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PUBLICATION RECORD

EFFECTIVE DATE	REVISION NUMBER	DESCRIPTION
02/06/2007	00	This technical information bulletin provides guidance in the performance of internal dose reconstructions. It incorporates the requirements of ORAUT-PROC-0003, *Internal Dose Reconstruction*, which will be cancelled. Incorporates internal formal and NIOSH review comments. Incorporates additional NIOSH review comments. There is no change in the assigned dose and no PER required. Training is required: As determined by the Task Manager. Initiated by Elizabeth M. Brackett.
09/08/2014	01	Revision to bring the document up to date with current practice and to provide additional guidance to dose reconstructors. Incorporates formal internal and NIOSH review comments. Constitutes a total rewrite of the document. Training is required: As determined by the Objective Manager. Initiated by Elizabeth M. Brackett.

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ACRONYMS AND ABBREVIATIONS

CAD	chronic annual dose
CFR	Code of Federal Regulations
d	day
DCAL	Dose and Risk Calculation (program)
DCAS	Division of Compensation Analysis and Support
DL	decision level
DOE	U.S. Department of Energy
ET	extrathoracic
g	gram
GI	gastrointestinal
GSD	geometric standard deviation
ICD-9	*The International Classification of Diseases, 9th Revision*
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Assessment
IREP	Interactive RadioEpidemiological Program
keV	kilovolts-electron, 1,000 electron volts
L	liter
LLI	lower large intestine
LNET	extrathoracic lymph nodes
LNTH	thoracic lymph nodes
LOD	limit of detection
MDA	minimum detectable activity or amount
MDD	minimum detectable dose
MPC	maximum permissible concentration
NCRP	National Council on Radiation Protection and Measurements
NIOSH	National Institute for Occupational Safety and Health
OBT	organically bound tritium
ORAUT	Oak Ridge Associated Universities Team
PID	Principal Internal Dosimetrist
POC	probability of causation
RBM	red bone marrow
REF	radiation effectiveness factor
SI	small intestine
SMT	stable metal tritide
SRDB Ref ID	Site Research Database Reference Identification (number)
TIB	technical information bulletin
U.S.C.	United States Code

ULI upper large intestine

§ section or sections

1.0 INTRODUCTION

Technical information bulletins (TIBs) are not official determinations made by the National Institute for Occupational Safety and Health (NIOSH) but are rather general working documents that provide historical background information and guidance to assist in the preparation of dose reconstructions at particular sites or categories of sites. They will be revised in the event additional relevant information is obtained about the affected site(s). TIBs may be used to assist NIOSH staff in the completion of individual dose reconstructions.

In this document, the word "facility" is used as a general term for an area, building, or group of buildings that served a specific purpose at a site. It does not necessarily connote an "atomic weapons employer facility" or a "Department of Energy (DOE) facility" as defined in the Energy Employees Occupational Illness Compensation Program Act of 2000 [42 U.S.C. § 7384l(5) and (12)].

1.1 PURPOSE

The purpose of this TIB is to provide information and guidance for reconstructing internal dose and to document the rationale for selection of certain default parameters.

1.2 SCOPE, APPLICABILITY, AND LIMITATIONS

There are many approaches that can be taken when reconstructing the internal dose component of a case. Options are dependent on several factors including the employment site, type and number of cancers, and availability of monitoring data for the Energy Employee. Not all of the approaches this document provides are applicable or appropriate for all cases.

The terminology and methods in this TIB are applicable for reconstructing doses on the Project and are not necessarily reflective of standard internal dosimetry practices in an operational program, where the program is being conducted to meet regulatory standards. Quantities of interest are different, and methods in this document are intended to be favorable to the claimant when a parameter is unknown rather than using a "most likely" value when there is uncertainty.

This document provides default values for use only when there is no better information to be found in the claimant file or the site profile. Claimant information also takes precedence over default values in the site profile. For example, most site profiles contain tables of minimum detectable activities or amounts (MDAs) for urine sample results. If the claimant file includes an explicit or implied MDA or reporting level in the bioassay result listing (e.g., "<" appears in front of a value), this specific value should be applied to the case rather than the default value from the site profile. Note that this direction does not apply if the claimant information is determined to be invalid, such as in the case of laboratory results that have been demonstrated to be inaccurate.

Section 2.0 defines terminology. Section 3.0 provides guidance for internal dose reconstruction. Attributions and annotations, indicated by bracketed callouts and used to identify the source, justification, or clarification of the associated information, are presented in Section 4.0.

2.0 TERMINOLOGY

2.1 SYSTEMIC VERSUS NONSYSTEMIC

Systemic organs and tissues are those to which radioactive material is transferred through blood circulation.

Material can be directly deposited in the respiratory and gastrointestinal (GI) tracts through the inhalation and ingestion of material, so they are considered nonsystemic organs. The lymph nodes are included in the nonsystemic organs. These regions are defined by the International Commission on Radiological Protection (ICRP).

The respiratory tract includes the extrathoracic regions (ET1 and ET2), lungs, thoracic lymph node (LNTH), extrathoracic lymph node (LNET), and BB (bronchial) region (ICRP 1994).

Components of the GI tract include the stomach, small intestine (SI), lower large intestine (LLI), upper large intestine (ULI), and colon (note that the colon is simply a weighted average of the LLI and ULI) (ICRP 1979).

2.2 METABOLIC VERSUS NONMETABOLIC ORGANS

Several organs are included in the general models in International Commission on Radiological Protection (ICRP) Publication 78 (ICRP 1998). However, for a given element, only a specific subset of these organs is included in the metabolic or biokinetic modeling. Organs that are specifically modeled are referred to as "metabolic" for this Project. Others for which a dose is calculated but are not specified by the ICRP element-specific model are referred to as "nonmetabolic" organs. The biokinetic models are based on the behavior of the particular element in the body, so the metabolic organs vary with the element of interest. For all elements, the metabolic organs include the GI tract (ICRP 1979) and, in the case of inhalation, the respiratory tract (ICRP 1994), because material is always deposited in these regions. In addition, if any part of the bone is specified in the ICRP model for an element, all bone parts, including red bone marrow (RBM) and bone surfaces, are considered to be metabolic.

2.3 POSITIVE AND NEGATIVE RESULTS

Decision level (DL) is defined in ANSI/HPS N13.30-2011 as the number of counts measured or final instrument measurement of a quantity of analyte at or above which a decision is made that the analyte is definitely present (HPS 2011). The term "definitely present" used in the standard is somewhat ambiguous, but what is meant is that the analyte is deemed to be present with a given probability α of being wrong. The probability α is often called the false-positive rate, and it describes the long-run frequency of deciding that analyte is present in a sample when in reality none is present. In practice, the result of an specific analysis is compared to the DL in order to decide if analyte is present in that sample.

Minimum detectable amount (MDA) is defined in the standard as being the smallest amount of an analyte in a sample that will be detected with a probability β of non-detection while accepting a probability α of erroneously deciding that a positive (non-zero) quantity of analyte is present in an appropriate blank sample. In other words, the MDA is the amount of analyte in samples that would produce results below the DL a fraction β of the time over the long run. The MDA is used to characterize the detection capabilities of the process and should not be compared to a specific analytical result to make the detection decision.

When discussing bioassay analyses used for dose reconstruction, a "positive result" typically refers to one that is greater than the MDA or reporting level while a "negative result" is less than that value. The use of MDA rather than DL for determining if a sample is positive is discussed in section 3.3. It is also possible for a result to be a true negative value (i.e., less than zero). Both uses of these words can be found in Project documents so it's important to understand which is being discussed.

For this Project, a result equal to the MDA is considered to be negative. This definition was chosen because many sites recorded the value of the MDA in the employee records for results less than the

MDA. If it is clear that this is not the case, a result equal to the MDA should be treated as positive. This exception should be documented in the site profile or dose reconstruction report.

In some instances, a site might have applied a reporting level that is greater than the MDA. This is most common when the nuclide is easily detected, such as ^{3}H, and a result at the MDA produces a very small dose. In such cases, only measurements with values that exceed the reporting level are recorded in the employee files. That is, results between the MDA and the reporting level are considered less-than values and are recorded as 0 or "<[the reporting level]." In these cases, the reporting level becomes the MDA by default and a missed dose should be based on the value of the reporting level rather than the MDA.

