Internal Dose Assessments

Nuclear Secured / Radiation Safety

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History and Approvals

History

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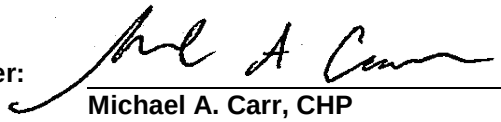
0	Y	For Issue (Rebranded CS-RS-PR-018)

Approvals

Preparer: 

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1. Purpose and Scope

1.1. Purpose

The purpose of this procedure is to provide specific guidance for the dose assessment for the intake of radionuclides based on in-vivo and in-vitro bioassay monitoring. Any calculated doses greater than 10 mrem **should** be included with the workers exposure record; however, all calculated doses greater than 100 mrem TEDE or 100 mrem to any individual organ or tissue **shall** be reported as part of the individual annual exposure record in accordance with 10CFR19 *Notices – Instructions and Reports to Workers; Inspection and Investigation*.

This procedure follows the regulatory requirements and guidance as contained in 10CFR20 and the US NRC guidance documents and is intended only as guidance. The actual calculation approach of a particular internal dose assessment will be specific to the exposure conditions and personnel monitoring methods. ANSI HPS N13.39, summarizes this approach by noting:

> *"It is not essential that pre-selected models be used for all cases; rather, a scientific approach is preferred for modeling the intake, retention, translocation, clearance, and excretion of radionuclides based on careful analysis of the data and characteristics of the internally deposited radionuclides."*

The approach for assessing internal exposure involves two steps. First, the estimated quantity of intake must be determined in µCi or Bq from available data, either through bioassay monitoring or DAC-hour tracking. This is typically determined using one of the following depending on the radionuclides of concern, detection sensitivities, chemical form and class of radionuclide:

- Direct measurement of radionuclides in the body (in-vivo),
- Measurement of radionuclides in excreta (in-vitro), or
- Measurement of radionuclide concentrations in air combined with personnel residence times (i.e., DAC-Hour tracking).

Once the intake amount is determined, the persons exposure is estimated as dose equivalent to the whole body (i.e., Committed Effective Dose Equivalent or CEDE) and/or a dose to a specific organ or tissue (i.e., Committed Dose Equivalent) through the use of available conversion factors such as those provided in Federal Guidance Report 11 for bioassay monitoring or through the use of the Annual Limit on Intake (ALI).

1.2. Scope

This procedure applies to all project personnel and subcontractors at field project sites where Nuclear Secured (NS) is responsible for personnel monitoring under the NS Radiation Protection Program (RPP).

2. References

2.1. 10CFR19 *Notices – Instructions and Reports to Workers; Inspection and Investigation*

2.2. 10CFR20 *Energy – Standards for Protection Against Radiation*

2.3. US NRC, Regulatory Guide 8.7, *Instructions for Recording and Reporting Occupational Radiation Dose Data,* 2005

2.4. US NRC, Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program,* Revision 1, 1993

2.5. US NRC, Regulatory Guide 8.34, *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses,* July 1992

2.6. ANSI HPS N13.39, *Design of Internal Dosimetry Programs*, January 2011

2.7. ANSI HPS N13.42, *Internal Dosimetry for Mixed Fission and Activation Products,* 1997

2.8. NUREG/CR-4884, *Interpretation of Bioassay Measurements*, July 1987

2.9. ICRP 23, *Report of the Task Group on Reference Man*

2.10. ICRP 30, *Limits for Intakes of Radionuclides by Workers*

2.11. ICRP 54, *Individual Monitoring for Intake of Radionuclides by Workers: Design and Interpretation*

2.12. ICRP 68, *Dose Coefficients for Intakes of Radionuclides by Workers*

2.13. ICRP 119, *Compendium of Dose Coefficients based on ICRP Publication 60*, 2012

2.14. EPA 520/1-88-020 (Federal Guidance Report No. 11), *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*, 1988

2.15. Health Physics, November 2002, Volume 83, Number 5, *Intake Retention Fractions Developed from Models Used in the Determination of Dose Coefficients Developed for ICRP Publication 68 – Particulate Inhalation*, Charles A. Potter

2.16. AE-SH-PR-002, *Incident Reporting and Notification*

2.17. NS-RS-PG-001, *Radiation Protection Program*

2.18. NS-RS-PR-102, *Project Records Management*

2.19. NS-RS-PR-500, *Personnel Monitoring*

2.20. NS-RS-PR-502, *Bioassay Sampling*

2.21. NS-RS-PR-505, *DAC-Hr Tracking*

3. General

3.1. Definitions

3.1.1. *Annual Limit on Intake (ALI)* – The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 rem (0.05 Sv) or a committed dose equivalent of 50 rem (0.5 Sv) to any individual organ or tissue. ALI values for intake by ingestion and by inhalation of selected radionuclides are given in Table 1, Columns 1 and 2, of Appendix B to 10CFR20.

