul	L-509	Wood-Zika, Annmarie	L-384
Mecozzi, Jim	L-372	Worley, Phil	L-384
Murray, Peter	L-701	ES&H Team Health Physicists	
O'Dell, Gaby	L-701		

Enclosure 1: Applicability of Federal Acts to Radiation Dose Reports

Tables 1 and 2 show the applicability of various Federal Acts, as they pertain to reports sent:

1. To the monitored individual.
2. To someone OTHER than the monitored individual.

Tables 3 and 4 show the requirements for marking and transmitting reports that are OUO and OUO-PII. Differences between the OUO and OUO-PII requirements are highlighted in yellow.

Table 1: Applicability of Federal Acts to Reports Sent to the Monitored Individual

If included on report:	Applicability			
	Privacy Act of 1974	Freedom of Information Act (FOIA)	Personally Identifiable Information (PII)	Health Insurance Portability & Accountability Act (HIPAA)
Name/Dose/ SSN, Birth date	No	No	No	No

Table 2: Applicability of Federal Acts to Reports Sent to Someone Other Than the Monitored Individual

If included on report:	Applicability			
	Privacy Act of 1974	Freedom of Information Act (FOIA), Personal Information	Personally Identifiable Information (PII) in a DATABASE	Health Insurance Portability & Accountability Act (HIPAA)
Name and Dose	YES	YES	No	No
Name and bioassay data	YES	YES	No	No
Name/Dose/ LLNL employee number	YES	YES	No	No
Name/Dose/ Home address	YES	YES	Not officially, but recommended	No
Name/Dose/ SSN	YES	YES	YES	No
Name/Dose/ Last-4-digits of SSN (xxx-xx-1234)	YES	YES	YES	No
Name/Dose/ Birth date	YES	YES	YES	No
Classification level if Act is applicable (See Table 3 for more information)	Official Use Only		Official Use Only – Personally Identifiable Information	NA

Table 3: Required Markings (source: https://ocec-r.llnl.gov/uci/pii.html)

<table>
<tr><th></th><th>OUO</th><th>OUO-PII</th></tr>
<tr><td>Classification level if Act is applicable</td><td>Official Use Only</td><td>Official Use Only – Personally Identifiable Information</td></tr>
<tr><td>Cover Page Marking</td><td><table><tr><th>Official Use Only</th></tr><tr><td>May be exempt from public release under the Freedom of Information Act (5 U.S.C 552), exemption and category:
Exemption 6, Personal Privacy</td></tr><tr><td>Department of Energy review required before public release</td></tr><tr><td>Date: [Date of guidance determination]
Name/organization: [Phil Worley or Michele Sundsmo]/Radiation Protection
Guidance Used (if applicable): NA</td></tr></table></td><td>Warning: This Document Contains Personally Identifiable Information (PII). Additional Controls Apply<table><tr><th>Official Use Only</th></tr><tr><td>May be exempt from public release under the Freedom of Information Act (5 U.S.C 552), exemption and category:
Exemption 6, Personal Privacy</td></tr><tr><td>Department of Energy review required before public release</td></tr><tr><td>Date: [Date of guidance determination]
Name/organization: [Phil Worley or Michele Sundsmo]/Radiation Protection
Guidance Used (if applicable): NA</td></tr></table></td></tr>
<tr><td>Subsequent Page markings</td><td>Mark the bottom of all pages (including the cover) OR the cover and only those subsequent pages containing OUO in the document with "Official Use Only" or "OUO" if space is limited.</td><td>Mark each subsequent page, "Official Use Only/ Personally Identifiable Information," or, if space is limited, the OUO and/or PII acronyms may be used in mark the page.</td></tr>
</table>

Table 4: Requirements for Transmitting OUO (source: https://ocec-r.llnl.gov/uci/pii.html)