3.0 GUIDANCE

3.1 SELECTION OF APPROPRIATE ORGANS FOR DOSE ESTIMATE

Dose must be calculated to the organ in which the cancer originated. ORAUT-OTIB-0005, *Internal Dosimetry Organ, External Dosimetry Organ, and IREP Model Selection by ICD-9 Code* (ORAUT 2012), correlates *The International Classification of Diseases, 9th Revision* (ICD-9) codes with the appropriate organs and tissues to be modeled in the Integrated Modules for Bioassay Assessment (IMBA) computer program. For cases where the organ of cancer origination is not included in IMBA, the use of "highest nonmetabolic organ" is specified. In such situations, the dose to be assigned to the organ is the largest dose among the reported organs in IMBA that are not part of the ICRP (1998) metabolic model for the particular radionuclide.

In practice, dose reconstructors typically do not need to make this determination. The Chronic Annual Dose (CAD) tool will select the highest nonmetabolic organ for the selected ICD-9 code when appropriate by calculating the doses to each nonmetabolic organ and assigning the largest. The following is primarily for informational purposes.

Organs that do not concentrate a radionuclide receive photon exposure because of their proximity to the concentrating organs. The newer ICRP biokinetic models consider exposure from beta and alpha radiation to these other organs by defining them as a "soft tissue" compartment and describing uptake and clearance rates for this compartment. Many of these nonmetabolic organ doses are calculated using these techniques. Because these organs are all considered soft tissue, and are therefore all similarly exposed, all of the doses are relatively equal. This implies that choosing the largest of these doses is favorable to claimants. However, it is possible for one of the organ doses to be much higher than the others due to a proximity to a concentrating organ that is emitting photon radiation. In this case, the location of the cancer must be evaluated to ensure the estimate is not unrealistically large. If it is, the next largest organ dose should be used.

IMBA can be used to determine which organs are not included in the metabolic model. Dose reconstructors should:

1. Select the appropriate element (any isotope will work) and load the ICRP defaults using the button on the tool bar;

2. Click **Biokinetics** (near the Close button); and

3. Click **Load ICRP Defaults**.

Several organ names will be highlighted in blue or purple at the top of the window. These are the modeled organs (organs that are specifically named in the model as concentrating the radionuclide) for the element. Therefore, the remaining organs, with the exceptions noted in Section 2.2, are not

part of the metabolic model and the largest dose among these organs (i.e., the highest nonmetabolic organ) is used for assigning doses to organs that are not included in the IMBA calculations.

3.2 SELECTION OF PARAMETER VALUES

Several parameters must be determined or assumed when assessing an internal dose. Specific knowledge of an individual case takes precedence (see Section 1.2). However, when values are unknown, default values should be applied. This section provides guidance on parameter selection.

3.2.1 Intake Mode

There are five intake routes included in IMBA: inhalation, ingestion, injection, wound, and vapor.

Inhalation is the most common route for workplace intakes, although there can be an ingestion component associated with it. When an inhalation intake is assigned based on air monitoring rather than bioassay data, an additional ingestion component must be assigned. See OCAS-TIB-009, *Estimation of Ingestion Intakes,* for guidance (NIOSH 2004).

Injection is the entry of material directly into the bloodstream; this is sometimes referred to as absorption. Part 1 of ICRP Publication 56 treats the inhalation of tritium oxide as injection (ICRP 1990).

Intake via a wound is typically characterized by two or more compartments, with a fraction of the material absorbed almost immediately into the bloodstream and additional components with longer half-lives from material that remains at the wound site. ORAUT-OTIB-0022, *Guidance on Wound Modeling for Internal Dose Reconstruction* (ORAUT 2005d), discusses modeling these intakes. Additional information can be found in National Council on Radiation Protection and Measurements (NCRP) Report 156 (NCRP 2006). Contact the Principal Internal Dosimetrist (PID) for assistance with wound modeling.

Vapor is a specific instance of an inhalation intake; it is defined as the gaseous form of substances that are normally in liquid or solid form. Iodine is typically modeled using this intake route. Elemental iodine (Type F) is selected as the material type using the ICRP Defs Load button in IMBA.

In the absence of information about how an intake might have occurred, inhalation is the default assumption when starting with bioassay data because this is the most likely route of entry in an occupational setting.

3.2.2 Particle Size Distribution

The particle size distribution dictates the assumed deposition pattern of inhaled material in the various regions of the respiratory tract. For occupational exposures, the ICRP Publication 66 default value is a 5-µm activity median aerodynamic diameter (ICRP 1994). This value should be used for evaluating inhalation intakes in the absence of known information as documented in the site profiles or the case file.

3.2.3 Material Type

Material type describes the rate of absorption of deposited material in the respiratory tract into blood. ICRP Publication 66 describes three types: F (fast solubilization), M (moderate solubilization), and S (slow solubilization) (ICRP 1994). The assignment of an element to one or more of these categories is based on the chemical form of the material. The recommendations of ICRP Publication 68 (ICRP 1995a) are used for this Project because they address worker intakes rather than those of

members of the public. If material types at a particular site are known, they are documented in the site profile and should be applied under the specifications in that document. Additional nonstandard material types should be applied in some cases, type Super S plutonium being the primary example.

For the majority of cases, it is likely that the material type is unknown or the individual worked in multiple areas, which makes exposure to multiple types possible. In such cases, an assessment of each type to which the element is assigned in ICRP Publication 68 (ICRP 1995a) (this is indicated in the IMBA selection menu) should be made, and the type that results in the largest dose to the organ of interest should be selected. The exception to this rule is in the case of a radionuclide where trace atoms are bound in a matrix of another nuclide. The primary example of this is ^{241}Am in a plutonium matrix. Americium is assigned to type M by ICRP Publication 68 but, when bound in a type S plutonium matrix, type S is also assumed for the ^{241}Am. Therefore, ICRP Publication 71 (ICRP 1995b) type S is selected in IMBA or the CAD tool (or other assessment method that might be used). This also applies to natural thorium where the progeny (e.g., ^{228}Ac, ^{228}Ra, ^{224}Ra) are assumed to be the same material type as the thorium parent.

For contaminants in a recycled uranium mixture, the nonuranium nuclides are assumed to be relatively tightly bound but not to behave outside of their own models. This is because the materials are primarily contaminants that have been mixed in with the uranium rather than progeny, so they are not as intimately bound. Therefore, the same material type should be applied to the contaminants as that selected for the uranium. If ICRP Publication 78 (ICRP 1998) does not assign the nuclide to the chosen uranium material type, the closest solubility should be selected. Table 3-1 provides guidance on material types for several elements that could be included as a recycled uranium contaminant.

Table 3-1. Selected material types for recycled uranium contaminants.

Uranium type	Contaminant	Contaminant types (unmonitored)
F	Pu	M
	Np	M
	Tc	F
	Th	M
M	Pu	M
	Np	M
	Tc	M
	Th	M
S	Pu	S
	Np	M
	Tc	M
	Th	S

In the case of ^{239}Pu, type Super S could need to be considered in addition to types M and S. This type potentially applies to all methods of assigning intakes including coworker doses and efficiency methods. ORAUT-OTIB-0049, *Estimating Doses for Plutonium Strongly Retained in the Lung* (ORAUT 2010), discusses conditions under which this type applies and appropriate adjustment factors to the intake and dose.

3.2.4 Radiation Type

The Interactive RadioEpidemiological Program (IREP) requires a Radiation Type to be associated with each entered equivalent dose. The radiation effectiveness factor (REF) is analogous to relative biological effectiveness in radiobiology. In IREP, the equivalent dose to an organ is converted to

absorbed dose and modified with the appropriate REF as part of the probability of causation (POC) calculation. The selected REF depends on the type of radiation, of which there are six:

- Alpha
- <15-keV electrons,
- >15-keV electrons,
- <30-keV photons,
- 30- to 250-keV photons, and
- >250-keV photons.

Note that >250-keV photons and >15-keV electrons are the reference radiations and have a point value REF of unity (i.e., the categories are interchangeable). The REFs for the other radiation types are expressed as distributions (Kocher 2002).

Many radionuclides emit multiple types of radiation. IMBA Expert ORAU-Edition has an option to split the dose assessment into its components for many but not all radionuclides. However, this adds significant time to the analysis and yields at least two times the number of entries that are required for IREP. Because of these concerns, and the IREP limit on number of doses that can be input, each radionuclide is assigned to a single radiation type. Attachment A contains the values to be used for all nuclides available in IMBA and the Project-developed tools. The radionuclides were assigned to a REF category based on the type and energy of emitted radiation that, on inspection, would appear to give the highest absorbed dose to the source organ. Consideration was also given to radiation types that are assigned a larger weighting factor.

Radionuclides that do not emit alpha radiation but have progeny that do are assigned to the alpha category because it is favorable to claimants. The single exception is ^{147}Pm, which is assigned to the "electrons E >15-keV" radiation category because of the extremely long half-life of the ^{147}Sm progeny.

