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ACRONYMS AND ABBREVIATIONS

d	day
DOE	U.S. Department of Energy
g	gram
GI	gastrointestinal
GSD	geometric standard deviation
hr	hour
ICRP	International Commission on Radiological Protection
IMBA	Integrated Modules for Bioassay Assessment (computer program)
IREP	Interactive RadioEpidemiological Program
LOD	limit of detection
MDA	minimum detectable activity
MPBB	maximum permissible body burden
MPC	maximum permissible concentration
nCi	nanocurie
pCi	picocurie
POC	probability of causation
REF	radiation effectiveness factor
TIB	technical information bulletin
U.S.C.	United States Code

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 historic 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. TIBs may be used to assist the 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 [EEOICPA; 42 U.S.C. § 7384l(5) and (12)]. EEOICPA defines a DOE facility as "any building, structure, or premise, including the grounds upon which such building, structure, or premise is located … in which operations are, or have been, conducted by, or on behalf of, the Department of Energy (except for buildings, structures, premises, grounds, or operations … pertaining to the Naval Nuclear Propulsion Program)" [42 U.S.C. § 7384l (12)]. Accordingly, except for the exclusion for the Naval Nuclear Propulsion Program noted above, any facility that performs or performed DOE operations of any nature whatsoever is a DOE facility encompassed by EEOICPA.

For employees of DOE or its contractors with cancer, the DOE facility definition only determines eligibility for a dose reconstruction, which is a prerequisite to a compensation decision (except for members of the Special Exposure Cohort). The compensation decision for cancer claimants is based on a section of the statute entitled "Exposure in the Performance of Duty." That provision [42 U.S.C. § 7384n(b)] says that an individual with cancer "shall be determined to have sustained that cancer in the performance of duty for purposes of the compensation program if, and only if, the cancer … was at least as likely as not related to employment at the facility [where the employee worked], as determined in accordance with the POC [probability of causation*] guidelines established under subsection (c) …." [42 U.S.C. § 7384n(b)]. Neither the statute nor the probability of causation guidelines (nor the dose reconstruction regulation) define "performance of duty" for DOE employees with a covered cancer or restrict the "duty" to nuclear weapons work.

As noted above, the statute includes a definition of a DOE facility that excludes "buildings, structures, premises, grounds, or operations covered by Executive Order No. 12344, dated February 1, 1982 (42 U.S.C. 7158 note), pertaining to the Naval Nuclear Propulsion Program" [42 U.S.C. § 7384l(12)]. While this definition contains an exclusion with respect to the Naval Nuclear Propulsion Program, the section of EEOICPA that deals with the compensation decision for covered employees with cancer [i.e., 42 U.S.C. § 7384n(b), entitled "Exposure in the Performance of Duty"] does not contain such an exclusion. Therefore, the statute requires NIOSH to include all occupationally derived radiation exposures at the facility in its dose reconstructions for employees at DOE facilities, including radiation exposures related to the Naval Nuclear Propulsion Program. As a result, all internal and external dosimetry monitoring results are considered valid for use in dose reconstruction. No efforts are made to determine the eligibility of any fraction of total measured exposure for inclusion in dose reconstruction. NIOSH, however, does not consider the following exposures to be occupationally derived:

- Radiation from naturally occurring radon present in conventional structures
- Radiation from diagnostic X-rays received in the treatment of work-related injuries

* The U.S. Department of Labor is ultimately responsible under the EEOICPA for determining the POC.

2.0 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.

3.0 APPLICABILITY AND LIMITATIONS

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

4.0 TERMINOLOGY

4.1 SYSTEMIC VS. 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, and are considered nonsystemic organs. The lymph nodes are included in the nonsystemic organs.

4.2 METABOLIC VS. NONMETABOLIC ORGANS

A number of organs are included in the general models provided by the International Commission on Radiological Protection (ICRP 1998). However, for a given element, only a specific subset of these organs is included in the metabolic or biokinetic modeling. Those organs that are specifically modeled are referred to as “metabolic” for the purposes of this Project. Others for which a dose is calculated but are not specified by the ICRP element-specific model are called 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) are considered to be metabolic.