Type of Transmission	OUO	OUO-PII
Mail (outside the Laboratory)	Use a sealed, opaque envelope or wrapping, marked with recipient's address, a return address, and the words "TO BE OPENED BY ADDRESSEE ONLY." Any of the following U.S. mail delivery categories may be used: first class, express, certified, or registered mail. Any commercial carrier may be used.	Use a sealed, opaque envelope or wrapping, marked with recipient's address, a return address, and the words "TO BE OPENED BY ADDRESSEE ONLY." U.S. mail delivery must be by registered mail. Any commercial carrier may be used.
Interoffice mail	Use a sealed, opaque envelope with the recipient's address and the words "TO BE OPENED BY ADDRESSEE ONLY" on the front.	Use a sealed, opaque envelope with the recipient's address and the words "TO BE OPENED BY ADDRESSEE ONLY" on the front.
Hand-carrying between facilities or within a facility	OUO information may be hand-carried between or within facilities as long as the person carrying the information can control access to the information.	PII information may be hand-carried between or within facilities as long as the person carrying the information can control access to the information.
Over tele-communication circuits	OUO information should be protected by encryption whenever possible when it is transmitted over telecommunications circuits. This may be accomplished through DOE public key systems or encryption algorithms that comply with all applicable federal laws, regulations, and standards addressing the protection of sensitive unclassified information (see DOE M200.1-1, Chapter 9). If encryption capabilities are not available and transmission by mail is not a feasible alternative, then regular e-mail or facsimile machines may be used to transmit the document.	PII information must be protected by encryption whenever possible when it is transmitted over telecommunications circuits. This may be accomplished through DOE public key systems or encryption algorithms that comply with all applicable federal laws, regulations, and standards addressing the protection of sensitive unclassified information (see DOE M200.1-1, Chapter 9).
E-mail	Use encryption, such as Entrust software, whenever possible. All LLNL employees may visit the Entrust Web Site or contact the Entrust coordinator (ext. 4-5599) to create an Entrust account. E-mail messages that contain OUO information should indicate "OUO" in the first line, before the body of the text. E-mail messages must also indicate when attachments contain OUO information.	Use only e-mail encryption approved for PII, such as Entrust software. All LLNL employees may visit the Entrust Web Site or contact the Entrust coordinator (ext. 4-5599) to create an Entrust account.
Unencrypted fax	Transmission must be preceded by a telephone call to the recipient so that the document can be controlled when it is received.	Only a secure fax may be used for transmitting PII. When using a fax, transmission must be preceded by a telephone call to the recipient so that the document can be controlled when it is received.

Attachment 1:

Example of an Appropriately Marked Memo that Contains Personnel Dosimetry Information

Attached is an RPFA memo template that has been customized for memos that contain Privacy Act and FOIA-protected information (Exemption 6, Personal Privacy). Note that the admonishment (the OUO box in the footer) has been customized for release via this memo template. If the admonishment is used in other contexts, replace 'date of memo' with the actual release date, and replace 'Michele Sundsmo / Radiation Protection Functional Area' with the name and organization of the person authorizing release.

Interdepartmental Letter
Environment, Safety & Health
Radiation Protection Functional Area

Mail Station L-xxx

Extension x-xxxx

Date
ESH-RP-2012-xxx

MEMORANDUM

To: Name

From: Your name here

Subject: *Subject Line (italics)*

Text

Your name here, XXX Team (or Team Lead)
Radiation Protection Functional Area

Enclosure(s): 1.
2.

[Remove (s) and numbers if only one enclosure]

Copy:
Last Name, First Name L-code
[Alphabetical order and L-code optional if distributing electronically]

Lawrence Livermore National Laboratory

Official Use Only
May be exempt from public release under the Freedom of Information Act (5 U.S.C 552), exemption and category: Exemption 6, Personal Privacy
Department of Energy review required before public release
Date: Date of memo; Guidance Used (if applicable): NA Name/organization: Michele Sundsmo/Radiation Protection Functional Area

Official Use Only

Appendix D: Memorandum of Understanding between LLNL and LANL: Agreement to Provide Support in Emergency Situations

Memorandum of Understanding between

Lawrence Livermore National Laboratory Radiation Protection

and

Los Alamos National Laboratory Radiation Protection:

Agreement to Provide Support in Emergency Situations

Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL) radiation protection organizations recognize that radiation protection resources at both laboratories could be overwhelmed during a major radiological emergency. In the past, there has been mutual recognition that either could call on the other in such an event and receive any available resources to assist in responding to the radiological emergency. This agreement formally documents this long-standing commitment between the two organizations. The following sections discuss specific functional areas within radiation protection where the two organizations have pre-identified the type of mutual support that could be requested/provided. Other functional areas where a need for mutual support is identified will be handled between the two organizations, as necessary.