3.2.5 Normalization of Bioassay Data

The regulations for this Project require the use of ICRP models for calculating internal doses and lists specific publications to be used (42 CFR Part 82). The biokinetic models and subsequent dose coefficients in those publications are based on male physiology and anatomy. Therefore, when urinalysis results are reported in units other than per day, the results are to be normalized to 24 hours using a conversion factor of 1.4 L/d for all individuals, male or female. For fecal samples, the default mass is 135 g/d.

Note that these values are to be used only for instances where a 24-hour sample has not been collected. If a 24-hour sample is indicated but the volume is not 1.4 L (or 135 g for fecal samples), do not adjust the result. Results are normalized prior to entry to the IMBA program. This applies to all data types (see 3.2.6.1).

If there is no indication as to the sample collection period and the site profile contains no additional information, normalize the result when the sample volume is less than that listed above. If the sample volume is greater than above, assume a 24-hour collection period and do not normalize the values. This is favorable to the claimant because normalization would reduce the reported value.

3.2.6 IMBA-Specific Parameters and Information

Additional information about IMBA and how it functions can be found in the IMBA documentation (under the Help menu in the program, in Documentation/Main documentation), in the IMBA procedure (ORAUT 2003b), and on the Project network on the obj3_dr (Q:) drive in DR Folders\DR Information\Internal Dosimetry\IMBA.

3.2.6.1 Data Type

IMBA defines the following data types:

- Real – This type indicates a valid result to be used in the intake calculation. IMBA will use this type of result as is. There must be at least one Real result entered for IMBA to perform an intake calculation.

- <LOD – This stands for "less than the limit of detection" and is used for results less than the MDA, as described in the section on fitting positive bioassay data (Section 3.4). The sample MDA is entered for the Measurement Rate or Measurement Value for results marked as this Data Type. IMBA uses a maximum likelihood method for estimating intakes; <LOD results will be treated as a distribution between zero and the LOD in the intake calculation. These results are displayed in brown on the graph.

- Excluded – IMBA will ignore all results with this Data Type indicated when calculating the intake. Excluded results are displayed in red on the graph.

3.2.6.2 Measurement Error

The inverse square of the Measurement Error is the weighting factor applied to the Measurement Rate for the intake fit. The larger the Measurement Error, the smaller the relative weight given to the result in the intake calculation. The fit to the data will tend to move toward those results assigned the smallest errors on an absolute scale.

Values entered as <LOD should have an error equal to the LOD (this is equivalent to $k = 1$ if using the Uniform Relative option).

For positive results, use the 1-sigma error associated with the result, when available. If there are no reported errors with the results, Measurement Error should be calculated using the Uniform Relative option with $k = 0.3$ for all positive (>MDA) results as a starting point. Note that in the case where all results are positive (i.e., all are labeled as Real), the value of k is arbitrary; the same intake will result from any factor, given the same k for all results.

A Uniform Relative error with equal values of k for all results might not be a reasonable estimate if there are well-defined peaks or if results vary by more than an order of magnitude. For example, given two results with values of 100 and 10, the fit would go closer to the 10 if a Uniform Relative error with $k = 0.3$ was applied because these would be treated as 100 ±30 and 10 ±3. Larger values will have more precise statistics and might need to be assigned relatively smaller errors to obtain a better fit. For a best estimate, alternative values for the error can be tried if a reasonable fit is not obtained (e.g., the majority of results appear to be underpredicted or the larger results are underpredicted). Application of a 10% error to the largest results while retaining a 30% error on the smaller positive results might improve the fit. Other values can be tried if this does not provide a satisfactory fit. Use of the Uniform Absolute option, with the same value entered for all results, will yield an unweighted fit (i.e., all results are weighted equally). Contact the PID for assistance if a reasonable fit cannot be obtained.

Note that changing the weighting factors on the results simply moves the data fit up and down, it will not change the shape of the curve.

3.2.6.3 Error Distribution

Individual bioassay results are assumed to have a normal distribution.

3.2.6.4 IMBA Limitations

IMBA is known to calculate inaccurate organ doses for some radionuclide and organ combinations. There are two categories of problems: shared versus independent kinetics and very short-lived radionuclides. In the case of the former issue, the current ICRP system models the progeny of a radionuclide using its kinetics, but because of limitations in the software, IMBA employs the older model technique of shared kinetics, where the progeny are assumed to follow the behavior of the parent. In the case of very short-lived nuclides, the reason for the problem is unknown but IMBA incorrectly calculates the annual doses from chronic intakes.

- Shared versus Independent Kinetics – The nuclides this issue affects are ^{210}Pb, ^{223}Ra, ^{224}Ra, ^{226}Ra, ^{228}Ra, ^{131}Te, ^{131m}Te, ^{228}Th, ^{232}Th, ^{234}Th, ^{232}U, and ^{233}U. The value IMBA reports might be larger or smaller than the value that is calculated using independent kinetics, depending on the nuclide and organ, and not all organs are affected for all nuclides. A summary of the differences is presented in Table B-1.

- Very Short-Lived Nuclides – The affected radionuclides are ^{228}Ac, ^{147}Pr, ^{131}Te, and ^{239}U. For chronic intakes, the doses IMBA reports are smaller than the actual values. The longer the intake, the larger the underestimate. Acute intakes are unaffected.

Table B-1 shows the radionuclide and organ combinations for which IMBA doses are high or low relative to the true value. In these cases, annual dose coefficients have been calculated with the Dose and Risk Calculation (DCAL) program (Eckerman et al. 2006). These coefficients have been incorporated into the CAD Workbook and verification of the values is documented in ORAUT-OTIB-0022, *Validation of DCAL Annual Dose Coefficients* (ORAUT 2008). The IMBA intake calculations are correct, so bioassay results can be input to IMBA for determining the intake.

For all radionuclide and organ combinations in Table B-1 that are high or low in IMBA, CAD must be used to calculate the dose (IMBA can be used for all other dose calculations). IMBA cannot be used as an overestimate for the high cases or as an underestimate for the low cases because the comparison is based on the 50-year committed dose and the annual doses can vary from this. In addition, in some instances, IMBA is high for one material type but low for another, but this is not indicated in the table.

Contact the PID when a best estimate is needed for time frames that cannot be calculated with CAD. When sending a case to the PID for a best estimate, be sure to include:

- Nuclide,
- Intake date(s),
- Material type,
- Intake (acute) or intake rate (chronic), as applicable and including units,
- Organ of interest,
- Date of diagnosis, and
- Claim due date.

3.3 ASSIGNMENT OF MISSED AND UNMONITORED DOSE

Although referred to as dose in the following section, *intake* is technically being assessed during the described periods. Doses from those intakes are assigned through the date of cancer diagnosis.

The presence of bioassay samples is often an indicator of potential for exposure, but if there are only baseline and termination samples (i.e., no other bioassay), they do not necessarily indicate a potential. Indicators of potential for internal radiation exposure include the following:

- Job title,
- Work location, and
- External dose.

By itself, lack of sampling for extended periods is an insufficient reason for assuming a change in exposure potential. If the three listed items do not change during an individual's employment history but there is information that indicates a potential for intake at some point (e.g., bioassay data or job title), a potential for intake must be assumed for the entire employment period. In some cases, the assignment of environmental intakes only is appropriate. See section 3.6.5 for additional information.

Note: Site-specific information typically takes the form of intakes based on air monitoring or source term information and is documented in the site profile.

Missed dose is the potential dose that could have been received by a bioassay program participant but, because of limitations in the monitoring system, was undetected. Missed dose is assigned using actual bioassay measurements and worker-specific employment information. In an operational setting, the application of dosimetric and biokinetic models to the MDA is the minimum detectable dose (MDD). The MDD is used for selecting bioassay programs to meet given monitoring requirements and is not assigned to workers. This dose is included in the dose reconstruction assessment and is assigned as the missed dose to the worker. The "true" dose is assumed to fall between 0 and that which would result in the prediction of bioassay results equal to the MDA.

In the early years of the weapons complex, most sites used the MDA to determine if activity had been detected, so the "<" values reported by the site are used in the missed dose assessment. In more recent years, sites have used DL to make the decision regarding the presence of activity. Results between the DL and MDA are accounted for in the missed dose calculation so are not considered to be positive when performing a dose reconstruction.

Unmonitored dose is the potential dose that could have been received by an Energy Employee but for which no monitoring of the individual was performed or monitoring data are not available. For unmonitored periods, the following priorities are used for assigning dose:

1. Known ratio with other monitored nuclides. For example, the contaminants in recycled uranium are not typically monitored directly but can be assessed based on a ratio to the calculated uranium intake.