3.1.2. *Bioassay (radiobioassay)* – The determination of kinds, quantities or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurement (in-vivo counting) or by analysis and evaluation of materials excreted or removed from the human body (in-vitro counting).

3.1.3. *Class (or lung class or inhalation class)* – A classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lung. Materials are classified as D, W, or Y, which applies to a range of clearance half-times: for Class D (Days) of less than 10 days, for Class W (Weeks) from 10 to 100 days, and for Class Y (Years) of greater than 100 days.

3.1.4. *Committed Dose Equivalent ($H_{T,50}$, or CDE)* – The dose equivalent to organs or tissues or reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

3.1.5. *Committed Effective Dose Equivalent ($H_{E,50}$, or CEDE)* – The sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues ($H_{E,50} = \Sigma W_T H_{T,50}$).

3.1.6. *Derived Air Concentration (DAC)* – The concentration of a given radionuclide in air which, if breathed by the reference man for a working year of 2,000 hours under conditions of light work (inhalation rate of 1.2 cubic meters of air per hour), results in an intake of one ALI. DAC values are given in Table 1, Column 3, of Appendix B to 10CFR20.

3.1.7. *Derived Air Concentration-hour (DAC-hour)* – The product of the concentration of radioactive material in air (expressed as a fraction or multiple of the derived air concentration for each radionuclide) and the time of exposure to that radionuclide, in hours. A licensee may take 2,000 DAC-Hrs to represent one ALI, equivalent to a committed effective dose equivalent (CDED) of 5 rem (0.05 Sv) or a committed dose

equivalent (CDE) of 50 rem (0.50 Sv) depending on the basis for the ALI.

3.1.8. *Dose Equivalent (H_T)* – The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and Sievert (Sv).

3.1.9. *Effective Dose Equivalent (H_E)* – The sum of the products of the dose equivalent to the organ or tissue (H_T) and the weighting factors (W_T) applicable to each of the body organs or tissues that are irradiated ($H_E = \Sigma W_T * H_T$).

3.1.10. *Exposure* – Being exposed to ionizing radiation or to radioactive material.

3.1.11. *Individual Monitoring* – (1) The assessment of dose equivalent by the use of devices designed to be worn by an individual; (2) The assessment of committed effective dose equivalent by bioassay (see Bioassay) or by determination of the time-weighted air concentrations to which an individual has been exposure, i.e., DAC-hours; or (3) The assessment of dose equivalent by the use of survey data.

3.1.12. *Intake Retention Fraction (IRF)* – The fraction of the original intake remaining in or retained by the body at time t following the time of intake.

3.1.13. *Internal Dose* – that portion of the dose equivalent received from radioactive material taken into the body.

3.1.14. *Nonstochastic Effect* – Health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also called a deterministic effect).

3.1.15. *Stochastic Effects* – Health effects that occur randomly and for which the probability of the effect occurring, rather than the severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

3.1.16. *Total Effective Dose Equivalent (TEDE)* – The sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

3.2. Responsibilities

Depending on personnel qualifications and the size of the project, project personnel may be assigned multiple roles and/or responsibilities.

3.2.1. NS Radiation Safety Officer

The NS Radiation Safety Officer (RSO) maintains and oversees the implementation of the NS RPP. The RSO shall ensure that radiation safety, radioactive materials management, and radiological operations procedures and programs are kept up to date such that they comply with current regulations and incorporate current and relevant industry practices and regulatory guidance. The RSO is also responsible for the review of all personnel exposure records and to ensure exposures are maintained below regulatory and NS administrative limits as applicable.

3.2.2. Project Manager

The Project Manager (PM) is responsible for ensuring that the proper program procedures and programs are implemented on the project site as required by customer agreements and contracts. The PM is responsible for ensuring that these programs and procedures are properly incorporated into project specific plans and procedures. The PM is responsible for ensuring that the NS RPP and client programs and procedures, as applicable, are available for use by project personnel.

3.2.3. Project Health Physicist

The Project Health Physicist (PHP) is responsible for assisting the RSO in providing health physics support to the PM and Radiation Protection Supervisor (RPS). This includes technical support, such as the review of bioassay results and the performance of internal dose assessments, to ensure procedural and regulatory compliance and to ensure that the project-specific Data Quality Objectives (DQOs) are met.