This agreement is made in anticipation of using it very infrequently, such as one time or less per year. At this low level of usage, it is unlikely that either organization will need to charge the other for support services performed. However, it is possible that charging for any level of service may be required at the mutual discretion of either LANL or LLNL. If it becomes necessary to charge for services rendered, notification of the potential charges will be made between the organizations as soon as possible and the details will be worked out in a timely manner.

This agreement will be reviewed on an annual basis to optimize the benefits between the two organizations.

IN-VITRO Measurements

The *in vitro* measurement programs at LANL and LLNL are similar in that both maintain Department of Energy Laboratory Accreditation Program (DOELAP) accreditation for quantification of isotopes of plutonium, americium, uranium, and thorium in urine and fecal material and for tritium in urine. Both organizations agree to provide emergency back-up capabilities for the other in these areas. Neither organization is required to develop new techniques or new analytical methods in support of this agreement, but both agree to notify the other in the event that capabilities change as soon as practical. These services will be provided on an as-needed basis in the event one of the organizations is unable to provide timely radioanalytical support due to unforeseen problems.

IN-VIVO Measurements

Both organizations maintain the capability and applicable DOELAP accreditations to perform *in-vivo* measurements of personnel in the event of a potential uptake of radioactive material. Both organizations agree to provide back-up *in-vivo* measurements for the other if the capability at one is lost due to unforeseen circumstances. Examples of such a circumstance include the physical loss of one organization's ability to provide the service because their *in-vivo* counting facility has been contaminated or there is an accident at one site that results in an unmanageable short-term workload

that prevents timely completion of *in vivo* monitoring. Each organization will notify the other if their *in-vivo* capabilities are degraded such that they would expect to utilize the other's capabilities in the event of an emergency.

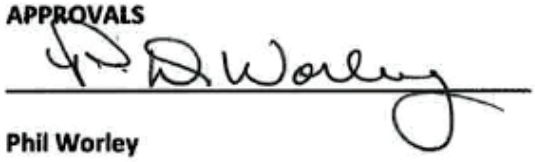
Internal Dosimetrist Services

Both organizations have experienced internal dosimetrists available to analyze potential internal doses of their workers. However, in a large-scale accident involving multiple individuals, or in the event a potentially large internal exposure it may be appropriate to have additional internal dosimetrist resources available to review the data and provide independent peer review of results. Both organizations agree to make such expertise available to the other, if requested.

Health Physicist

Both organizations have experienced and qualified health physicists available to provide technical direction to various Programs at their respective Laboratories. However, in the event of a large-scale accident additional technical resources could be needed by either organization. In addition, changing work priorities and schedules at either Laboratory could cause fluctuations in the need for additional or reduced health physics resources. Both organizations agree to notify the other of increased or decreased needs for such resources and to provide assistance, as possible.

APPROVALS



Date: 3/27/2013

Phil Worley

Radiological Control Manager

Lawrence Livermore National Laboratory

Date: 3/25/13

Scotty Jones

Radiological Control Manager

Los Alamos National Laboratory

Appendix E: References

5 U.S.C. § 552a. United States Code, *The Privacy Act of 1974.*

10 CFR 835. Code of Federal Regulations, *Occupational Radiation Protection*, retrieved May 15, 2015 from www.ecfr.gov.

ANSI/HPS 2001. American National Standards Institute/Health Physics Society ANSI/HPS N13.39-2001, *Design of Internal Dosimetry Programs*, Health Physics Society, McLean, Virginia, 2001.

ANSI/HPS 2011. American National Standards Institute/Health Physics Society ANSI/HPS N13.30-2011, *Performance Criteria for Radiobioassay*, Health Physics Society, McLean, Virginia, 2011.