2. Coworker data.

3. Site-specific information. Note that this information typically takes the form of default intake values documented in the site profile.

4. Missed dose (extension of the missed dose calculation beyond the last bioassay result).

The line between missed and unmonitored dose is not well defined because material from an intake is excreted over an extended period depending on the half-life and retention characteristics of the nuclide. A long-lived, long-retained nuclide (e.g., plutonium, uranium) can be retained for decades with continuous excretion of small amounts. One result after many years of employment can contain activity from all previous intakes and provide information for determining an intake amount for all previous years, and, in such a situation, a lack of bioassay samples for several years would not be considered unmonitored because an upper bound can be placed on the intake. This is not true for nuclides that are eliminated relatively rapidly from the body (e.g., ^{137}Cs, ^{3}H). An unmonitored period can precede a monitored period for these shorter-retained nuclides.

For both types of nuclides, an individual can be monitored for some period, after which there is an unmonitored period. The period after the last bioassay sample is considered unmonitored for both long- and short-retained materials.

An individual's bioassay data always take precedence over other data (e.g., coworker, site-specific values), unless the bioassay has been shown to be flawed or not representative of the individual's exposure.

For long-lived, long-retained radionuclides:

- Missed dose is calculated from the start of the potential intake period through the date of the last bioassay sample. This period is considered to be monitored regardless of the date of the first bioassay sample.

- Unmonitored dose is assigned from the day after the last bioassay sample through the end of the potential exposure period.

- Long-lived, long-retained nuclides include plutonium, uranium, and americium, unless the only monitoring method is chest counting. Types F and M are not retained for significant periods in the lungs.

For short-lived or short-retained radionuclides:

- Missed dose is calculated in the intervals where there are bioassay results; other periods are considered to be unmonitored. Gaps of greater than 2 years between results are considered to be unmonitored. Note that for very short-retained materials, notably ^{3}H and ^{131}I, this period would be less. Guidance on ^{3}H assessment is contained in ORAUT-OTIB-0011, *Tritium Calculated and Missed Dose Estimates* (ORAUT 2004c). In general, ^{3}H exposure is assumed only during periods when bioassay samples were collected because it is cheap, easy, and quick. The primary exception to this rule is when a site began using ^{3}H before the implementation of a bioassay program.

- Unmonitored dose is assigned for the period up until 1 year before the first bioassay sample for the nuclide of interest.

- Missed dose is calculated from 1 year before the first bioassay result through the date of the last bioassay sample.

- If there are more than 2 years between two consecutive samples:

  - Missed dose is calculated through the date of the first of these samples.

  - Unmonitored dose is assigned from the day after the first sample until 1 year before the second sample.

  - Missed dose is calculated starting at 1 year before the date of the second result.

- Short-lived, short-retained nuclides include ^{137}Cs, ^{106}Ru, ^{144}Ce, and ^{90}Sr.

3.3.1 Missed Dose Determination

Missed dose is assigned using actual bioassay sample parameters (e.g., specific dates and MDAs) and associated dosimetry program information. As noted in 3.3, the true missed dose falls between 0 and the dose that would result in bioassay values equal to the MDA. This range is described by the triangular distribution, with a minimum of 0, a mode equal to the dose that yields bioassay results equal to half of the MDA, and a maximum that is twice that, or where the bioassay results are equal to the MDA. Therefore, when calculating missed dose, a result equal to half of the MDA is used in the calculation. The resulting dose is assigned as the mode of the triangular distribution. Note that in some instances the reporting level will be used in place of the MDA; see section 2.3 for information.

At a minimum, the MDA and date of the last sample result in the relevant period are used for the calculation. When calculating a missed dose to compare to a fitted dose (for best estimate), the MDA and date of the last result less than the MDA are used.

To calculate a missed dose, a chronic intake throughout the possible exposure period is assumed. The specific dates can vary depending on the bioassay method's MDA over time.

If the detection threshold changes through the intake period, the following must be considered in determining the chronic intake:

- If the detection threshold decreases over time and the radionuclide/absorption type reaches equilibrium slowly in the compartment of interest (e.g., in urine, type M or S plutonium or transuranic elements or type S uranium), perform the fit using the date of the last sample and half of the associated detection threshold and assume a single chronic intake for the entire potential exposure period. Only the lowest MDAs need to be considered in this scenario because any assessment of early values will result in the overestimation of the later, smaller MDA values.

- When the MDA oscillates, usually due to samples with individually reported MDAs, selection of the sample to use for the missed dose calculation can be case dependent. For an overestimate the use of the largest MDA is appropriate, and conversely, the smallest value can be used for an underestimate. A best estimate will be dependent on the pattern of the results but in general a line that runs through the center of the values would be suitable. Contact the Principal Internal Dosimetrist if you need assistance.

- If the detection threshold decreases over time for radionuclide/absorption types that reach equilibrium rapidly, or if the detection threshold increases over time, use IMBA to determine chronic intakes applicable to each period (note that this is applicable only if there is a bioassay result in the period). To do this:

  - In IMBA, set the number of intakes to the number of periods of different detection thresholds in which the Energy Employee has bioassay results.

  - The first chronic intake period begins on the day the exposure began and continues to the date of the final sample in that detection threshold period.

- Each following chronic intake is assessed from the day after the previous period to the date of the last sample in the next detection threshold period, or to the last day of exposure for the final exposure period.

- Perform the fit assigning half of the associated detection threshold to the date of the last sample in each period.

Calculate the annual organ doses from the intakes of each radionuclide and enter the doses into IREP using a triangular distribution and:

- Set the lower bound (Parameter 1) to 0.
- Set the mode (Parameter 2) to the annual organ doses as calculated above.
- Set the upper bound (Parameter 3) to 2 times the mode.

3.3.2 Coworker Data

Coworker exposure distributions are developed from available dosimetric data from DOE or Atomic Weapons Employer sites. ORAUT-PLAN-0014, *Coworker Data Exposure Profile Development,* (ORAUT 2004b), provides a generic discussion on the development of these datasets. ORAUT-OTIB-0019, *Analysis of Coworker Bioassay Data for Internal Dose Assignment* (ORAUT 2005c), contains more specific information on the derivation of internal dosimetry data parameters. Site-specific TIBs and site profiles are available for some sites and provide assumptions for intakes based on coworker dosimetry analyses.

Coworker dose is applied as a best estimate for individuals with a potential for intakes of radioactive material but who lack bioassay data or have unmonitored intervals. Data can be lacking because it was not available from the site or because monitoring was not performed. Workers with a significant potential for intake should be assigned doses at the 95th percentile with a constant distribution, while those with less potential are assigned the 50th percentile with a lognormal distribution. When coworker analyses do not define how or to whom the intake should apply, "significant potential" is subjective, but in general it applies to people who were radiation workers with a potential for intakes of radioactive material. The dose reconstructor must make this decision based on the worker's job titles and work locations, as well as other information in the file that could indicate a potential for intake. ORAUT-OTIB-0014, *Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace* (ORAUT 2004a), provides guidance on job categories that are typically most likely to be in the upper end of the distribution. For sites that handled multiple independent sources of radionuclides, the site-specific TIBs or site profiles, where possible, provide guidance on which nuclides to assign. However, this could be a matter of dose reconstructor judgment, again, based on information in the file.

3.3.3 Example Assignment of Coworker and Unmonitored Doses

Employment: 03/1/1957 to 07/12/1989

Job information: Production worker; single work location; no significant fluctuations in external dose results

Bioassay: All results <MDA
Plutonium-239 urine samples on 05/4/1960, 12/11/1963, 11/17/1980
Strontium-90 urine samples on 03/12/1965, 09/18/1965, 08/01/1966, 01/05/1978, 07/12/1978, 04/30/1979

Plutonium-239 dose calculation:

1. Calculate missed dose from 03/1/1957 through 11/17/1980 using 0.5 MDA on 11/17/1980.
2. For the period from 11/18/1980 through 07/12/1989:

    a. Assign coworker dose if it is available.
    b. If coworker data are not available but the site profile contains default intake values for individuals who were potentially exposed, assign the site profile values.
    c. If no other information is available, extend the missed dose through this period.