5.0 GUIDANCE

5.1 SELECTION OF APPROPRIATE ORGANS FOR DOSE ESTIMATE

Dose must be calculated to the organ in which the cancer originated. ORAUT (2006) correlates 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 assigned to the organ is the largest dose among the organs reported in IMBA that are not part of the ICRP (1998) metabolic model (referred to as the nonmetabolic organs, as described in Section 4.2) for the particular radionuclide.

Organs that do not concentrate a radionuclide will 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. Using these techniques, many of these other organ doses are calculated. Because these organs are all considered soft tissue and thus are 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 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 part of the metabolic model. Select the appropriate element (any isotope will work), load the ICRP defaults (using the button on the tool bar), and select the **Biokinetics** button (close to the **Close** button). Click on **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 4.2, 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.

5.2 SELECTION OF PARAMETER VALUES

5.2.1 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 could be an ingestion component associated with it. When an inhalation intake is assigned based on air monitoring data rather than bioassay, an additional ingestion component must be assigned. See OCAS-TIB-009 (NIOSH 2004) for guidance.

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

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 (2005d) contains guidance on modeling these intakes.

Vapor is actually a specific instance of an inhalation intake; it is defined as the gaseous form of substances that are normally in liquid or solid form (James 2005). Iodine is typically modeled using this intake route.

In the absence of information regarding 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..

5.2.2 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 (1994) default value is 5 μm activity median aerodynamic diameter. This value is to be used for evaluating inhalation intakes in the absence of known information, as documented in the site profiles or the case file.

5.2.3 Material Type

Material type describes the rate of absorption of deposited material in the respiratory tract into blood. ICRP (1994) describes three types, F (fast solubilization), M (moderate solubilization), and S (slow solubilization); the assignment of an element to one 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, as opposed to members of the public. If material types at a particular site are known, they will be documented in the site profile and should be used. However, for the majority of cases it is likely that the material type is unknown or the individual might have worked in multiple areas, making exposure to multiple types possible. In such cases, an assessment of each type *to which the element is assigned in ICRP 68* (this is indicated in the IMBA selection menu) shall be made, and that which results in the largest dose to the organ of interest shall 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 Am-241 in a plutonium matrix; americium is assigned to Type M by the ICRP (1995a) but when bound in a Type S plutonium matrix, Type S is also assumed for the Am-241 and ICRP Publication 71 (ICRP 1995b) Type S is selected in IMBA.

5.2.4 Radiation Type

IREP requires a Radiation Type to be associated with each entered equivalent dose. The radiation effectiveness factor (REF) is analogous to the relative biological effectiveness used 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 POC calculation. The REF selected depends on the type of radiation, of which there are six:

- Alpha
- Electrons <15 keV
- Electrons >15 keV
- Photons <30 keV
- Photons 30-250 keV
- Photons >250 keV

Photons >250 keV and electrons >15 keV are the *reference radiations* and have a point value REF of unity. The REFs for the other radiation types are expressed as a distribution. A summary of 2.5, 50, and 97.5 percentiles for the REF distributions is shown in Table 5-1. Note that only tritium is included in the electron <15 keV category.

Many radionuclides emit multiple types of radiation. IMBA has an option to split the dose assessment into its components for a number of radionuclides, although not all. However, this adds significant time to the analysis and yields at least two times the number of entries 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 radiation emitted[†] that, on inspection, would appear to give

[†] The program Radiation Decay (available at http://www.btinternet.com/~ablumsohn/chemis.htm) was used. For radionuclides not listed in Radiation Decay, output from the National Nuclear Data Center (http://www.nndc.bnl.gov/mird/) was used.

Table 5-1. The 95% confidence intervals and medians for IREP REF classes.