3.2.4. Radiation Protection Supervisor

The Radiation Protection Supervisor (RPS) is responsible for implementing the NS RPP at the project location and oversees project personnel in regards to radiation and respiratory protection and reports directly to both the PM and the RSO. The RPS shall support the PHP and the RSO in all internal dose assessments as necessary and to provide the necessary supporting documentation.

3.2.5. Project Personnel

All project personnel are responsible for providing bioassay samples as requested by the RPS and following the sampling protocols as specified. Project personnel are also responsible for notifying the RPS of any recently administered or scheduled medical procedures involving the administration of medical radioisotopes.

3.3. Precautions and Limitations

3.3.1. DAC-Hr tracking may be used to track internal dose, however, the preferred method is to have a bioassay monitoring program in accordance with NS-RS-PR-500, *Personnel Monitoring* and NS-RS-PR-502, *Bioassay Sampling*.

3.3.2. Medically administered radioisotopes are not considered occupational dose and do not require a dose assessment.

3.3.3. The internal dose assessment is only as good as the data provided as the basis for internal exposure. The better the understanding of the exposure event, the better the estimate.

3.3.4. Use logarithmic interpolation to determine the intake retention fractions (IRFs) for elapsed times not found on standard IRF tables.

3.3.5. The continuous intake model, Section 5.5, assumes a relatively uniform intake over time. For non-uniform intakes (e.g. based on air sample data), it is usually best to model as multiple acute intakes, Section 5.4.

3.3.6. An internal dose calculation should be performed or reviewed by a CHP for all positive bioassay results. Any significant dose (i.e., 10 mrem or more) should be added to the individual's dose record; however all doses in excess of 100 mrem shall be recorded.

3.3.7. If a project is being conducted for the Department of Energy, the applicable regulations should be consulted. The DOE has adopted, in 10CFR835, newer exposure models for the derived secondary standards, annual limits on intake and derived air concentrations. The newer models impact primarily the thorium radionuclides raising the ALI and the DAC by a factor of 7 to 30.

3.3.8. For the intake of inferred radionuclides, use the calculated intake of the measured radionuclide.

3.3.9. Dose models and conversion factors have been updated and revised over time. Check with the applicable regulatory agency as necessary to determine which dose models and conversion factors have been adopted and recognized.

4. Pre-Requisites / Requirements

4.1. Dose Records are to be handled and controlled as personally identifiable information (PII) documents in accordance with NS-RS-PR-102, *Project Records Management*.

4.2. Document the exposure investigation on an exposure investigation form, Attachment 7.1 or equivalent.

4.3. Document any assigned exposure in an internal dose assessment report, see Section 5.10 including exposure estimate methods, analyses and any supporting documentation including any dose assessment worksheets (e.g., Attachments 7.2 through 7.4).

5. Procedure

5.1. Assessment Determination

5.1.1. Determine whether an Internal Dose Investigation and Assessment is warranted. Situations which may warrant an investigation and internal dose assessment include but are not limited to the following:

- Facial contamination or positive nasal swabs
- Positive bioassay results from an unplanned event
- Bioassay results higher than anticipated
- Intake greater than 0.02 ALI (100 mrem CEDE) expected
- Airborne concentrations exceeding the protection factor of respiratory protection utilized

5.1.2. Notify the RPS, PM and RSO and initiate an incident report in accordance with AE-SH-PR-002, *Incident Reporting and Notification* for any unplanned event or higher exposure than planned. If there are any questions as to whether an incident report is required, contact the PHP, PM and/or RSO for guidance.

5.1.3. If there are any questions as to whether an internal dose assessment is required, contact the PHP and RSO for guidance.

5.2. Internal Exposure Investigation

5.2.1. Make an initial assessment whether a potential over-exposure may have occurred and notify the RSO in order to make the proper regulatory notifications in accordance with NS-RS-PR-500, *Personnel Monitoring*.

5.2.2. Preliminary estimates of intake may be determined using DAC-Hr tracking provided information is available in accordance with NS-RS-PR-505, *DAC-Hr Tracking*.

5.2.3. Restrict the person's work activities as necessary until the internal exposure investigation and dose assessment are complete.

5.2.4. If required, document the reason for performing an internal dose assessment as part of the exposure investigation.

5.2.5. Interview the affected individual(s) and attempt to determine where the intake occurred, what work was being performed and if any other individuals were involved.

- Specific work activities and dates performed,
- Radioactive materials that were handled,
- Radiological controls implemented,

- Other work being performed in the general area,
- Estimated duration of potential exposure(s).

5.2.6. Interview Health Physics personnel, who provided work coverage (if applicable), and determine if work methods may have been the cause of the intake.