Strontium-90 dose calculation:

1. Assign coworker data or site default values from 03/01/1957 to 03/12/1964.
2. Calculate missed dose from 03/13/1964 to 08/01/1966.
3. Assign coworker data or site default values from 08/02/1966 to 01/05/1977.
4. Calculate missed dose from 01/06/1977 to 04/30/1979.
5. Assign coworker data or site default values from 05/01/1979 to 07/12/1989.
6. If there are other nuclides associated with ^{90}Sr (such as detailed in ORAUT 2014), perform the above calculations first and assign the associated radionuclides from the resulting intakes in steps 1 through 5.

3.3.4 Short-Duration Missed Dose

The fraction of an element that is absorbed into blood from the small intestine (SI) is defined by the parameter f1. A very small (i.e., $<1 \times 10^{-3}$) f1 value combined with a long half-life results in small fractions of material being excreted via urine. Because of the slow ingrowth to urinary excretion from chronic intakes, assessment of missed dose for nuclides with these small f1 values can result in implausibly large intake rates when the bioassay result is shortly after the start of intake, particularly for those with relatively long half-lives. When calculating a missed dose for a period of less than 1 year, the coworker intake rate should be assigned as a best estimate for nuclides with an f1 value <0.001 and a half-life greater than 50 years.

3.4 FITTING POSITIVE BIOASSAY RESULTS

This section describes the process for fitting results to an intake. Specific details of the mechanics of using IMBA are addressed in ORAUT-PROC-0002, *Use of Integrated Modules for Bioassay Analysis (IMBA)* (ORAUT 2003b).

3.4.1 General Philosophy

The fitting of bioassay data to an intake is a somewhat subjective process, particularly when dealing with historical data because intake dates are frequently unknown and additional follow-up sampling is not possible. Fits should be as simple as possible; no more complexity than necessary should be applied to a given case. This means if a quick and simple over- or underestimate can be performed using the bioassay data (see Section 3.5 for discussion), no further fitting should be tried.

In general, the overall pattern of the data should be fit rather than each individual result. It is not realistic to develop an intake scenario that yields predicted results that are identical to the measured values for all or even most of the measurements because the retention and elimination of radioactive materials, as well as the measurement of the material, are stochastic processes that result in statistical variations. For urine samples, the concentration will even vary throughout the day. In addition, an exact match to each measured result is often achieved only through a set of very unrealistic assumptions that are often not favorable to claimants. An example of this is fitting each

positive result to a separate intake. This often requires the assumption that each intake occurred only 1 or 2 days before the bioassay sample. If the samples were collected as part of the routine bioassay program (as opposed to incident-related samples), it is unlikely that the program caught each unsuspected intake immediately upon occurrence.

3.4.2 General Guidelines

Assessment of positive bioassay results is subjective in the absence of known intakes, so the following guidelines are provided:

- Use all positive bioassay results, starting with the first positive value.
- For results <MDA:
  - Enter the MDA value for both the Measurement Result and Measurement Error.
  - Include the first negative (<MDA) result after each set of positive results and set Data Type equal to "<LOD."
  - If there are multiple positive results, include no more than two consecutive negative results. For fewer than five consecutive positive results, include only one negative result. Use of additional <LOD results, particularly for chronic exposures, frequently yields a fit that appears to underestimate the general trend of the data.
  - All other <MDA results should have a Data Type of "Excluded."
  - Note that the presence of a result less than the MDA does not mean that a new intake must be assigned for the next result greater than the MDA.
- Although not necessarily used in fitting, all results (including those that are excluded) should be plotted on the graph because they must be consistent with the final fit.
- Fit all of the results simultaneously (i.e., a single IMBA run), even if there are multiple intakes. A mix of chronic and acute intakes can be applied, as can a single or multiple chronic intakes. A single chronic intake can also be fit when there are only intermittent positive results that are relatively small (e.g., within a factor of 2 of the MDA); this could be representative of a low-level chronic intake just below the MDA. Note that the limitations on the use of <LOD apply here as well.
- For positive results, use the 1-sigma error associated with the result when available. If there are no reported errors with the results, see the discussion in Section 3.2.6.2 for guidance.
- If there are many results less than the MDA or stretches of employment where all results are less than the MDA, missed dose will be assessed separately. See the discussion in Section 3.3.1.
- Use known information about intakes where available (e.g., intake date, material type, and particle size distribution). For unknown parameters, begin with default values where possible. These can be adjusted as necessary, but there must be sufficient justification when doing so.

  For an unknown intake date, the default is the midpoint between the date of the positive result and that of the previous sample. Intake dates should not be varied if there are only a few results for each intake unless projections from the intakes are inconsistent with later data

(e.g., several <MDA results are predicted to have had detectable levels of activity). As discussed in Section 3.4.1, it is neither necessary nor desirable to obtain an exact fit to each result because variation in excretion rate is to be expected.

- If the material type is unknown, perform a fit for each possible type. Select the one that yields the largest total dose to the applicable organ for the years of interest. Note that the largest intake does not necessarily correlate to the largest dose. In some cases it may be possible to rule out a material type based on later, overpredicted sample results or disagreement with other measurement types. If one type provides an unarguably better fit, use it. This can generally be shown only in cases where:
  - A single intake has many (more than 10) consecutive positive results,
  - There are contemporary data (later than 1989) associated with intakes 25 years or more earlier (depending on the nuclide and its associated half-life), or
  - Results from other bioassay methods cannot be reconciled with the larger dose determinations (e.g., the intake determined from urine samples predicts detectable activity in a chest count but all results are <MDA; in this case, the material type that yields this larger intake would be ruled out).
- If the majority of results are positive and scattered throughout the intake period (with no more than a few consecutive <MDA results), use all results for the intake assessment. If the data are not censored (results <MDA are recorded as measured rather than as a "<" value or as the MDA), enter the result as recorded with a Data Type of Real. Otherwise, enter the MDA for the value and mark it <LOD. Note that the issue of measurement error (Section 3.2.6.2) also applies here.

3.5 OVERALL ASSESSMENT METHODS

There are typically several approaches that can be applied to a given case. The best approach is that which takes the least amount of time while still producing the correct decision. Many cases do not require a detailed, accurate dose assessment; efficiency methods can be used to expedite case completion with sufficient levels of precision to allow the U.S. Department of Labor to arrive at correct compensation decisions. There are two general types of expediting methods that can be applied: overestimates and underestimates. When neither of these can be applied to a case, a more refined assessment is needed.

3.5.1 Overestimate

An overestimate is the assignment of an intake or dose that exceeds the possible exposure of the worker. If the resulting POC, including all sources of potential exposure, is less than 45% (note that this value is determined by Project Management and NIOSH and is subject to change), further refinement is not necessary because it will only lower the assigned dose.

This method is typically appropriate to cancers of nonmetabolic organs because the radioactive material does not concentrate in such organs. Therefore, relatively large intakes can yield small doses. The method also lends itself to the development of generic values that can be used for many individuals. Individual overestimates can also be made using individual-specific information.

3.5.1.1 Generic Overestimates

Several methods have been developed and documented in TIBs. Summaries and general applicability of these are described in Section 3.6; specific details are in each document.

Most of the overestimating methods are applicable to individuals with no positive bioassay results. However, this can be extended to individuals with positive results as long as the positive results are taken into account (i.e., it is shown that the assigned intake yields larger projected values than those reported or the positive results are assessed separately and the subsequent dose is added to the efficiency method results).

3.5.1.2 Individual-Specific Overestimates

Overestimates can sometimes be applied to individuals with positive bioassay data. In such cases, most of the bioassay results should be overpredicted by the selected intake. This can be done by running a chronic intake assessment using only the largest bioassay result; all others should be plotted but excluded from the fit. If there are several large results, use of the earliest value to perform the fit will typically yield the largest intake. After calculating the intake, review the measured (Measurement Rate) versus predicted (Theoretical Rate) results to determine if most results have been overpredicted (this can be done quickly with the graph).

If there are later results that are underpredicted, determine the ratio of the measured result to the predicted result, multiply the intake by this ratio, then run the Intakes-to-Bioassay calculation to demonstrate that all bioassay results have been overpredicted.

A similar method can also be used when there is an acute intake. Start by using only a single result, and adjust the intake as necessary to obtain an overestimate of all of the results associated with the intake.

3.5.2 Underestimate

An underestimate is the assignment of a dose to a worker that is less than the dose that would potentially be assigned under this program. If the resulting POC is greater than 52% (note that this value is determined by Project Management and NIOSH and is subject to change), further refinement is not necessary because it will only increase the assigned dose. An underestimate is typically performed in the form of a partial assessment of dose, such as reconstruction of a single incident, missed dose only, or the underprediction of all or most positive bioassay results. The assigned distribution in IREP will depend on the type of dose (e.g., missed and fitted) that is calculated.