Radiation class	2.5 percentile	50 percentile	97.5 percentile
Alpha Solid tumors	3.4	18.0	101.0
Alpha Leukemia	1.0	4.1	42.0
Photon >250 keV	-	1.0	-
Photon 30-250 keV	1.0	1.9	4.7
Photon <30 keV	1.1	2.4	6.1
Electron >15 keV	-	1.0	-
Electron <15 keV	1.2	2.4	5.0

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 daughters that do are assigned to the alpha category because it is the choice that is favorable to claimants. The single exception is ^{147}Pm, which is assigned to the "electrons E>15keV" radiation category, because of the extremely long half-life of the daughter, ^{147}Sm.

5.2.5 Integrated Modules for Bioassay Analysis (IMBA)-Specific Parameters

5.2.5.1 Data Type

- Real: This data type indicates a valid result, to be used in the 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 5.3). The sample MDA is entered for the *Measurement Rate* or *Measurement Value.* IMBA uses a maximum likelihood method for estimating intakes; if the underlying error distribution of the measurements is known (or reasonably well-estimated), the probability that the true value is between zero and the limit of detection can be calculated as the area under the probability distribution curve.
- Excluded: IMBA will ignore all results with this Data Type indicated when calculating the intake. Excluded results are displayed in red on the graph.

5.2.5.2 Measurement Error

The inverse square of the *Measurement Error* is the weighting factor applied to the *Measurement Rate* for the intake fit. For positive results, use the one sigma error associated with the result, when available.

If there are no errors reported with the results, *Measurement Error* should be calculated using the *Uniform Relative* option, with k = 0.3 as a starting point. Note that in this instance the value of k is

somewhat arbitrary; the same intake will result from any percentage, given the same percentage for all results. This might not be a reasonable estimate if there are some reasonably well-defined peaks or results vary by more than 1 order of magnitude. Larger values will have more precise statistics and might need to be assigned relatively smaller errors to obtain a better fit. Alternative values for the error should 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 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). If you cannot obtain a reasonable fit, contact the Principal Internal Dosimetrist for assistance.

5.2.5.3 Error Distribution

Individual bioassay results are assumed to be normally distributed.

5.3 FITTING POSITIVE BIOASSAY RESULTS

This section describes the process for fitting results to an intake. Specific details of the mechanics of using IMBA are included in ORAUT (2003b).

Note: For the purpose of this discussion, *positive* means a result greater than the reporting level (this could be the MDA, detection level, or some other value that the site used) and *negative* means less than or equal to this value. This definition was chosen because many sites reported the value of the MDA for results less than the MDA; if it is clear that is not the case, a result equal to the MDA should be treated as positive.

5.3.1 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 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 5.5 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 reported values for all or even most of the reported results because the retention and elimination of radioactive materials, as well as the measurement of the material, are stochastic processes; varying amounts of material will be in the various measured compartments over time. 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, and often not favorable to claimants, assumptions. An example of this is fitting each positive result to a separate intake. This often requires the assumption that each intake occurred only one or two days prior to the bioassay sample; if the samples were collected as part of the routine bioassay program (as opposed to incident follow ups), it is unlikely that the program caught each unsuspected intake immediately upon occurrence.

5.3.2 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.

- In IMBA, for results < MDA, *Measurement Result* = MDA value, *Data Type* = "< LOD." Include the first negative (<MDA) result following each set of positive results. If there are multiple positive results, include no more than two 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. 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.

- 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 one sigma error associated with the result, when available. If there are no errors reported with the results, *Measurement Error* should be calculated using the *Uniform Relative* option, with k = 0.3.

  Note: This might not be a reasonable estimate if there are some reasonably well-defined peaks or results vary by more than an order of magnitude; see the discussion in Section 5.2.5.2.

- Set *Error Distribution* = Normal.

- Use known information about intakes where available (e.g., intake date, material type, particle size distribution). For unknown parameters, begin with default values where possible, e.g., assign intake date at the midpoint between two consecutive samples (this may not be reasonable if the results are more than a year or so apart). 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 5.3.1, it is not necessary, nor desirable, to obtain an exact fit to each result because variation in excretion rate is to be expected.