5.2.7. If other individuals were involved in the same work activities, they should have a bioassay performed.

5.2.8. Determine the most likely exposure scenario for the intake model based on the exposure event(s) as understood. The exposure scenarios include:

- Single Acute Intake,
- Multiple Acute Intakes, or
- Continuous Intake

5.2.9. Determine the data needed to estimate the person's committed dose equivalent.

5.2.10. Accumulate the following information as applicable in order to perform the dose assessment:

- Date and time of the intake for single and multiple acute intakes,
- Monitoring period for continuous intakes,
- Personnel Protection Equipment and controls being implemented,
- Likely exposure pathway(s) (e.g., Inhalation vs. ingestion),
- Radionuclides of concern and their relative fractions,
- Bioassay results,
- Air monitoring data and RWP entry logs (i.e., DAC-Hr tracking),
- Pulmonary clearance class of compounds (as applicable),
- Measurement system error and detection sensitivities.

5.2.11. Perform additional surveys in the affected work area to determine if radiological conditions might have changed.

5.2.12. Review the radiation work permit and survey data to determine if the radiological controls imposed were adequate.

5.2.13. Re-create the exposure scenario as necessary through mock-ups, models and diagrams and/or verbally walking through the event as necessary.

5.2.14. Identify any events that led to the potential exposure event, why it may have happened (root causes), and what can be done to prevent further potential

exposures. Possible contributing factors to be considered include:

- Areas not properly posted,
- Existing radiological controls are not adequate,
- Poor work practices,
- Personnel training,
- Unplanned event.

5.2.15. If the investigation shows that poor radiological work practices, inadequate training, or unidentified working conditions were the cause of exposure, provide recommendations for corrective actions and submit to the PHP and/or RSO for review and approval. This may include either a stop work order to re-assess existing work controls and/or refresher training for personnel.

5.2.16. Submit the exposure investigation for review and approval by the PHP and/or RSO.

5.2.17. Include a copy of the exposure investigation as part of the internal dose assessment report.

5.2.18. Perform the internal dose assessment for the individual in accordance with Sections 5.3 through 5.5 as applicable depending on the exposure scenario.

5.3. Single Acute Intake

5.3.1. Complete the dose assessment worksheet for a single acute intake, Attachment 7.2 or equivalent using the following information.

5.3.2. Record the individual's name and personal information as required.

5.3.3. Record the date and time that the bioassay was obtained.

5.3.4. Record the best estimate of the date and time of the intake. The date and time may be estimated using available information including the RWP access logs, estimates based on the recollection of activities, the individual's work schedule, air sampling data and operational history. If the information is insufficient to determine the time of intake, it is acceptable to assume the intake occurred at the mid-point for the time period since the last bioassay measurement, their hire date or potential first date of exposure from the current bioassay sampling date. It is also acceptable to conservatively assume the intake occurred immediately following the previous bioassay measurement, hire date or potential first date of exposure.

5.3.5. Calculate and record the elapsed time in days between the estimated time of the event or intake and the time that the bioassay was obtained.

5.3.6. Record the radionuclide(s) of concern. Include those radionuclides that were detected through bioassay as well as those that can only be inferred based on the

radionuclide distribution and process knowledge.

5.3.7. Enter the class of the radionuclide(s) of concern based on the chemical form as specified by the PHP and/or RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclide. Depending on the dose models utilized this will either be D/W/Y for days, weeks, years or F/M/S for fast, moderate and slow.

5.3.8. Enter the activity, $A_{i\text{-}Bio}$, from the whole body count bioassay results.

- For urine samples reported in μCi/ml or pCi/ml, multiply the reported result by the actual 24-hr void volume or the "reference man" daily void (1,400 ml per day for men or 1,000 ml per day for women).
- For fecal samples reported in μCi/g or pCi/g, multiply the reported results by the actual 24-hr weight of excretion, or the "reference man" daily excretion weight (135 g per day for men or 100 g per day for women).

5.3.9. Enter the IRF for each radionuclide present corresponding to the type of bioassay measurement (e.g., urine, fecal, whole body count, etc) for the elapsed time between the time of the event and the bioassay as determined in Step 5.3.5.

5.3.10. Determine the original estimated intake for each radionuclide using the following equation by dividing the total activity in the bioassay sample by the appropriate IRF.

$$I_i = \frac{A_{i-Bio}}{IRF_i(t)}$$ [1]

Where:
- I_i = Estimated intake in μCi, or Bq for radionuclide *i*
- $A_{i\text{-}Bio}$ = Total activity for radionuclide *i* in μCi or Bq as reported by the bioassay
- $IRF_i(t)$ = Intake Retention Fraction for the elapsed time between the exposure event and the time of bioassay sampling.[2, 3]

5.3.11. Ensure the total activity $A_{i\text{-}Bio}$ is decay corrected based on the time of bioassay since the actual sample analysis may occur several days or weeks following sampling.