An underestimate is most likely to be successful when applied to metabolic organs, particularly in cases where the detection level for the nuclide is large. This is frequently the case with actinides in the earlier decades of the complex. In such cases, a missed dose calculation alone might be adequate for determining compensability.

Because this method is dependent on an individual's bioassay data, the details are case-specific and do not lend themselves to a generic approach that can be documented in a TIB.

3.5.3 Best Estimate

A best estimate is required when an efficiency method results in a decision that is incompatible with the assumptions (i.e., an underestimate yields a POC less than 52% and an overestimate yields a POC greater than 45%; as noted previously, the specific values are subject to change). The purpose of this Project is to provide dose reconstructions with sufficient levels of precision to allow the

U.S. Department of Labor to arrive at correct compensation decisions. A best estimate is based on all available data and is the most realistic assessment that can be performed with these data and the requirements of the Energy Employees Occupational Illness Compensation Program Act of 2000. It can include some parameter values that are under- or overestimated if the outcome is consistent with those assumptions. When information for a particular parameter value is unknown or there are multiple options, the choice that is favorable to claimants (i.e., the one resulting in the largest POC) is selected.

3.5.3.1 Performing a Best Estimate Using Bioassay Data

A best estimate uses all available information. Both missed and fitted dose are included (unless all data can be fit at once, as discussed in Section 3.4.2) as follows:

1. Ignore positive data (this means that the date of the last result <MDA is used for the missed dose calculation) and perform a missed dose (mode only) calculation as described in Section 3.3.1. If multiple material types are possible, select the one that yields the largest total dose to the applicable organ for the years of interest. If there are no results <MDA, no missed dose is calculated.

2. Fit the positive data in accordance with Section 3.4. Unless known intake dates are documented or bioassay results are indicated to be "special" rather than "routine," it is not considered a best estimate to assign all intake dates at 1 to 2 days before the date of a positive bioassay sample. As noted above, this is not a realistic scenario and in most cases is not favorable to the claimant. If this is the only way a fit can be obtained, it is likely that an inappropriate material type is being applied or too much effort is being made to fit every result exactly.

3. Assigned annual dose for a given year is the maximum value from step 1 or 2. Choose the IREP annual dose distribution type based on missed or fitted dose assignment:

   - For years in which the dose determined in step 1 is larger than that from step 2, use the triangular distribution, where Min = 0, Mode = annual dose, and Max = Mode*2.

   - For years in which the dose from step 2 is equal to or larger than that from step 1, use the lognormal distribution, where Median = annual dose and the geometric standard deviation (GSD) = 3.

3.5.3.2 Multiple Cancers

Consistent assumptions must be made for all cancers when performing a best estimate. This means that the same material type must be used for all cancers for a given nuclide and intake combination for a best estimate. If there are exceptions to this rule, they will be documented in TIBs specific to the circumstance.

3.6 INTERNAL DOSIMETRY GUIDANCE DOCUMENTS

This section summarizes several documents that provide efficiency methods or additional information for making decisions on exposures to assign to a particular worker. This is intended as an overview only; refer to the individual documents for the current revision and for applicability and limitations of each.

3.6.1 OCAS-IG-002, *Internal Dose Reconstruction Implementation Guideline*

DCAS general guidance document on methods and approaches that can be used to reconstruct occupational radiation dose from internally deposited radionuclides in support of EEOICPA.

3.6.2 ORAUT-OTIB-0001, *Maximum Internal Dose Estimates for Savannah River Site (SRS) Claims*

This method uses the largest recorded intakes in the history of the Savannah River Site to assign an overestimated intake for workers (ORAUT 2003a). An average of the largest five intakes for each monitored nuclide was used. Although it is conceivable that an individual had an intake in excess of one of the values, it is very unlikely that the worker had large undocumented intakes of all radionuclides present on the site. Tritium is not included; if the worker had the potential for significant or chronic intakes of tritium, additional dose must be included.

3.6.3 ORAUT-OTIB-0002, *Maximum Internal Dose Estimates for Certain DOE Complex Claims*

This document has been withdrawn and is no longer to be used.

3.6.4 ORAUT-OTIB-0011, *Tritium Calculated and Missed Dose Estimates*

IMBA will not directly calculate intakes from ^{3}H urine data, so an alternative tool was developed. This OTIB provides documentation of the method for estimating tritium missed and calculated doses from urine data (ORAUT 2004c).

3.6.5 ORAUT-OTIB-0014, *Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace*

Internal radiation doses to some employees were limited to doses from inhalation of airborne radionuclides in the ambient environment from site operations or contamination rather than from localized airborne radionuclides from uncontained radioactive materials in the workplace. For these employees, assignment of environmental dose only is appropriate. ORAUT-OTIB-0014 (ORAUT 2004b) provides guidance for determining such instances based on:

- Job description,
- Work location,
- Time frame, and
- Presence or absence of internal monitoring data.

3.6.6 ORAUT-OTIB-0018, *Internal Dose Overestimates for Facilities with Air Sampling Programs*

This method is based on limiting air concentrations (ORAUT 2005a). A chronic exposure to the maximum permissible concentration (MPC) throughout employment is assumed. Because of this, the method applies only to sites that controlled exposure to intakes based on rigorous air sampling programs. While it is possible for a worker to have been occasionally exposed to levels exceeding the MPC, it is very unlikely that an individual was continuously exposed at such levels for 40 hours per week throughout the employment period. An additional conservatism is achieved by assuming that the airborne activity was comprised of the single nuclide, in each year of intake, that results in the largest dose to the organ of interest rather than assigning a mixture of radionuclides.

3.6.7 ORAUT-OTIB-0022, *Guidance on Wound Modeling for Internal Dose Reconstruction*

This document focuses on how to use IMBA to evaluate intakes of plutonium by wound, although the concept can be applied to other radionuclides (ORAUT 2005d). Guidance on initial parameters is provided.

3.6.8 ORAUT-OTIB-0033, *Application of Internal Doses Based on Claimant-Favorable Assumptions for Processing as Best Estimates*

This method (ORAUT 2005b) applies a graded approach to internal dose overestimates and unites the application of ORAUT-OTIB-0014 (ORAUT 2004a), ORAUT-OTIB-0018 (ORAUT 2005a), and coworker dose. Some judgment is needed to apply these values; guidance is provided based on:

- The period during which the Energy Employee worked,
- The processes conducted at the site at which the Energy Employee worked,
- The job category and work location of the Energy Employee, and
- The results of bioassay measurements for the Energy Employee.

3.6.9 ORAUT-OTIB-0049, *Estimating Doses for Plutonium Strongly Retained in the Lung*

A handful of accidental intakes of plutonium oxides have exhibited long-term retention of plutonium in the lung exceeding that predicted by the standard Type S model. This OTIB provides adjustment factors for calculating a best estimate of the annual organ doses for intakes of type Super S plutonium and describes the conditions for applicability of this method (ORAUT 2010).

3.6.10 ORAUT-OTIB-0054, *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses*

Reactor operations can produce a wide assortment of radionuclides but routine bioassay monitoring typically includes only those that predominate the mixture or are reported as a gross measurement that could contain an assortment of nuclides. This OTIB provides guidance on the assignment of radionuclide-specific intakes of mixed fission and activation products when air sampling or urinalysis data associated with reactors or reactor fuels are available only as gross or total beta activity or gross or total gamma activity (ORAUT 2014). The derived ratios can also be applied to cases where the activity of a single radionuclide in the mixture is known, such as ^{137}Cs from a whole body count result or ^{90}Sr in a urine sample.

3.6.11 ORAUT-OTIB-0066, *Calculation of Dose from Intakes of Special Tritium Compounds*

This document provides guidance on how to use urine bioassay data to calculate best estimates of doses for intakes of organically bound tritium (OBT) and stable metal tritides (SMT).

3.7 SPECIFIC ISSUES

3.7.1 Plutonium Mixtures

Plutonium-239 is found in various mixtures depending on the purpose of the material. This typically includes several plutonium isotopes as well as ^{241}Am from ^{241}Pu decay. A given bioassay technique does not necessarily measure all of the components; different methods can be used to measure the different nuclides. There are two primary complications in assessing intakes of these mixtures: (1) ^{241}Am activity increases over time while the plutonium activities are decreasing, which means that the ratios are not constant and makes the age of the material a factor; and (2) an assumption that is

favorable to the claimant for one technique might not be for another technique. Dose reconstructors must therefore be sure to take all information into account.

Note that if the material is from a plutonium heat source, the primary plutonium isotope is ^{238}Pu and this discussion is not applicable.