- If material type is unknown, perform a fit for each possible type. Select the one yielding the largest total **dose** (note that the largest intake does not necessarily correlate to the largest dose) to the applicable organ (for the years of interest). If one type provides an unarguably better fit, use it. This can generally be shown only in cases where:

  - A single intake has many (>10) consecutive positive results,

  - There are contemporary (later than 1989) data associated with intakes 25 yr 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 yielding 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 to do 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 = Real. Otherwise, enter the MDA for the value and mark it <LOD. Note that the issue of measurement error, discussed in Section 5.2.5.2, also applies here.

5.4 ASSIGNMENT OF MISSED AND UNMONITORED DOSE

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.

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: 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 will be excreted over an extended period of time, 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., Cs-137, Po-210). 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 following 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 non-representative of the individual's exposure.

For long-lived/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 following the last bioassay sample through the end of the potential exposure period.

- Long-lived/retained nuclides include: plutonium, uranium, americium.

For short-lived/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 two years between results are considered to be unmonitored. Note: For very short retained materials, notably H-3 and I-131, this period would be less. Guidance on H-3 assessment is contained in OTIB-0011 (ORAUT 2004d). In general, H-3 exposure is assumed only during periods where bioassay samples were collected because it is cheap, easy, and quick. The primary exception to this rule is when a site began using H-3 prior to the implementation of a bioassay program.

- Unmonitored dose is assigned for the period up until one year prior to the first bioassay sample for the nuclide of interest.

- Missed dose is calculated from one year prior to the first bioassay result through the date of the last bioassay sample.

- If there are more than two 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 one year prior to the second sample.

    - Missed dose is calculated starting at one year prior to the date of the second result.

- Short-lived/retained nuclides include: Cs-137, polonium, Ru-106, Ce-144, Sr-90.

The presence of bioassay samples are often an indicator of potential for exposure, but baseline and/or termination samples alone (i.e., no bioassay other than a single baseline and/or a single termination measurement) do not necessarily indicate a potential. Indicators of potential for internal radiation exposure include the following:

- Job title

- Work location

- External dose

- By itself, lack of sampling for extended periods is an insufficient reason for assuming a change in exposure potential. If the three items listed above do not change during an individual's employment history but there is information, such as bioassay data or job title, that indicates a

potential for intake at some point, a potential for intake must be assumed for the entire employment period.

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.

5.4.1 Missed Dose Determination

Missed dose is assigned using actual bioassay sample parameters (e.g., specific dates and MDAs) and associated dosimetry program information.

The MDA and date associated with the last sample result are used for the calculation. When calculating a missed dose to compare to a fitted dose (for best estimate), the MDA and date associated with 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/ transuranics or Type S uranium), perform the fit using the date of the last sample and half of the associated detection threshold, assuming a single chronic intake for the entire potential exposure period.

- 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 the Interactive RadioEpidemiological Program (IREP) using a triangular distribution.

Set the lower bound (parameter 1) to zero.

Set the mode (parameter 2) to the annual organ doses calculated above.

Set the upper bound (parameter 3) to 2 times the mode.

5.4.2 Coworker Data

Coworker exposure distributions are developed from available dosimetric data from DOE or Atomic Weapons Employer sites. ORAUT (2004c) provides a generic discussion on the development of these data sets while 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.

5.4.2.1 Application of Coworker Data

Coworker dose is applied as a best estimate to unmonitored individuals (or workers with unmonitored intervals) with a significant potential for intakes of radioactive material, or as an overestimate for those unlikely to have had intakes. When coworker analyses do not define how or to whom the intake should apply, "significant potential" is subjective but in general applies to people who were radiation workers. The Dose Reconstructor must make this decision based on the worker's job titles and work locations, as well as any other information in the file that could indicate a potential for intake. 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, but this could be a matter of Dose Reconstructor judgment, again based on information in the file.