Bihl 1993. D. E. Bihl, R. L. Buschborn, and M. J. Sula, *Experience with a Routine Fecal Sampling Program for Plutonium Workers*. Health Phys. 65(5):550-555; 1993.

CEC/DOE 1992. *Guidebook for the Treatment of Accidental Internal Radionuclide Contamination of Workers*, G. B. Gerber, R. G. Thomas, editors, *Radiation Protection Dosimetry*, Nuclear Technology Publishing, Kent, England, 1992.

DOE 2004. Department of Energy Office of Worker Protection Policy and Programs Radiological Control Technical Position RCTP 2004-01, *Guidance on the Revision of Internal Dose Estimates in Response to Updated Internal Dosimetry Methodologies*.

DOE 2008. Department of Energy Standard DOE-STD-1121-2008, *Internal Dosimetry*, October 2008.

DOE 2009. Department of Energy Standard DOE-STD-1098-2008, Change Notice 1, *Radiological Control*, May 2009.

DOE 2011. Department of Energy Guide DOE G 441.1-1C, Change 1, *Radiation Protection Programs Guide for Use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection*, July 8, 2011.

DOE 2013. Department of Energy Standard DOE-STD-1128-2013, *Good Practices for Occupational Radiological Protection in Plutonium Facilities*, April 2013.

DOE 2014. *Instructions for Preparing Occupational Exposure Data for Submittal to the Radiation Exposure Monitoring System (REMS) Repository*, January 29, 2014, retrieved May 19, 2015 from http://energy.gov/ehss/.

Hickman 2012. D. P. Hickman, *Lawrence Livermore National Laboratory's Book of Minimum Detectable Activity for Direct Measurement of Internally Deposited Radionuclides in Radiation Workers – CY2011*, LLNL-TR-605945, December 3, 2012.

ICRP 1975. *Report of the Task Group on Reference Man*. ICRP Publication 23. Pergamon Press, New York, New York, 1975.

ICRP 1979. *Limits for Intakes of Radionuclides by Workers.* ICRP Publication 30 (Part 1). Ann. ICRP 2 (3-4).

ICRP 1980. *Limits for Intakes of Radionuclides by Workers.* ICRP Publication 30 (Part 2). Ann. ICRP 4 (3-4).

ICRP 1981. *Limits for Intakes of Radionuclides by Workers*. ICRP Publication 30 (Part 3). Ann. ICRP 6 (2-3).

ICRP 1988. *Limits for Intakes of Radionuclides by Workers: An Addendum*. ICRP Publication 30 (Part 4). Ann. ICRP 19 (4).

ICRP 1991. *1990 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 60. Ann. ICRP 21 (1-3).

ICRP 1993. *Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 2 Ingestion Dose Coefficients*. ICRP Publication 67. Ann. ICRP 23 (3-4)

ICRP 1994a. *Human Respiratory Tract Model for Radiological Protection*. ICRP Publication 66. Ann. ICRP 24 (1-3).

ICRP 1994b. *Dose Coefficients for Intakes of Radionuclides by Workers*. ICRP Publication 68. Ann. ICRP 24 (4).

ICRP 1995. *Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 3 Ingestion Dose Coefficients*. ICRP Publication 69. Ann. ICRP 25 (1).

ICRP 1997a. *General Principles for the Radiation Protection of Workers*. ICRP Publication 75. Ann. ICRP 27 (1).

ICRP 1997b. *Individual Monitoring for Internal Exposure of Workers*. ICRP Publication 78. Ann. ICRP 27 (3-4).

ICRP 2001. *Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother*. ICRP Publication 88. Ann. ICRP 31 (1-3).

ICRP 2002. *Basic Anatomical and Physiological Data for Use in Radiological Protection Reference Values*. ICRP Publication 89. Ann. ICRP 32 (3-4).

ICRP 2004. *Doses to Infants from Ingestion of Radionuclides in Mothers' Milk*. ICRP Publication 95. Ann. ICRP 34 (3-4).

ICRP 2007. *The 2007 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 103. Ann. ICRP 37 (2-4).