3.7.1.1 Background Information

Plutonium mixtures are characterized by their ^{240}Pu content; they are referred to by its weight percentage. Weapons-grade mixtures are 6% by weight ^{240}Pu while fuel-grade plutonium is 12% by weight ^{240}Pu.

Americium-241 builds up from near zero at the end of irradiation; however, it is removed during separation of the plutonium product and begins to build up again as the ^{241}Pu remaining in the product decays. Therefore, the ratio of ^{241}Pu to $^{239+240}$Pu decreases from the time of the end of irradiation because of decay (its half-life is only 14.4 years); whereas the ratio of ^{241}Am to $^{239+240}$Pu increases from the time of the last separation of the ^{241}Am from the plutonium.

3.7.1.2 Assumptions for Use in Dose Reconstruction

As with all dose reconstructions, when there is known information about an intake, it should be used regardless of default assumptions. In this instance, if the plutonium mixture or age of the material is known, it should be used rather than the information below.

3.7.1.2.1 Mixture of Material

If the mixture is unknown and the intake is being calculated from urine sample results, the 12% mixture may be used as a default assumption that is favorable to claimants.

Because there is less ^{241}Am in the 6% mixture than the 12% mixture, use of a 6% mixture is the default starting point for limiting doses based on chest counts.

If both types of data are available, it is necessary to compare them. For noncompensable claims, it is acceptable to overpredict one of the sets of monitoring results. However, if the claim is compensable the selected intake scenario must not contradict any of the claimant's monitoring data (urine or chest counting). For example, if the intake is based on urine samples with fuel-grade plutonium (12% mixture), run a prediction to lung counts based on the intake (using the Intakes to Bioassay tab in the IMBA Bioassay Calculations window). If the predicted values are greater than the measured values of ^{241}Am in the lung including ingrowth from ^{241}Pu, the intake can be used for a noncompensable case but not for a compensable case. In the latter case, the intake would then be determined using the 6% mixture assumptions to fit the chest count results. Although unlikely, a prediction from this intake to the urine sample results is then necessary to ensure that they are not overpredicted.

3.7.1.2.2 Age of Material

Until the fifth year of site operation, assume fresh plutonium. For years 5 through 9, assume a 5-year-old plutonium mixture. After these times, 10-year-old plutonium should be assumed. These assumptions can be used whether the bioassay being used is urine or chest counting.

3.7.2 Methods for Assessing Isotopic Uranium Results

Note: Isotopic results are from samples that were analyzed using alpha spectroscopy; individual results were reported for ^{234}U, ^{235}U, ^{238}U, and sometimes ^{236}U.

When a urine sample is analyzed for uranium using a gross alpha technique, the measured activity is representative of the total uranium activity because all isotopes are alpha emitters of relatively similar energies. When uranium is analyzed isotopically, each isotope is measured separately and the individual components must all be accounted for in the dose assessment because this is a known mixture of material. That is, assessing only one or two of the components, even if they are >MDA and the others are not, will result in an underestimate because at a minimum ^{234}U, ^{235}U, and ^{238}U will be present in a mixture. On the other hand, for a best estimate it is not appropriate to assess each component individually and sum the results unless all isotopes are >MDA because the isotopes will not be present in equal concentrations for any mixture.

There are several options for assessing an isotopic uranium urine result. The selected method will be dependent on case details.

The general rule of thumb for all cases is to start with the isotope with the highest activity. For depleted uranium this is ^{238}U; for all others it is ^{234}U.

3.7.2.1 Underestimate

Assessment of a single isotope can be used as an underestimate for a compensable claim. The appropriate IREP distribution will be dependent on the type of intake that was calculated:

- Triangular for missed dose, and
- Lognormal for fitted dose.

3.7.2.2 Overestimate

For an overestimate, the activity from all three isotopes can be summed and assessed as ^{234}U. For isotopes <MDA, add the MDA value (all three MDAs can be added for an overestimated missed dose).

Run the intake and dose estimates using the MDA values rather than 0.5 MDA.

Use a constant distribution for the doses in IREP.

3.7.2.3 Best Estimate

If all isotopes are >MDA:

- Sum the individual results.
- Run the intake and dose as ^{234}U.
- Use a lognormal distribution and GSD = 3 in IREP.

If ^{234}U and ^{238}U >MDA:

- Sum the ^{234}U and ^{238}U results.
- Run the intake assessment as ^{234}U.
- Divide the result by 0.965 to obtain total intake activity.

Note: Uranium-235 activity content typically only varies between 1% and 3.5% of the total activity regardless of the enrichment (see the uranium mixes in IMBA for examples). The factor here assumes the maximum amount; if it is overestimated, it will have little impact on the total dose because it is a small fraction. However, if the enrichment is known for a given claim, the known value should be used.

- Run the intake calculated in the previous step as ^{234}U for the dose assessment.
- Use a lognormal distribution and GSD = 3 in IREP.

If only ^{234}U or only ^{238}U >MDA:

- Run the intake assessment for the positive result.
- Determine the appropriate enrichment assumption.
- Calculate the intakes of the remaining isotopes from the ratios in an assumed enrichment.
- Sum the intake rates for all isotopes and assess the dose as ^{234}U.
- Use a lognormal distribution and GSD = 3 in IREP.

If no isotopes >MDA (note that this is now simply a missed dose assessment):

- Determine the appropriate enrichment assumption.
- Assess ^{234}U (^{238}U for depleted uranium) intake using 0.5 MDA for the result.
- Calculate the intakes of the remaining isotopes from the ratios in an assumed enrichment.
- Sum the intake rates for all isotopes and assess the dose as ^{234}U.
- Use a triangular distribution in IREP with:
  - Min = 0.
  - Mode = calculated dose.
  - Max = 2 × calculated dose.

Note: The substitution of ^{234}U for all isotopes does not apply to mixtures that contain ^{232}U.

3.7.3 Assignment of Thoron and Radon Dose

For lung cancers, IREP requires ^{222}Rn exposures to be entered in units of working level months (WLM). Radon-220 (also known as thoron) exposures are also frequently recorded in these units, but because the decay products have characteristics that are sufficiently different from ^{222}Rn, the exposure model is not applicable to thoron. In these circumstances, the reported thoron values must be converted to dose. DCAS-TIB-0011, *Lung Dose Conversion Factor for Thoron WLM* (NIOSH 2013), contains conversion factors from WLM to dose for respiratory tract segments for ^{220}Rn and ^{219}Rn. Because the exposure model applies specifically to the lung for radon, it also contains conversion factors for ET1 and ET2 for ^{222}Rn.

3.7.4 Assessment of Mixtures of Radionuclides

When dealing with mixtures of materials, such as those discussed in section 3.2.3, all components must be considered and summed for the dose comparison when determining the type that is favorable to the claimant.

When several nuclides may have been present at a site, the one or two primary dose contributors were frequently monitored and reported. Dose from additional radionuclides is assigned based on ratios to these primary nuclides. Principal examples of these ratios include weapons grade plutonium, recycled uranium, and mixed fission and activation products. Site profiles contain details of the

plutonium and uranium mixtures specific to the site, as well as other mixtures that are site-specific. ORAUT-OTIB-0054 (ORAUT 2014) provides guidance on the assignment of mixed fission and activation products.

When a best estimate is being performed, review the nuclides that are included in a ratio method and do not assign any that were directly monitored because doing so would account for the same nuclide twice. For example, recycled uranium contains plutonium and some sites that handled recycled uranium also handled plutonium. A bioassay sample for plutonium would account for any plutonium dose regardless of whether it came from a uranium or plutonium mixture.

4.0 ATTRIBUTIONS AND ANNOTATIONS

All information requiring identification was addressed via references integrated into the reference section of this document.

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ATTACHMENT A
RADIATION TYPES BY NUCLIDE FOR ENTRY INTO IREP

Table A-1. Radiation types by nuclide for entry into IREP.

Nuclide	Radiation type[a]	Nuclide	Radiation type[a]	Nuclide	Radiation type[a]
Ac-227	Alpha	I-133	Electrons E >15 keV	Rn-222	Radon
Ac-228	Alpha	I-134	Photons E >250 keV	Ru-103	Electrons E >15 keV
Ag-110m	Photons E >250 keV	I-135	Photons E >250 keV	Ru-106	Electrons E >15 keV
Am-241	Alpha	Ir-192	Photons E >250 keV	S-35	Electrons E >15 keV
Am-243	Alpha	La-140	Photons E >250 keV	Sb-124	Photons E >250 keV
As-74	Photons E >250 keV	Lu-174	Photons E = 30–250 keV	Sb-125	Photons E >250 keV
As-76	Electrons E >15 keV	Mn-54	Photons E >250 keV	Sc-46	Photons E >250 keV
Au-194	Photons E <30 keV	Mn-56	Electrons E >15 keV	Sm-151	Electrons E >15 keV
Ba-133	Photons E >250 keV	Mo-99	Electrons E >15 keV	Sn-113	Electrons E >15 keV
Ba-140	Photons E >250 keV	Na-22	Photons E >250 keV	Sr-85	Photons E >250 keV
Bk-249	Alpha	Na-24	Photons E >250 keV	Sr-89	Electrons E >15 keV
C-14	Electrons E >15 keV	Nb-94	Photons E >250 keV	Sr-90	Electrons E >15 keV
Ca-45	Electrons E >15 keV	Nb-95	Electrons E >15 keV	Sr-91	Electrons E >15 keV
Ce-139	Photons E = 30–250 keV	Ni-63	Electrons E >15 keV	Ta-182	Photons E >250 keV
Ce-141	Electrons E >15 keV	Np-237	Alpha	Tb-160	Electrons E >15 keV
Ce-143	Electrons E >15 keV	Np-239	Alpha	Tc-99	Electrons E >15 keV
Ce-144	Electrons E >15 keV	P-32	Electrons E >15 keV	Te-131	Photons E >250 keV
Cf-249	Alpha	P-33	Electrons E >15 keV	Te-131M	Electrons E >15 keV
Cf-252	Alpha	Pa-231	Alpha	Th-228	Alpha
Cl-36	Electrons E >15 keV	Pa-233	Alpha	Th-230	Alpha
Cm-242	Alpha	Pa-234	Alpha	Th-232	Alpha
Cm-243	Alpha	Pb-210	Alpha	Th-234	Alpha
Cm-244	Alpha	Pm-147	Electrons E >15 keV	Tl-201	Photons E = 30–250keV
Co-57	Photons E = 30–250 keV	Po-208	Alpha	Tl-202	Photons E >250 keV
Co-58	Photons E >250 keV	Po-209	Alpha	Tl-204	Electrons E >15 keV
Co-60	Photons E >250keV	Po-210	Alpha	Tm-170	Electrons E >15 keV
Cr-51	Photons E >250 keV	Pr-143	Photons E >250 keV	U-232	Alpha
Cs-134	Electrons E >15 keV	Pr-147	Electrons E >15 keV	U-234	Alpha
Cs-137	Electrons E >15 keV	Pu-236	Alpha	U-235	Alpha
Eu-152	Photons E >250 keV	Pu-238	Alpha	U-236	Alpha
Eu-154	Electrons E >15 keV	Pu-239	Alpha	U-238	Alpha
Eu-155	Electrons E >15 keV	Pu-240	Alpha	U-239	Alpha
Eu-156	Electrons E >15 keV	Pu-241	Alpha	Y-88	Photons E >250 keV
Fe-55	Photons E <30 keV	Pu-242	Alpha	Y-90	Electrons E >15 keV
Fe-59	Electrons E >15 keV	Ra-220	Alpha	Y-91	Electrons E >15 keV
H-3	Electrons E <15 keV	Ra-223	Alpha	Yb-169	Photons E >250 keV
Hf-181	Electrons E >15 keV	Ra-224	Alpha	Zn-65	Photons E >250 keV
I-125	Photons E <30 keV	Ra-226	Alpha	Zr-95	Electrons E >15 keV
I-129	Photons E = 30–250 keV	Ra-228	Alpha		
I-131	Electrons E >15 keV	Rn-220	Alpha		

a. E = energy; the REFs for >15-keV electrons and >250-keV photons are equal. To minimize the number of lines in IREP, these two categories can be entered with either energy type and combined if the same distribution type.

ATTACHMENT B
IMBA DOSE ASSESSMENT LIMITATIONS

IMBA is known to calculate inaccurate organ doses for some radionuclide and organ combinations. See Section 3.2.6.4 for a complete discussion of the issues. Table B-1 provides a summary of the differences between IMBA-calculated doses and the true value; those indicated to be high or low cannot be assessed with IMBA. These are general trends and may not apply to all material types for the listed organ or for any given year of annual dose.

Table B-1. IMBA doses relative to the true value (calculated using DCAL).[a]

Organ	Ac-228 (chronic intakes only)	Pb-210	Pr-147 (chronic intakes only)	Ra-223	Ra-224	Ra-226	Ra-228	Te-131	Te-131m
Adrenals	Low	High	Low	–	Low	–	Low	(b)	High
Bladder	Low	High	Low	–	Low	–	Low	(b)	–
Bone surf	Low	–	Low	–	High	–	Low	(b)	High
Brain	Low	High	Low	–	Low	–	Low	(b)	–
Breast	Low	High	Low	–	Low	–	Low	(b)	High
Esophagus	Low	High	Low	–	Low	–	Low	(b)	–
Kidneys	Low	Low	Low	Low	Low	Low	Low	(b)	High
Liver	Low	High	Low	–	Low	–	Low	(b)	High
Muscle	Low	High	Low	–	Low	–	Low	(b)	–
Ovaries	Low	High	Low	–	Low	–	Low	(b)	High
Pancreas	Low	High	Low	–	Low	–	Low	(b)	High
RBM	Low	Low	Low	–	High	–	Low	(b)	High
Skin	Low	High	Low	–	Low	–	Low	(b)	High
Spleen	Low	Low	Low	–	Low	Low	Low	(b)	High
Testes	Low	High	Low	–	Low	–	Low	(b)	High
Thymus	Low	High	Low	–	Low	–	Low	(b)	–
Thyroid	Low	High	Low	–	Low	–	Low	(b)	Low
Uterus	Low	High	Low	–	Low	–	Low	(b)	High
LNET	Low	High	Low	–	–	–	–	(b)	–
LNTH	Low	High	Low	–	–	–	–	(b)	High
ET1	Low	High	Low	–	–	–	–	(b)	–
ET2	Low	High	Low	–	–	–	–	(b)	–
Lungs	Low	High	Low	–	–	–	–	(b)	–
Stomach	Low	High	Low	–	Low	–	Low	(b)	High
SI	Low	High	Low	–	–	–	Low	(b)	–
ULI	Low	High	Low	–	–	High	Low	(b)	–
LLI	Low	High	Low	–	–	High	Low	(b)	–
Colon	Low	High	Low	–	–	High	Low	(b)	–

a. A dash (-) indicates that the IMBA value is less than 10% different from the DCAL values and can be used for a dose assessment.

b. Because Te-131 falls into both categories, it is not possible to cover all possible scenarios. There are two competing issues: (1) overestimates for a number of organs because of the kinetics issue and (2) underestimates of all organs for chronic intakes, the magnitude of which increases as the length of intake increases. Therefore, IMBA cannot be used to calculate doses from Te-131.

ATTACHMENT B
IMBA DOSE ASSESSMENT LIMITATIONS (continued)

Organ	Th-228	Th-229	Th-232	Th-234	U-232	U-233 (type S inh. only)	U-239 (chronic intakes only)
Adrenals	High	High	High	–	Low	–	Low
Bladder	High	High	High	–	Low	–	Low
Bone surf	High	High	High	High	Low	Low	Low
Brain	High	High	High	–	Low	–	Low
Breast	High	High	High	–	Low	–	Low
Esophagus	High	High	High	–	Low	–	Low
Kidneys	High	High	High	–	Low	–	Low
Liver	–	–	High	–	Low	Low	Low
Muscle	High	High	High	–	Low	–	Low
Ovaries	High	High	High	–	Low	Low	Low
Pancreas	High	High	High	–	Low	–	Low
RBM	High	High	High	–	Low	Low	Low
Skin	High	High	High	–	Low	–	Low
Spleen	High	High	High	–	Low	–	Low
Testes	High	High	High	–	Low	Low	Low
Thymus	High	High	High	–	Low	–	Low
Thyroid	High	High	High	–	Low	–	Low
Uterus	High	High	High	–	Low	–	Low
LNET	–	High	High	–	–	–	Low
LNTH	–	–	High	–	–	–	Low
ET1	–	–	High	–	–	–	Low
ET2	–	–	High	–	–	–	Low
Lungs	–	–	High	–	–	–	Low
Stomach	High	High	High	–	Low	–	Low
SI	High	High	High	–	Low	–	Low
ULI	Low	High	High	–	Low	–	Low
LLI	Low	High	High	–	Low	–	Low
Colon	Low	High	High	–	Low	–	Low

a. A dash (-) indicates that the IMBA value is less than 10% different from the DCAL values and can be used for a dose assessment.