5.3.12. Depending on the source tables for the IRFs, make sure they are decay corrected values. If not and they are based on stable isotopes, the IRFs need to be corrected

[1] US NRC, Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program*, Revision 1, 1993 (Equation 1)
[2] NUREG/CR-4884, *Interpretation of Bioassay Measurements*, July 1987
[3] Health Physics, November 2002, Volume 83, Number 5, Intake Retention Fractions Developed from Models Used in the Determination of Dose Coefficients Developed for ICRP Publication 68 – Particulate Inhalation, Charles A. Potter

by a factor of $e^{-\lambda t}$ to account for radiological decay.

5.3.13. Determine the intake from all other radionuclides as applicable that were not detected in the bioassay measurement by inferring or scaling their activities based on the radionuclide distribution and their ratio to the measured radionuclide at the time of intake.

5.3.14. Perform follow-up bioassays as necessary and refine the intake estimate in accordance with Section 5.7.

5.4. Multiple Acute Intakes

5.4.1. Complete the dose assessment worksheet for a multiple acute intakes, Attachment 7.3 or equivalent using the following information.

5.4.2. Record the individual's name and personal information as required.

5.4.3. Record the date and time that the bioassay was obtained.

5.4.4. Record the best estimate of the dates and times of each intake. The dates and times may be estimated using available information including RWP access logs, DAC-hour tracking logs, estimates based on the recollection of activities, the individual's work schedule, air sampling data or operational history.

5.4.5. Calculate and record the elapsed time in days between the estimated time for each intake event and the time that the bioassay was obtained.

5.4.6. Record the radionuclide(s) of concern. Include those radionuclides that were detected through bioassay as well as those that can only be inferred based on the radionuclide distribution and process knowledge.

5.4.7. Enter the class of the radionuclide(s) of concern based on the chemical form as specified by the PHP and/or RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclide. Depending on the dose models utilized this will either be D/W/Y for days, weeks, years or F/M/S for fast, moderate and slow.

5.4.8. Enter the activity, $A_{i\text{-}Bio}$, from the whole body count or bioassay sample results.

- For urine samples reported in μCi/ml or pCi/ml, multiply the reported result by the actual 24-hr void volume or the "reference man" daily void (1,400 ml per day for men or 1,000 ml per day for women).
- For fecal samples reported in μCi/g or pCi/g, multiply the reported results by the actual 24-hr weight of excretion, or the "reference man" daily excretion weight (135 g per day for men or 100 g per day for women).

5.4.9. Determine the fractional distribution of intake for each acute exposure using DAC-Hr

tracking (or other assumptions based on events). The sum of the fractions will add up to 1.

5.4.10. The activity that appears in the bioassay from multiple acute intakes is assumed to follow the following equation.

$$A_{i-Bio} = I_i * \sum [f_i(t) * IRF_i(t)]$$

Where:
- $A_{i\text{-}Bio}$ = Total activity for radionuclide *i* in μCi or Bq as reported by the bioassay
- I_i = Total intake in μCi or Bq of radionuclide i
- $f_i(t)$ = Fraction of intake for radionuclide *i* for each event at time *t* prior to bioassay
- $IRF_i(t)$ = Intake Retention Fraction for the elapsed time between the exposure event and the time of bioassay sampling

5.4.11. Determine the total intake by re-arranging the prior equation as follows.

$$I_i = \frac{A_{i-Bio}}{\sum [f_i(t) * IRF_i(t)]}$$

5.4.12. Ensure the total activity $A_{i\text{-}Bio}$ is decay corrected based on the time of bioassay since the actual sample analysis may occur several days or weeks following sampling.

5.4.13. Depending on the source tables for the IRFs, make sure they are decay corrected values. If not and they are based on stable isotopes, the IRFs need to be corrected by a factor of $e^{-\lambda t}$ to account for radiological decay.

5.4.14. Determine the intake from all other radionuclides as applicable that were not detected in the bioassay measurement by inferring or scaling their activities based on the radionuclide distribution and their ratio to the measured radionuclide at the time of intake.

5.4.15. Perform follow-up bioassays as necessary and refine the intake estimate in accordance with Section 5.7.

5.5. Continuous (Uniform) Intake

5.5.1. Complete the dose assessment worksheet for continuous intake, Attachment 7.4 or equivalent using the following information.