ICRP 2012. *Compendium of Dose Coefficients based on ICRP Publication 60*. ICRP Publication 119. Ann. ICRP 41(Suppl.).

James 2004a. A. C. James, et al., *User Manual for IMBA Expert USDOE-Edition Phase II*.

James 2004b. A. C. James, et al., *User Manual for IMBA Expert USDOE-Edition Phase II—Appendix A: Technical Basis*.

LLNL 2009. *LLNL Technical Basis Manual for Internal Dosimetry*, LLNL-TM-407875, Rev. 2, January 1, 2009.

LLNL 2011. *Whole Body Counter Manual*, Sections 1–8, March 31, 2011.

LLNL 2012. *Development of the Health Physics Discipline Action Plan*, HP-FO-104 Rev 0.1, November 9, 2012.

LLNL 2013. *Spectroscopy Laboratory Procedure Manual – Alpha Spectroscopy*, SLAB-01 Rev 0.0, December 11, 2013.

LLNL 2014a. *Bioassay Laboratory Administration*, RP-BLAB-001, Rev 0, April 25, 2014.

LLNL 2014b. *Spectroscopy Laboratory Procedure Manual – Gamma Spectroscopy*, SLAB-02 Rev 0.0, May 1, 2014.

LLNL 2014c. *Reporting Occurrences to DOE*, PRO-0082, July 14, 2014.

LLNL 2014d. Environment, Safety, and Health Manual, Volume I, Document 1.2, *ES&H Policies of LLNL*, July 22, 2014.

LLNL 2014e. Radiation Protection Functional Area Quality Assurance Plan, LLNL-AM-665565, RP-DES-001 Rev 0.1, December 5, 2014.

LLNL 2014f. Environment, Safety, and Health Manual, Volume II, Document 10.1, *Occupational Medical Program*, September 17, 2014.

LLNL 2015a. Environment, Safety, and Health Manual, Volume II, Document 20.2, *LLNL Radiological Safety Program for Radioactive Materials*, March 2, 2015.

LLNL 2015b. Environment, Safety, and Health Manual, Volume II, Document 20.1, *Occupational Radiation Protection*, March 27, 2015.

LLNL 2015c. *Completing the Radiation/Contamination Survey Form*, HP-FO-120 Rev 2.2, May 15, 2015.

LLNL 2015d. *Identification and Response to Unexpected Radiological Conditions*, HP-FO-601 Rev 1.0, June 22, 2015.

LLNL 2015e. *LLNL Technical Basis Manual for Internal Dosimetry*, Rev. 3 in draft as of October 2015.

Mansfield 2012. W. G. Mansfield, et al., *Internal Dosimetry and Monitoring for Special Tritium Compounds (STCs)*, LLNL-TM-565620, July 20, 2012.

NCRP 1980. National Council on Radiation Protection and Measurements Report No. 65, *Management of Persons Accidentally Contaminated with Radionuclides*, Washington, D.C., 1980.

NCRP 1987. National Council on Radiation Protection and Measurements Report No. 87, *Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition*, Bethesda, Maryland, 1987.

NCRP 2007. National Council on Radiation Protection and Measurements Report No. 156, *Development of a Biokinetic Model for Radionuclide-Contaminated Wounds and Procedures for their Assessment, Dosimetry, and Treatment*, Bethesda, Maryland, 2007.

NCRP 2008. National Council on Radiation Protection and Measurements Report No. 161, *Management of Persons Contaminated with Radionuclides: Handbook*, Bethesda, Maryland, 2008.

NRC 1993. U. S. Nuclear Regulatory Commission, NUREG-1400, *Air Sampling in the Workplace*, Office of Nuclear Regulatory Research, September 1993.

Shingleton 2014. K. L. Shingleton, *LLNL Radiation Protection Program Revision 9.4*, LLNL-MI-664423, November 21, 2014.

Wood 2000. R. Wood, C. Sharp, P. Gourmelon, B. Le Guen, G. N. Stradling, D. M. Taylor and M.-H. Hengé-Napoli, *Decorporation Treatment—Medical Overview*. Radiation Protection Dosimetry. 87(1);51-57; 2000.