5.4.2.2 Type S Plutonium

Because of the interdependence between individual bioassay results and because detection sensitivities and radiation controls have improved over time, it is generally not possible to fit Type S plutonium to the coworker data in a manner that would be representative of all individuals for all periods. In general, intakes based on the early results greatly overpredict the later values. Therefore, only a minimizing intake has been calculated for Type S plutonium in most of the coworker TIBs. In such cases, to apply coworker data to sites with plutonium:

Use the Type M plutonium intakes for all systemic organs.

For *nonsystemic* organs, do the following:

- Run the Type M intakes. If this results in a POC > 50%, no further assessment is necessary. If this does not result in a POC > 50%,

- Run the minimizing Type S intake. If this still does not yield a POC > 50%,

- Manually fit the coworker bioassay data (these data are listed in a table in the site-specific TIB; electronic versions of the information are available through the Principal Internal Dosimetrist) for the time frame of interest for the employee, using the assumption of Type S material. Use standard fitting techniques to fit the plutonium urinalysis. Acute or chronic intakes can be assigned, depending on the patterns in the data. Both the 50th - and 84th -percentile data must be fit. If a lognormal distribution is assumed, the 50th-percentile intakes are assigned as the intake and the 84th-percentile is used to determine the geometric standard deviation (GSD) for each intake (GSD = 84th/50th percentile intake for each period). No GSD less than 3 may be assigned (i.e., if the calculated GSD<3, enter 3 in IREP).

5.4.3 Example Assignment of Coworker and Unmonitored Doses

Employment: 3/1/1957 to 7/12/1989
Job information: Production worker; no change in work location; no significant fluctuations in external dose results
Bioassay: Plutonium urine sample on 5/4/1960, 12/11/1963, 11/17/1970
Fission product urine samples 3/12/1965, 9/18/1965, 8/1/1966, 1/5/1978, 7/12/1978, 4/30/1979

Plutonium dose assignments:
If **no** coworker data or site default values exist, calculate missed dose from 3/1/1957 through 7/12/1989 using 0.5 MDA on 11/17/1970.

If there are coworker data or site default values:

1. Calculate missed dose from 3/1/1957 through 11/17/1970 using 0.5 MDA on 11/17/1970. (Note that "real" dose could also be assigned in this time frame if there were positive bioassay results).

2. For the period from 11/18/1970 through 7/12/1989:
   Assign coworker dose if it's available.

   If coworker data are not available, but the site profile contains default intake values for individuals who were potentially exposed, assign the TBD values.

Fission product assignment:
Check the TBD (or coworker OTIB) for the nuclide to be assumed when running FP results. In most cases these are Sr-90 or Cs-137, and in general they will be relatively short-lived/retained.

1. Assign coworker data or site default values from 3/1/1957 to 3/12/1964.
2. Calculate missed dose (or real dose, if there are positive bioassay results) from 3/13/1964 to 8/1/1966.
3. Assign coworker data or site default values from 8/2/1966 to 1/5/1977.
4. Calculate missed dose (or real dose, if there are positive bioassay results) from 1/6/1977 to 4/30/1979.
5. Assign coworker data or site default values from 5/1/1979 to 7/12/1989
6. If there are mixtures associated with the fission products, perform the above calculations first and assign the associated radionuclides from the resulting intakes in steps 1 through 5.

5.5 ASSESSMENT METHODS

There are typically a number of approaches that can be applied to any 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 while retaining an accurate *compensation* decision. 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 best estimate is needed.

5.5.1 Overestimate

An overestimate, for an internal dose assessment, is assignment of an intake or dose that exceeds the possible exposure of the worker. If the resulting probability of causation (POC), including all sources of potential exposure, is less than 45% (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 employee-specific information.

5.5.1.1 Generic Overestimates

Several methods have been developed and documented in technical information bulletins. Summaries and general applicability of these are described in Section 5.6; specific details are in the documents.

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).

Date limitations apply to several of the overestimate methods. These time restrictions can be relaxed for individual cases where it can be shown that the appropriate limits or monitoring assumed in the basis of the method were in place at the facility in question.

5.5.1.2 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*) vs. 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.

5.5.2 Underestimate

An underestimate is the assignment of an intake or dose to a worker that is less than the intake or dose that would potentially be assigned under this program. If the resulting POC is greater than 52% (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.