5.5.2. Record the individual's name and personal information as required.

5.5.3. Record the date and time that the bioassay was obtained.

5.5.4. Record the period of exposure (i.e., duration of intake) in days based on the time of the prior bioassay sample, RWP access logs, DAC-Hr tracking, estimates based on the recollection of activities, the individual's work schedule, air sampling data or operational history.

5.5.5. Establish the number of integration intervals between the last day of exposure and the date the bioassay was obtained.

5.5.6. Calculate and record the elapsed time in days between the first day of exposure (i.e., onset of intake) and each integration interval date.

5.5.7. Enter the class of the radionuclide(s) of concern based on the chemical form as specified by the PHP and/or RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclide. Depending on the dose models utilized this will either be D/W/Y for days, weeks, years or F/M/S for fast, moderate and slow.

5.5.8. Enter the inhalation class of the radionuclide(s) of concern based on the chemical form as specified by the PHP and/or RSO. If the chemical form or inhalation class is not known, use the most restrictive class for the radionuclide.

5.5.9. Enter the activity, $A_{i\text{-}Bio}$, from the whole body count or bioassay results.

- For urine samples reported in μCi/ml or pCi/ml, multiply the reported result by the actual 24-hr void volume or the "reference man" daily void (1,400 ml per day for men or 1,000 ml per day for women).
- For fecal samples reported in μCi/g or pCi/g, multiply the reported results by the actual 24-hr weight of excretion, or the "reference man" daily excretion weight (135 g per day for men or 100 g per day for women).

5.5.10. Determine the total intake assuming the intakes are distributed equally in size and time and may be approximated using a relationship based on time integration of the IRF using the following equation.

$$I_i = \frac{A_{i-Bio} * n}{\left(\frac{IRF_i\,(t-T) + IRF_i(t)}{2}\right) + \sum IRF_i(t-n)}$$ [4]

Where: I_i = Total intake in μCi or Bq during the period of exposure for radionuclide i

$A_{i\text{-}Bio}$ = Total activity for radionuclide *i* in μCi or Bq as

[4] US NRC, Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program*, Revision 1, 1993 (Equation 9) – Sample calculation provided as Example 7 of the reference.

reported by the bioassay

T = Period of exposure or duration of intake in days

t = Time from onset of intake to the time of bioassay in days

IRF_i = Intake Retention Fraction corresponding to the type of measurement at the specified time after the onset of exposure

n = Number of increments

5.5.11. After calculating the intake for each radionuclide as measured in the bioassay, estimate the intake of any other radionuclides by inferring the calculated intake from the fractional distribution of radionuclides in the workplace air samples or as determined by process knowledge.

5.6. Prior Event Contribution

5.6.1. For instances were a prior exposure may impact the bioassay results, the contribution of the prior exposure event should be determined.

5.6.2. From prior Bioassay result, use the single acute intake exposure model and determine any potential contribution to the current bioassay results (i.e., residual activity already accounted during a prior dose assessment).

5.6.3. Subtract the prior exposure contribution from the current bioassay result.

5.6.4. Follow the applicable exposure model for the current monitoring period as applicable to perform the dose assessment.

5.7. Refining the Intake

5.7.1. Follow-up bioassay monitoring may be required as directed by the PHP and/or RSO to track the elimination of the radionuclides from the body and to provide modified or revised dose assessments as necessary.

5.7.2. Establish follow-up bioassay monitoring and sample frequencies as directed by the PHP and/or RSO depending on the radionuclide class and/or expected biological half-life. Table 5-1 may be used as guidance based on the suspected biological half-life (e.g., elimination rate) of the radionuclide(s) of concern.

5.7.3. The frequency of follow-up bioassay measurements will be determined by the PHP and/or RSO and should be performed if the initial estimates for intake exceed 0.1 ALI.

5.7.4. Re-perform the dose assessment using any follow-up bioassay data to verify initial assumptions and to verify any Intake Retention Fractions.

5.7.5. Refine the models, methods, and information as available following the guidance of a CHP.

Table 5-1
Follow-up Bioassay Monitoring Frequencies

T_{eff} [a]	Frequency
1 – 7 days	daily to weekly
1 – 2 weeks	weekly to bi-weekly
>2 weeks	bi-weekly to monthly

a Effective or biological ½ life in days

5.7.6. If several bioassay measurements have been performed over a period of time, an estimate of the intake may be obtained using the following; otherwise, the intake may be calculated based on each bioassay and an average intake determined.

$$I = \frac{\sum[IRF_i(t) * A(t)_{i-Bio}]}{\sum IRF_i(t)^2}$$ [5]

5.7.7. Revise the personnel's Intake and document the new dose assessment.

5.7.8. Submit the revised assessment to the RSO for review and approval.

5.8. Committed Effective Dose Equivalent

5.8.1. Determine the appropriate DCF depending on the dose model used and the type of intake (ingestion vs inhalation) and the chemical form of the radionuclide or class. Dose conversion factors can be located in several reference documents depending on the dose models used such as ICRP 119, *Compendium of Dose Coefficients based on ICRP Publication 60*, 2012 and EPA 520/1-88-020 (Federal Guidance Report No. 11), *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*, 1988.

5.8.2. Multiply the radionuclide intake by the appropriate DCF.

$$CEDE_i = I_i * DCF_i * 3.7E6$$

Where: I_i = Estimated total intake of radionuclide i in µCi
$DCFi$ = Dose conversion factor for radionuclide i

[5] US NRC, Regulatory Guide 8.9, *Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program*, Revision 1, 1993 (Equation 5)

3.7E6 = Conversion factor for Sv/Bq to rem/µCi. Conversion factors may vary depending on reporting units

5.8.3. Calculate and record the total *CEDE* from all applicable radionuclides of concern as follows:

$$CEDE = \sum CEDE_i$$

5.9. Committed Dose Equivalent

5.9.1. Organ or tissue specific Committed Dose Equivalent(s) (CDEs) shall be calculated for each radionuclide when the radionuclide is limited by a non-stochastic ALI to a specific organ as applicable.

5.9.2. Determine the appropriate DCF for organ T depending on the dose model used and the type of intake (ingestion vs inhalation) and the chemical form of the radionuclide or class. Dose conversion factors can be located in several reference documents depending on the dose models used such as ICRP 119, *Compendium of Dose Coefficients based on ICRP Publication 60*, 2012 and EPA 520/1-88-020 (Federal Guidance Report No. 11), *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*, 1988.

5.9.3. Multiply the radionuclide intake by the appropriate organ DCF.

$$CDE_{T,i} = I_i * DCF_{T,i} * 3.7E6$$

Where: I_i = Estimated total intake of radionuclide *i* in µCi
$DCF_{T,i}$ = Dose conversion factor for radionuclide *i* and organ *T*
3.7E6 = Conversion factor for Sv/Bq to rem/µCi. Conversion factors may vary depending on reporting units

5.9.4. Calculate and record the total *CEDE* from all applicable radionuclides of concern as follows:

$$CDE = \sum CDE_i$$

5.10. Exposure Record and Approval

5.10.1. The PHP and/or RSO shall prepare an Internal Dose Assessment report

summarizing the dose assessment results including the basis and methods used for the assessment.

5.10.2. Attach copies of all supporting information including the Internal Dose Investigation form, whole body count and bioassay results, RWP entry logs, air sample results, DAC-Hr tracking and dose assessment worksheet and any other pertinent information as applicable.

5.10.3. Submit the completed Dose Assessment to the RSO for review and approval. If the RSO prepared the report, an independent review shall be made by someone other than the RSO, preferably a CHP.

5.10.4. Once the assessment has been approved, the assessment shall be placed in the personnel dose record with all supporting documentation including all information needed to complete the NRC Form 5 or equivalent.

6. Records

6.1. Internal Exposure Investigation

6.2. Dose Assessment Worksheets

6.3. External Dose Assessment Report

7. Appendices and Forms

7.1. Internal Exposure Investigation

7.2. Dose Assessment Worksheet – Single Acute Intake

7.3. Dose Assessment Worksheet - Multiple Acute Intakes

7.4. Dose Assessment Worksheet - Continuous Intake

Attachment 7.1 **Internal Exposure**

Last Name:	**First Name:**
SSN:	**RWP:**
Reason for Investigation:	
Date and Time of Event:	**Estimated CEDE:**
Summary of Events:	
Interview / Investigation Results:	
Root Causes:	
Basis and Method of Dose Assessment:	
Recommendations / Restrictions:	
Review and Approval	
Performed by:	**Signature/Date:**
Reviewed by:	**Signature/Date:**

Attachment 7.2 Dose Assessment Worksheet – Single Acute Intake

Name:	SSN:
Intake Pathway [a]:	Bioassay Type:
Intake Date and Time:	Bioassay Date and Time:
Elapsed Time t (Days) [b]:	Estimated DAC-Hrs:

a Intake Pathway is typically Inhalation.
b Elapsed time is the time between the event and the time of bioassay collection.