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.

5.5.3 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 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 given these data. 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.

5.5.3.1 Performing a Best Estimate Using Bioassay Data

A best estimate uses all information available. Both missed and fitted dose are included (unless all data can be fit at once, as discussed in 5.3.2), as follows:

1. Ignore positive data (this means that the date of the last result less than the MDA is used for the missed dose calculation) and perform a missed dose (mode only) calculation as described in Section 5.4.1. If multiple material types are possible, select the one yielding the largest total dose to the applicable organ for the years of interest.

2. Fit the positive data in accordance with Section 5.3.

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

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

    - For years in which the dose from 2 is equal to or larger than that from 1, use the lognormal distribution, where Median = Annual dose and GSD = 3.

5.6 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.

5.6.1 OTIB-0001: Maximum Internal Dose Estimates for Savannah River Site (SRS) Claims

This method (see ORAUT 2003a) uses the largest recorded intakes in the history of the SRS to assign an overestimated intake for workers. An average of the largest five intakes for each monitored nuclide was used; although it is conceivable that a given individual had an intake in excess of one of the values, it is very unlikely that a single individual 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.

5.6.2 OTIB-0002: Maximum Internal Dose Estimates for Certain DOE Complex Claims

This method (see ORAUT 2004a) is based on the ICRP Publication 2 control value of maximum permissible body burden (MPBB) (ICRP 1959). It assumes that an intake resulting in 10% MPBB would be noticed and that there would be some sort of indication in the worker's records. The assumed source term includes the more significant radionuclides expected to be found on a variety of sites:

- Reactor sites
- Nonreactor sites
- Uranium sites

A tritium dose must be assigned separately (i.e., it is not included in this method) if there was a significant potential for intake. Because tritium intakes are very easy to monitor, an individual was likely to have been monitored should this be the case.

A single acute intake of all of the radionuclides listed for a particular site type is assumed, and is assigned on the first day of employment. The method allows for nuclides not present on a given site to be excluded from assignment, but this must be used with caution because part of the basis for the overestimate is that no single individual would have had undetected intakes of a large number of radionuclides. Application is limited to specific organs because the intakes were maximized for systemic organs.

5.6.3 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 resulting from site operations or contamination, as opposed to localized airborne radionuclides from uncontained radioactive materials in the workplace. For such employees, assignment of environmental dose only is appropriate. This document (ORAUT 2004b) provides guidance for determining such instances. Guidance is based on:

- Job description
- Work location
- Time frame
- Presence/absence of internal monitoring data

5.6.4 OTIB-0018: Internal Dose Overestimates for Facilities with Air Sampling Programs

This method (see ORAUT 2005a) is similar to that presented in OTIB-0002 (ORAUT 2004a), but is based on limiting air concentrations rather than MPBB. 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 employment. An additional conservatism is achieved by assuming that the airborne activity was comprised of the single nuclide, in each year of intake, resulting in the largest dose to the organ of interest, rather than assigning a mixture of radionuclides.

5.6.5 OTIB-0033: Application of Internal Doses Based on Claimant-Favorable Assumptions for Processing as Best Estimates

This method (see ORAUT 2005b) applies a graded approach to internal dose overestimates, and unites the application of OTIB-0014 (ORAUT 2004b), 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.

5.7 RECYCLED URANIUM

When assigning dose due to contaminants in recycled uranium, the same material type should be applied to the contaminants as that selected for the uranium. If the ICRP (1998) does not assign the nuclide to the chosen uranium material type, the closest solubility should be selected. Table 5-2 contains material types for several elements that could be included as a recycled uranium contaminant.

Table 5-2. Material types for recycled uranium contaminants.

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

REFERENCES

ICRP (International Commission on Radiological Protection), 1959, *Report of Committee II on Permissible Dose for Internal Radiation*, Publication 2, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1979, *Limits for the Intake of Radionuclides by Workers, Part 1*, Publication 30, Part 1, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1990, *Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1*, Publication 56, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1994, *Human Respiratory Tract Model for Radiological Protection*, Publication 66, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1995a, *Dose Coefficients for Intakes of Radionuclides by Workers*, Publication 68, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1995b, *Age-dependent Doses to Members of the Public from Intakes of Radionuclides: Part 4 Inhalation Dose Coefficients*. Publication 71, Pergamon Press, Oxford, England.

ICRP (International Commission on Radiological Protection), 1998, *Individual Monitoring for Internal Exposure of Workers*, Publication 78, Pergamon Press, Oxford, England.

NIOSH (National Institute for Occupational Safety and Health), 2004c, *Estimation of Ingestion Intakes*, OCAS-TIB-009, Rev. 00, Office of Compensation Analysis and Support, Cincinnati, Ohio, April 13.

ORAUT (Oak Ridge Associated Universities Team), 2003a, *Technical Information Bulletin: Maximum Internal Dose for Savannah River Site (SRS) Claims*, ORAUT-OTIB-0001, Rev. 00, Oak Ridge, Tennessee, July 15.

ORAUT (Oak Ridge Associated Universities Team), 2003b, *Use of Integrated Modules for Bioassay Analysis (IMBA),* ORAUT-PROC-0002, Rev. 01, Oak Ridge, Tennessee, August 14.

ORAUT (Oak Ridge Associated Universities Team), 2004a, *Technical Information Bulletin – Maximum Internal Dose Estimates for Certain DOE Complex Claims*, ORAUT-OTIB-0002, Rev. 01 PC-2, Oak Ridge, Tennessee, May 7.

ORAUT (Oak Ridge Associated Universities Team), 2004b, *Technical Information Bulletin – Assignment of Environmental Internal Doses for Employees Not Exposed to Airborne Radionuclides in the Workplace*, ORAUT-OTIB-0014, Rev. 00, Oak Ridge, Tennessee, June 22.

ORAUT (Oak Ridge Associated Universities Team), 2004c, *Coworker Data Exposure Profile Development*, ORAUT-PLAN-0014, Rev. 00, Oak Ridge, Tennessee, November 24.

ORAUT (Oak Ridge Associated Universities Team), 2004d, *Tritium Calculated and Missed Dose Estimates*, ORAUT-OTIB-0011, Rev. 00, Oak Ridge, Tennessee, June 29.

ORAUT (Oak Ridge Associated Universities Team), 2005a, *Internal Dose Overestimates for Facilities With Air Sampling Programs*, ORAUT-OTIB-0018, Rev. 01, Oak Ridge, Tennessee, August 9.

ORAUT (Oak Ridge Associated Universities Team), 2005b, *Application of Internal Doses Based on Claimant-Favorable Assumptions for Processing as Best Estimates*, ORAUT-OTIB-0033, Rev. 00, Oak Ridge, Tennessee, April 20.

ORAUT (Oak Ridge Associated Universities Team), 2005c, *Analysis of Coworker Bioassay Data for Internal Dose Assignment*, ORAUT-OTIB-0019, Rev. 01, Oak Ridge, Tennessee, October 7.

ORAUT (Oak Ridge Associated Universities Team), 2005d, *Guidance on Wound Modeling for Internal Dose Reconstruction*, ORAUT-OTIB-0022, Rev. 02, Oak Ridge, Tennessee, November 18.

ORAUT (Oak Ridge Associated Universities Team), 2006, *External Dosimetry Organ, Internal Dosimetry Organ, and IREP Model Selection by ICD-9 Code*, ORAUT-OTIB-0005, Rev. 02 PC-1, Oak Ridge, Tennessee, February 10.

NBS (National Bureau of Standards), 1953, *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*, Handbook 52, U.S. Department of Commerce, Washington, D.C., March 20. [SRDB Ref ID: 12332]

ATTACHMENT A

Radionuclide	Radiation type*
Ac-227	Alpha
Ac-228	Alpha
Ag-110m	Photons E>250 keV
Am-241	Alpha
Am-243	Alpha
As-74	Photons E>250 keV
Ba-133	Photons E>250 keV
Ba-140	Photons E>250 keV
Bk-249	Alpha
C-14	Electrons E>15 keV
Ca-45	Electrons E>15 keV
Ce-139	Photons E=30-250 keV
Ce-141	Electrons E>15 keV
Ce-143	Electrons E>15 keV
Ce-144	Electrons E>15 keV
Cf-249	Alpha
Cf-252	Alpha
Cl-36	Electrons E>15 keV
Cm-242	Alpha
Cm-243	Alpha
Cm-244	Alpha
Co-57	Photons E=30-250 keV
Co-58	Photons E>250 keV
Co-60	Photons E>250keV
Cr-51	Photons E>250 keV
Cs-134	Electrons E>15 keV
Cs-137	Electrons E>15 keV
Eu-152	Photons E>250 keV
Eu-154	Electrons E>15 keV
Eu-155	Electrons E>15 keV
Eu-156	Electrons E>15 keV
Fe-55	Photons E<30 keV
Fe-59	Electrons E>15 keV
H-3	Electrons E<15 keV
Hf-181	Electrons E>15 keV
I-125	Photons E<30 keV
I-129	Photons E=30-250 keV
I-131	Electrons E>15 keV

Radionuclide	Radiation type*
I-133	Electrons E>15 keV
I-134	Photons E>250 keV
I-135	Photons E>250 keV
Ir-192	Photons E>250 keV
La-140	Photons E>250 keV
Lu-174	Photons E=30-250 keV
Mn-54	Photons E>250 keV
Mo-99	Electrons E>15 keV
Na-22	Photons E>250 keV
Na-24	Photons E>250 keV
Nb-94	Photons E>250 keV
Nb-95	Electrons E>15 keV
Ni-63	Electrons E>15 keV
Np-237	Alpha
Np-239	Alpha
P-32	Electrons E>15 keV
P-33	Electrons E>15 keV
Pa-231	Alpha
Pa-233	Alpha
Pa-234	Alpha
Pb-210	Alpha
Pm-147	Electrons E>15 keV
Po-208	Alpha
Po-209	Alpha
Po-210	Alpha
Pr-143	Photons E>250 keV
Pr-147	Electrons E>15 keV
Pu-236	Alpha
Pu-238	Alpha
Pu-239	Alpha
Pu-240	Alpha
Pu-241	Alpha
Pu-242	Alpha
Ra-220	Alpha
Ra-223	Alpha
Ra-224	Alpha
Ra-226	Alpha
Ra-228	Alpha

Radionuclide	Radiation type*
Rn-220	Alpha
Rn-222	Radon
Ru-103	Electrons E>15 keV
Ru-106	Electrons E>15 keV
S-35	Electrons E>15 keV
Sb-124	Photons E>250 keV
Sb-125	Photons E>250 keV
Sm-151	Electrons E>15 keV
Sn-113	Electrons E>15 keV
Sr-85	Photons E>250 keV
Sr-89	Electrons E>15 keV
Sr-90	Electrons E>15 keV
Sr-91	Electrons E>15 keV
Ta-182	Photons E>250 keV
Tb-160	Electrons E>15 keV
Sm-151	Electrons E>15 keV
Tc-99	Electrons E>15 keV
Te-131	Photons E>250 keV
Te-131M	Electrons E>15 keV
Th-228	Alpha
Th-230	Alpha
Th-232	Alpha
Th-234	Alpha
Tl-202	Photons E>250 keV
Tl-204	Electrons E>15 keV
Tm-170	Electrons E>15 keV
U-232	Alpha
U-234	Alpha
U-235	Alpha
U-236	Alpha
U-238	Alpha
U-239	Alpha
Y-88	Photons E>250 keV
Y-90	Electrons E>15 keV
Y-91	Electrons E>15 keV
Yb-169	Photons E>250 keV
Zn-65	Photons E>250 keV

* The radiation effectiveness factors (REF) for electrons > 15 keV and photons > 250 keV 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.