Nuclide	Nuclide Class	Activity [a] $A_{i\text{-}Bio}$ (uCi)	Retention Fraction [b] IRF_i (t)	Intake [c] I_i (uCi)	Dose Conv. Factor [d]		Dose [e]	
					WB DCF_i (Sv / Bq)	Organ DCF_i (Sv / Bq)	WB $CEDE_i$ (rem)	Organ CDE_i (rem)
TOTAL								

a Total activity based on the bioassay sampling results.
b Intake Retention Fraction at time t in days from the exposure event to the time of bioassay.
c Total intake of the initial exposure or event. Determined by dividing the bioassay activity $A_{i\text{-}Bio}$ by $IRF_i(t)$ to get I_i.
d Dose conversion factor in Sv / Bq either for the effective whole body dose or the organ dose.
e Reported Dose in rem; Whole Body (WB) or Organ as determined by multiplying $A_{i\text{-}Bio}$ by DCF_i and a conversion factor of 3.7E6 rem / μCi per Sv / Bq.

Completed by:	Date:
Reviewed by:	Date:

Attachment 7.3 Dose Assessment Worksheet - Multiple Acute Intakes

Name:		SSN:	
Intake Pathway [a]:	Bioassay Type:	Date and Time:	
Intake / Event	1	2	3
Intake Date and Time:			
Elapsed Time t (Days) [b]:			
Estimated DAC-Hrs:			

a Intake Pathway is typically Inhalation.
b Elapsed time is the time between each specific event and the time of bioassay collection.

Nuclide	Nuclide Class	Event	Retention Fraction [a] IRF_i (t)	Intake Fraction [b] f_i	Retained Fraction [c] f_i*IRF_i (t)	Activity [d] $A_{i\text{-}Bio}$ (uCi)	Intake [e] I_i (uCi)	Dose Conv. Factor [f] WB DCF_i (Sv / Bq)	Dose Conv. Factor [f] Organ DCF_i (Sv / Bq)	Dose [g] WB CEDE (rem)	Dose [g] Organ CDE (rem)
		1									
		2									
		3									
TOTAL				1.0	Σ =						

a Intake Retention Fraction at time t in days for each specific exposure event to the time of bioassay.
b Intake fraction of the total intake attributed to that event. May be estimated by the fraction of the total DAC-Hrs or the number of hours attributed to that event.
c Retained fraction of the entire intake attributed to that event. Determined by multiplying the fraction, f_i, by the $IRF_i(t)$.
d Total activity based on the bioassay sampling results.
e Total cumulative intake. Determined by dividing the bioassay activity $A_{i\text{-}Bio}$ by the sum Σ [f_i times $IRF_i(t)$] to get I_i.
f Dose conversion factor in Sv / Bq either for the effective whole body dose or the organ dose.
g Reported Dose in rem; Whole Body (WB) or Organ as determined by multiplying $A_{i\text{-}Bio}$ by DCF_i and a conversion factor of 3.7E6 rem / μCi per Sv / Bq.

Completed by:	Date:

Reviewed by:	Date:

Attachment 7.4 Dose Assessment Worksheet - Continuous Intake

Name:			SSN:		
Intake Pathway [a]:		Bioassay Type:		Date:	
First Exposure Date:		Last Exposure Date:		Days of Exposure:	
Intake Interval (Day)	**1st**	**2nd**	**3rd**	**4th**	**Last**
Interval Date:					
Elapsed Time t (Days) [b]:					

a Intake Pathway is typically Inhalation.
b Elapsed time is the time between the onset of intake and the reference interval date

Nuclide	Nuclide Class	Interval (Days)	Retention Fraction [a] IRF_i (t)	Retention Fraction [b] IRF_i (t)	Activity [c] $A_{i\text{-}Bio}$ (uCi)	Intake [d] I_i (uCi)	Dose Conv. Factor [e] WB DCF_i (Sv / Bq)	Dose Conv. Factor [e] Organ DCF_i (Sv / Bq)	Dose [f] WB CEDE (rem)	Dose [f] Organ CDE (rem)
		1st								
		Last								
		2nd								
		3rd								
		4th								
TOTAL		n =		Σ =						

a Intake Retention Fraction at time t in days for each exposure interval to the time of bioassay.
b Carry over the Intake Retention Fraction for each interval with the exception of the 1st and last which is carried over as the average of the two.
c Total activity based on the bioassay sampling results.
d Total cumulative intake. Multiply the bioassay activity $A_{i\text{-}Bio}$ by the total number of exposure intervals, n, and divide by the sum Σ [IRF_i (t) + $IRF_{i\text{-}avg}$ (first and last)]

e Dose conversion factor in Sv/Bq either for the effective whole body dose or the organ dose

f Reported Dose in rem; Whole Body (WB) or Organ as determined by multiplying $A_{i\text{-}Bio}$ by DCF_i and a conversion factor of 3.7E6 rem / μCi per Sv / Bq.

Completed by:	Date:
Reviewed by:	Date: