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DRAFT REGULATORY GUIDE

Contact: C. T. Raddatz (301)492-3745

Draft Regulatory Guide DG-8009
(Proposed Revision 1 to Regulatory Guide 8.9)
INTERPRETATION OF BIOASSAY MEASUREMENTS

A. INTRODUCTION

In 10 CFR Part 20, "Standards for Protection Against Radiation," Section 20.1204 requires that each licensee, in accordance with 10 CFR 20.1502, take suitable and timely measurements of quantities of radionuclides in the body, quantities of radionuclides excreted from the body, concentrations of radioactive materials in the air in the work area, or any combination of such measurements as may be necessary for detection and assessment of individual intakes of radioactivity.

This guide is being developed to describe a practical and consistent method acceptable to the NRC staff for estimating intake of radionuclides from bioassay measurements. Programmatic bioassay guidance may be provided by other documents, including ICRP-54 (Ref. 1). By using the method described in NUREG/CR-4884, "Interpretation of Bioassay Measurements" (Ref. 2), and the information provided in this guide, licensees will be able to demonstrate compliance with the intake limits specified in 10 CFR Part 20. Since the guide relies heavily on NUREG/CR-4884, it is recommended that licensees obtain a copy of NUREG/CR-4884 in order to optimize the use of this regulatory guide.

Any information collection activities mentioned in this draft regulatory guide are contained as requirements in 10 CFR Part 20, which would provide the regulatory basis for this guide. Part 20 has been submitted to the Office of Management and Budget for clearance that may be appropriate under the Paperwork Reduction Act. Such clearance, if obtained, would also apply to any information collection activities mentioned in this guide.

This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received complete staff review and does not represent an official NRC staff position.

Public comments are being solicited on the draft guide (including any implementation schedule) and its associated regulatory analysis or value/impact statement. Comments should be accompanied by appropriate supporting data. Written comments may be submitted to the Regulatory Publications Branch, DFIPS, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Copies of comments received may be examined at the NRC Public Document Room, 2120 L Street NW., Washington, DC. Comments will be most helpful if received by March 6, 1992.

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B. DISCUSSION

Dose limits for adults who are occupationally exposed to radioactive materials are specified in 10 CFR 20.1201. Bioassay measurements may be made and interpreted as one mechanism to determine compliance with these limits (see 10 CFR 20.1204). In addition, bioassay measurements may need to be performed to confirm the adequacy of airborne control measures as part of a licensee's respiratory protection program (10 CFR 20.1703(a)(3)(ii)).

Bioassay methods are available to measure or analyze radioactive material in body organs or in the whole body (in vivo) and in excreta (in vitro). In vivo measurements can be made using a whole body counter, thyroid counter, lung counter, or other similar device. In vitro analysis usually involves standard radiochemical techniques and instrumentation, such as gamma spectral analysis or chemical separation followed by alpha counting and beta counting of material excreted or eliminated from the body or material surgically excised from the body.

Detection and quantification of an intake may require monitoring of both the work environment and the worker. Neither bioassay nor air sampling alone is necessarily sufficient; both may be necessary for an accurate assessment of internal radiation exposures.

NUREG/CR-4884, "Interpretation of Bioassay Measurements" (Ref. 2), contains information sections to aid licensees in determining estimates of the intake of a radionuclide on the basis of bioassay measurements. Appendix B to NUREG/CR-4884 contains the primary information that is useful to licensees in converting bioassay measurements to estimates of intakes, including tabulated intake retention fractions (IRFs) for single intakes by ingestion and for single intakes by inhalation of D, W, and Y compounds. IRFs give the fraction of an intake of radioactive material expected to be present in a compartment (e.g., lungs, GI tract, total body, or excreta) at a specific time after intake. IRFs for ^{14}C monoxide, ^{14}C dioxide, and tritiated water are listed separately. D, W, and Y are pulmonary clearance classes that have been established as an indication of the solubility of inhaled compounds; these classes specify the biological half-life of a compound in the pulmonary region of the lung. Class D (days) comprises all compounds with biological half-lives shorter than 10 days; Class W (weeks), all compounds with biological half-

lives between 10 and 100 days; and Class Y (years), all compounds with biological half-lives longer than 100 days.

Sections 1 through 8 and Appendix A of NUREG/CR-4884 contain descriptions of the models used and other information useful in interpreting bioassay results. Appendix A to NUREG/CR-4884 contains examples of using the methods presented. Because NUREG/CR-4884 predates the 1991 revision to Part 20, these examples may not be completely consistent with the current regulatory requirements in 10 CFR 20.1001 - 20.2401. However, the examples can aid in understanding evaluations of intake from bioassay measurements. The examples provided in Appendix A to this regulatory guide both clarify the use of NUREG/CR-4884 and are consistent with the requirements of 10 CFR 20.1001 - 20.2401.

The radionuclide intakes evaluated from bioassay measurements can be compared to the ALIs presented in Appendix B to §§ 20.1001 through 20.2401 to determine the internal dose to the individual (see the introduction to Appendix B).

C. REGULATORY POSITION

Each licensee, in accordance with 10 CFR 20.1502, must take suitable and timely measurements of quantities of radionuclides in the body, quantities of radionuclides excreted from the body, concentrations of airborne radioactive materials in the work area, or any combination of such measurements as may be necessary for detection and assessment of individual intakes of radioactivity. To comply with 10 CFR 20.1502, NUREG/CR-4884 provides a consistent approach acceptable to the NRC staff for estimating intakes. Estimated intakes may be rounded off to two significant figures.

The regulatory positions in this regulatory guide supersede the information contained in NRC IE Information Notice No. 82-18, "Assessment of Intakes of Radioactive Material by Workers."

1. USE OF RETENTION FRACTIONS TO CALCULATE INTAKE

1.1 The intake of radioactive material through inhalation or ingestion may be calculated using the intake retention fractions (IRFs) contained in

Appendix B to NUREG/CR-4884. The intake (I) is determined by dividing the measured activity, in vivo or in vitro (A_i), by the respective IRF based on time (t) after exposure. When a single measurement is to be used to calculate intake, Equation 1 is used.

$$I = \frac{A_i(t)}{IRF(t)} \quad \text{Equation 1}$$

Evaluating the measured activity over multiple time periods provides better estimates of the intake. Examples of the use of IRFs to calculate intake are in Appendix A to this guide.

1.2 Three pulmonary clearance classes have been established as an indication of the solubility of inhaled compounds. These classes, called D, W, and Y, specify the biological half-life of the compound in the pulmonary region of the lung. Class D (days) comprises all compounds with biological half-lives shorter than 10 days; Class W (weeks), all compounds with biological half-lives between 10 and 100 days; and Class Y (years), all compounds with biological half-lives longer than 100 days. The appropriate solubility class for most known compounds may be found in Appendix B to §§ 20.1001 - 20.2401.

In general, when the IRF for a "soluble" compound of unknown or unspecified chemical form is required, the most conservative IRF of any D compound for that element is to be used. When the IRF for an "insoluble" compound of unknown chemical composition is required, the most conservative IRF for either a W or Y compound for that element is to be used.

1.3 Specific information on the behavior of radionuclides in an individual may be used for estimating intakes and assessing doses according to 10 CFR 20.1204(c). Several measurements may be required to properly characterize the intake. Actual intake can be estimated using the minimized chi-squared statistic based on multiple measurements (see Appendix A to NUREG/CR-4884, Reference 2).

$$I = \frac{\sum_i \text{IRF}(i) A(i)}{\sum_i \text{IRF}(i)^2}$$

Equation 2

where:

- I = Best estimate of intake with units the same as A(i),
 IRF(i) = Intake retention fraction associated with the ith measurement
 A(i) = Value of the ith bioassay measurement (e.g., 24-hour urine, accumulated urine, total body), decay corrected to time of sampling, with appropriate units (e.g., μCi , Bq, or μg).

1.4 Variations from predicted results for specific individuals can be expected. Excretion of radionuclides may be influenced by the worker's diet, health condition, age, level of physical and metabolic activity, or physiological characteristics. The solubility of the inhaled radionuclide, the particle size distribution, and the time of the excretion also influence the elimination rate of radionuclides. Therefore, final assessment should be determined by someone trained or experienced in the interpretation of bioassay measurements.

1.5 To apply the methods of Equation 2 to the calculation of an individual's radionuclide intake, data on the total activity in 24-hour urine,* 24-hour feces,* accumulated urine, or accumulated feces is required. Alternatively, the radionuclide content in the total body, systemic organs, lungs, nasal passages, or GI tract can be determined. The total activity is then divided by the appropriate IRF. If 24-hour or accumulated samples have not been collected, the following equations may be used to estimate the accumulation of activity in urine or feces.

*The term "24-hour urine" refers to the total urine output collected over a 24-hour period, and the term "24-hour feces" refers to the total fecal output collected over a 24-hour period.

$$\Delta A_i = C_i E (t_i - t_{i-1}) \quad \text{Equation 3}$$

$$A_i = \Delta A_1 + \Delta A_2 + \dots \Delta A_i \quad \text{Equation 4}$$

where:

- i = The sequence number of the sample
- t_i = The time (days) after intake that sample i is collected
- C_i = The radionuclide concentration in urine (activity/L) or feces (activity/g) of sample i, decay corrected to the time of sampling
- E = Daily excretion rate (use measured rates or assume values of 1.4 L/day for urine or 135 g/day for feces)
- ΔA_i = Activity or amount of radioactive material in sample i normalized to standard parameters
- A_i = Accumulated activity up to time t_i

2. ADJUSTING INTAKE ESTIMATES FOR MULTIPLE AND CONTINUOUS INTAKES

2.1 Single IRFs may be modified and used to evaluate multiple and continuous intakes (see Ref. 2, NUREG/CR-4884, Appendix B, Section 9).

2.2 Air sampling results may be used to determine whether intakes are likely to have been single intakes, multiple intakes of varying sizes, continuous constant intakes, or continuous intakes with variable magnitude. Example 3 in Appendix A to this guide illustrates a method of determining continuous or multiple intakes using the IRFs for single exposures. (Guidance on air sampling is being developed in proposed Revision 1 to Regulatory Guide 8.25, "Air Sampling in the Workplace," DG-8003, which was issued for public comment in September 1991.)

2.3 In practice, a worker may receive repeated exposures to the same radionuclide during a specific period of time. If these intakes are separated

by more than four effective half-lives, each one may be treated as a single intake. The individual intakes may be summed to estimate the total intake.

2.4 Continuous intakes may be approximated using a relationship in which the expected exposure rate equals the total observed activity divided by the total exposure period. The integral of the IRFs over the time of the exposure and the time since the end of the exposure are found by using the single IRFs listed in Appendix B to NUREG/CR-4884 (Ref. 2) and a numerical integration approximation technique. The result will be acceptably accurate as long as the intakes are distributed reasonably equally in size and time and the integration area is divided into the appropriate number of regions. The number of regions to be used is based on standard numerical integration techniques. In general, using 8 to 10 regions provides a good degree of accuracy.*

For bioassay measurements taken during an exposure interval, the equation is:

$$\langle q(t) \rangle = \frac{A}{T} \int_0^t \text{IRF}(u) \, du \quad \text{for } t < T \quad \text{Equation 5}$$

Using the trapezoidal rule to solve Equation 5 yields the following approximation:

$$\langle q(t) \rangle \approx \frac{A}{T} \frac{t}{n} \left[\frac{\text{IRF}(t) + \text{IRF}(t=0.1\text{days})}{2} + \text{IRF}(u_1) + \dots + \text{IRF}(u_{n-1}) \right]$$

For bioassay measurements taken after an exposure interval, the equation is:

*An IRF can be expressed as a sum of exponential terms and can vary by approximately 2 orders of magnitude in the first 1000 days following an exposure (Ref. 2). The composite trapezoidal rule can be used to numerically evaluate an integral that is equally partitioned. Using this rule to evaluate the integral $\int f(x) \, dx$ yields a relative error of 3.6% for 8 intervals, 2.7% for 9 intervals; and 2.2% for 10 intervals.

$$\langle q(t) \rangle = \frac{A}{T} \int_{t-T}^t \text{IRF}(u) \, du \quad \text{for } t \geq T \quad \text{Equation 6}$$

Likewise, Equation 6 may be approximated using the trapezoidal rule:

$$\langle q(t) \rangle \approx \frac{A}{n} \left[\frac{\text{IRF}(t-T) + \text{IRF}(t)}{2} + \text{IRF}(u_1) + \dots + \text{IRF}(u_{n-1}) \right]$$

$\langle q(t) \rangle$ = Amount of activity in compartment or whole body at time t following onset of intake [Note: using NUREG/CR-4884 notation, $\langle q(t) \rangle$ is equivalent to $A(t)$]

A = Total intake during period T [Note: using NUREG/CR-4884 notation, A is equivalent to I]

T = Duration of intake (exposure interval)

t = Time from onset of intake to time of measurement

u = Variable time between integration limits

$\text{IRF}(u)$ = Intake retention fraction in compartment or whole body for a single intake of a radionuclide

n = number of increments (8 to 10 increments are needed to achieve a reasonable degree of accuracy)

3. CORRECTING INTAKE ESTIMATES FOR PARTICLE SIZE DIFFERENCES

The IRFs presented in NUREG/CR-4884 and the ALIs in Appendix B to §§ 20.1001 - 20.2401 are based on 1-micrometer activity median aerodynamic diameter (AMAD) particles. When appropriate, adjustments based on a different distribution of particle sizes* may be made in the IRFs given in Appendix B to NUREG/CR-4884. In general, larger inhaled particles are deposited preferentially in the upper portions of the respiratory tract and clear faster

*Guidance on the methodology to determine the AMAD is being developed and was issued in September 1991 for public comment in the Proposed Revision 1 to Regulatory Guide 8.25, DG-8003.

than smaller particles. Equation 7, taken from NUREG/CR-4884 (Ref. 2), is to be used following intake, depending on the solubility of the compound.

Equation 7

$$\text{IRF (AMAD)} = \text{IRF (1 } \mu\text{m)} \sum_T \left[f_{N-P,T} \frac{H_{50T}W_T}{\sum_T H_{50T}W_T} \frac{D_{N-P}(\text{AMAD})}{D_{N-P}(1 \mu\text{m})} + \right. \\ \left. f_{T-B,T} \frac{H_{50T}W_T}{\sum_T H_{50T}W_T} \frac{D_{T-B}(\text{AMAD})}{D_{T-B}(1 \mu\text{m})} + \right. \\ \left. f_{P,T} \frac{H_{50T}W_T}{\sum_T H_{50T}W_T} \frac{D_P(\text{AMAD})}{D_P(1 \mu\text{m})} \right]$$

where:

- IRF(AMAD) = Total body IRF for inhalation of Class D, W, or Y compounds for activity median aerodynamic diameter (AMAD) of interest;
- IRF(1 μm) = Total body IRF for inhalation of 1 μm AMAD aerosols (these IRFs are given in Appendix B to NUREG/CR-4884)
- N-P, T-B, P = The compartments or regions of deposition of the respiratory tract: the nasopharyngeal passage region (N-P), the tracheobronchial region (T-B), and the pulmonary region (P)
- $f_{N-P,T}$, $f_{T-B,T}$, $f_{P,T}$ = The fraction of committed dose equivalent in the tissue T resulting from deposition in the N-P, T-B, and P regions, respectively (These values are listed in the Supplement to Part 1 of ICRP Publication 30 (Ref. 3). Each radionuclide's table of committed dose equivalent in target organs or tissues indicates these

fractions in parentheses beneath the value of the committed dose equivalent.) (The values in Example 2 in Appendix A to this guide should be used rather than those listed in Reference 2, NUREG/CR-4884, Table B.8.1, which incorrectly lists the data originally presented in ICRP-30 for these fractions.)

- H_T = Committed dose equivalent for tissue (or organ) T
- W_T = Tissue (or organ) weighting factor, from 10 CFR 20.1003
- D_{N-P}, D_{T-B}, D_p = Regional deposition fractions for an aerosol entering the respiratory system (Values to be used in this equation are presented in Example 2, in Appendix B to this guide. These values are to be used instead of those listed in Reference 2, in Table B.8.1 in NUREG/CR-4884, because NUREG/CR-4884 incorrectly lists the data from ICRP-30 (Ref. 3).)
- Σ_T = Summation over all tissues (and organs) T

For Class D compounds, the time after intake for which Equation 8 begins to yield valid results is less than 1 day. For Class W compounds, this time is about 7 days following intake, and for Class Y compounds, about 9 days following intake.

The above method for revising the IRF for different particle sizes is applicable for the total body IRF. Revised IRF for other tissues and excreta may be derived based on the modeling of ICRP Publication 30 (Ref. 3), which is very detailed and requires an understanding of the interrelationship of the interlinking differential equations that describe the lung model. The appendix to ICRP Publication 30 and Section 2.5 of NUREG/CR-4884 provide additional information for evaluating IRF for different particle size distributions.

4. USE OF CALCULATED INTAKES FOR DOSE CALCULATION AND REGULATORY COMPLIANCE

4.1 The intake determined by using any of the above methods may be used for determining internal doses to personnel.

4.2 Once the intake is determined, the internal doses should be calculated using the annual limit on intake (ALI) values in Table 1 of Appendix B to §§ 20.1001 - 20.2401 to determine the significance of the the bioassay result. The quotient of the estimated intake of a radionuclide by its respective stochastic ALI value when multiplied by 5 rems gives an estimate of the committed effective dose equivalent of an exposed worker, which can then be added to the worker's deep-dose equivalent (for external exposures) in order to determine the worker's total radiation exposure status. These results should then be evaluated for compliance with the dose limits of 10 CFR 20.1201. In cases of significant exposures, follow-up bioassay procedures should be used to confirm and improve the accuracy of the dose estimates of the intake.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants regarding the NRC staff's plan for using this regulatory guide.

This proposed revision has been released to encourage public participation in its development. Except in those cases in which an applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method to be described in the active guide reflecting public comments will be used in the estimation of the intake of radionuclides from bioassay measurements.

REFERENCES

1. International Commission on Radiological Protection, "Individual Monitoring for Intake of Radionuclides by Workers: Design and Interpretation," ICRP Publication 54, Pergamon Press, New York, 1988.
2. E. T. Lessard et al., "Interpretation of Bioassay Measurements," NUREG/CR-4884, U.S. Nuclear Regulatory Commission, July 1987.
3. International Commission on Radiological Protection, "Limits for Intakes of Radionuclides by Workers," ICRP Publication 30, Part 1, and ICRP Publication 30, Supplement to Part 1, Appendix A, Pergamon Press, New York, 1978.

APPENDIX A
EXAMPLES OF THE USE OF INTAKE RETENTION FRACTIONS

The following examples illustrate the methods for proper interpretation of bioassay measurements. The purpose of these examples is not to define the scope of a bioassay program or the response of a bioassay program to a positive bioassay measurement. These examples do not illustrate the use of all possible bioassay or health physics measurements that may be available (e.g., excreta and air sampling measurements) during a specific exposure incident. Rather, these examples demonstrate the proper interpretation of several types of bioassay measurements. The examples demonstrate the use of retention fractions to:

- Estimate intake from one or several bioassay measurements
- Adjust intake estimates for multiple or continuous intakes
- Correct intake estimates for particle size differences
- Determine estimates of intake using data for reference man.

EXAMPLE 1

Use of Retention Fractions to Calculate Intake

CASE 1: Inhalation of Soluble ^{137}Cs and Insoluble ^{60}Co (In Vivo)

Results of routine whole body counting of personnel show that a worker has detectable body burdens of both ^{137}Cs and ^{60}Co . Monitoring has been performed at 1-year intervals, and the exact time of the exposure is not known.

The results of the current whole body count are as follows:

0.014 μCi (518 Bq) of ^{137}Cs
0.052 μCi (1926 Bq) of ^{60}Co

Evaluation Procedure

First, find the intake retention fractions (IRFs) for ^{137}Cs and ^{60}Co in the "Alphabetical Index to Appendix B," NUREG/CR-4884 (page B-809). Assume a $1\ \mu\text{m}$ particle size. The index indicates the following:

- Cesium: Class D IRFs, starting on page B-109 (B-111)
- Cobalt: Class W IRFs, starting on page B-208 (B-212)
Class Y IRFs, starting on page B-373 (B-377)
Ingestion IRFs, starting on page B-521 (B-525)

(Note: The numbers in parentheses indicate the actual page in NUREG/CR-4884 where the data used in this example can be found.)

Since the results of a whole body count are known, find the IRF values for 365 days for ^{137}Cs (Class D) and ^{60}Co (Classes W and Y), shown in the column "Total Body" in Appendix B to NUREG/CR-4884. Since the time of exposure is not known, use the IRFs for 365 days, as this assumes the intake occurred just after the last whole body count, 1 year prior to the current count. This yields the most conservative estimate of the time of exposure, because it maximizes the amount of the intake as determined from the bioassay measurement. In actual situations, air samples would probably be available and could be used to better define the intake pattern.

Interpolate to find the appropriate IRF as follows:

$$IRF(\text{Day } X) = \left[\frac{IRF(\text{Day } Y) - IRF(\text{Day } Z)}{(\text{Day } Y) - (\text{Day } Z)} \right] \times [\text{Day } X - \text{Day } Y] + IRF(\text{Day } Y)$$

where:

IRF (day X) = Interpolated IRF value, calculated at day X, which lies between two NUREG/CR-4884 IRF values occurring at days Y and Z; in this case, X = 365 days, Y = 300 days, and Z = 400 days

IRF (day Y) = IRF value occurring at day Y, in this case, 300 days

IRF (day Z) = IRF value occurring at day Z, in this case, 400 days

Solving for ^{137}Cs , Class D, yields the following:

$$\begin{aligned} \text{IRF}_{365 \text{ days}} &= \left[\frac{\text{IRF}_{300 \text{ days}} - \text{IRF}_{400 \text{ days}}}{300 \text{ days} - 400 \text{ days}} \right] \times [365 \text{ days} - 300 \text{ days}] + \text{IRF}_{300 \text{ days}} \\ &= \left[\frac{8.55 \text{ E-2} - 4.52 \text{ E-2}}{-100 \text{ days}} \right] \times 65 \text{ days} + 8.55 \text{ E-2} \\ &= 5.93 \text{ E-2} \end{aligned}$$

Interpolating for ^{137}Cs (Class D), ^{60}Co (Class Y), and ^{60}Co (Class W) yields the following.*

$$\begin{aligned} \text{IRF } (^{137}\text{Cs}, \text{ Class D}) &= 5.93\text{E-2} \\ \text{IRF } (^{60}\text{Co}, \text{ Class Y}) &= 9.37\text{E-2} \\ \text{IRF } (^{60}\text{Co}, \text{ Class W}) &= 1.16\text{E-2} \end{aligned}$$

Determine the intake by dividing the measured whole body activity by the respective IRF.

$$\text{Intake } (^{137}\text{Cs}, \text{ Class D}) = 0.014 \mu\text{Ci}/0.0593 = 0.24 \mu\text{Ci} (8,880 \text{ Bq})$$

$$\begin{aligned} \text{Intake } (^{60}\text{Co}, \text{ Class Y}) &= 0.052 \mu\text{Ci}/0.0937 \\ &= 0.55 \mu\text{Ci} \\ &= (20,350 \text{ Bq}) \end{aligned}$$

*The values in Tables 1, 2, and 3 in Appendix B to §§ 20.1001 - 20.2401 are presented in the computer "E" notation. In this notation, 6E-02 represents a value of 6×10^{-2} or 0.06; 6E+2 represents 6×10^2 or 600; and 6E+0 represents a value of 6×10^0 or 6.

$$\begin{aligned}
 \text{Intake } (^{60}\text{Co, Class W}) &= 0.052 \mu\text{Ci}/0.0116 \\
 &= 4.5 \mu\text{Ci} \\
 &= (166,500 \text{ Bq})
 \end{aligned}$$

Based on Regulatory Position 1.2, the IRF for an insoluble ^{60}Co compound is needed to calculate the intake, and the most conservative IRF for either W or Y compounds is to be used. Therefore, one would assume that a ^{60}Co Class W compound was inhaled.

Because of the conservative assumptions about the time of intake, the intake is probably less than the estimates above.

CASE 2: Inhalation of P-32

A laboratory worker accidentally breaks a flask, resulting in a single inhalation of a P-32 compound. A review of the air sampling data obtained at the time of the incident indicates that the phosphorus compound and aerosol are properly categorized as a 1 micrometer class D aerosol.

At 2 days, 10 days, and 20 days after the incident, 24-hour urine samples are obtained from the individual. An aliquot from each sample is counted on the day of collection in a liquid scintillation counter to determine the P-32 activity concentration. Using 1.4 liters per day as the 24-hour urine volume and the 24-hour urine IRFs for 2, 10, and 20 days from the table on page B-25 of NUREG/CR-4884 (IRFs in NUREG/CR-4884 are decay corrected) results in the following:

(t_i) Time After Intake (Days)	(C_i) Decay Corrected Activity in Urine ($\mu\text{Ci}/\text{L}$)	IRF	(A_i) Estimated Value of P-32 in 24-hr Urine (μCi)
2	1.5E+0	4.17 E-2	2.120
10	1.3E-1	4.34 E-3	0.187
20	6.0E-2	1.55 E-3	0.084

The best estimate of intake is calculated using Equation 2 in Regulatory Position 1 to obtain the least squares best estimate of the intake. This is calculated from the bioassay measurements obtained on three different days following the incident:

$$I = \frac{\sum_i \text{IRF}_i A_i}{\sum_i \text{IRF}_{(i)}^2}$$

$$I = \frac{(2.12 \times 4.17\text{E-}2) + (1.87\text{E-}1 \times 4.34\text{E-}3) + (8.42\text{E-}2 \times 1.55\text{E-}3)}{(4.17\text{E-}2)^2 + (4.34\text{E-}3)^2 + (1.55\text{E-}3)^2}$$

$$I = 50.76 \mu\text{C} \quad \text{P-32}$$

CASE 3: Determination of Day of Inhalation

Routine bioassay measurements for ¹³¹I for two workers in a radiopharmaceutical laboratory are as follows:

	Monitoring Date	Activity in 24-hr Urine	Activity in Whole Body
Worker 1	May 15		Background
	May 22	94.4 nCi (3.50E3 Bq)	110 nCi (4.70E3 Bq)
	May 24	4.8 nCi (1.78E2 Bq)	84 nCi (3.11E3 Bq)
Worker 2	May 15		Background
	May 22	127 nCi (4.70E3 Bq)	220 nCi (8.15E3 Bq)
	May 24	9.2 nCi (3.40E2 Bq)	161 nCi (5.96E3 Bq)

Since air sampling data are not available, the day on which the exposure occurred is unknown. Proper evaluation of the intake depends on a determination of the date of exposure.

Evaluation Procedure

The first step is to use the bioassay measurements and the IRFs given in Appendix B to NUREG/CR-4884 to determine the date of intake. This can be done by determining the ratio of the measured activity in the 24-hour urine sample to the activity measured by the whole body count, and comparing it to the ratio of IRFs found in Appendix B to NUREG/CR-4884 (pages B-103 and B-101, respectively).

A table containing the ratio of the theoretical 24-hour urine IRFs to the theoretical whole body IRFs could be constructed using Appendix B to NUREG/CR-4884 (pages B-103 and B-101). This could be done for the 6 or 7 days during which the intake most likely occurred.

Days Post-intake	Ratio of Theoretical IRFs 24-hour Urine to Whole Body
1	$3.04E-1/2.74E-1 = 1.1$
2	$6.24E-2/1.87E-1 = 0.33$
3	$1.62E-2/1.55E-1 = 0.10$
4	$4.47E-3/1.37E-1 = 0.033$
5	$1.31E-3/1.25E-1 = 0.010$
6	$3.29E-4/1.14E-1 = 0.0029$
7	$2.53E-4/1.04E-1 = 0.0024$

Next, calculate the ratio (R_{a1}) of the actual measured 24-hour urine activity to the measured whole body activity for Worker 1 on May 22.

$$R_{a1} = \frac{94.5}{110} = 0.86$$

The ratio of the measurements made for Worker 2 on May 22 (R_{a2}) is:

$$R_{a2} = \frac{127}{220} = 0.58$$

Examine the ratios of the theoretical 24-hour urine to whole body IRFs in the table above and locate the two ratios between which the ratio of the actual measurements, R_a , falls. The R_a values (0.86 and 0.58) fall between the theoretical ratios of 1.1 and 0.33, which correspond to 1 or 2 days following intake. This suggests that the intake occurred between 1 to 2 days before May 22. The results of additional follow-up bioassay measurements on May 24 confirm the estimate of an intake 1 to 2 days before May 22.

CASE 4: Uranium Intake

An accident at a facility that produces UF_6 (uranium hexafluoride) results in a worker being exposed to an unknown concentration of UF_6 with a natural isotopic distribution. The UF_6 is known to be a Class D compound. Urine samples are collected and analyzed. The results are shown in the following table.

Time of Sample (Days)	Concentration of Uranium in Urine ($\mu\text{g/L}$)
0.2	6,100
0.6	990
2.0	90
3.0	210

There is a separate limit in Appendix B to §§ 20.1001 - 20.2401 for uranium intake, based on chemical toxicity. This limit is expressed as footnote 3 to Appendix B, but the limit is also provided in the text of 10 CFR 20.1201(e).

Evaluation Procedure

The first step would be to construct the following table:

(1)	(2) (Measured)	(3)	(4) (Calculated)	(5) (Calculated)
Time Post-intake (Days)	Concentration of U in Urine ($\mu\text{g/L}$)	IRF	Uranium in Accumulated Urine (μg)	Intake (μg)
0.2	6,100	0.050	1,708	34,160
0.6	990	0.132	2,262	17,140
2.0	90	0.259	2,438	9,413
3.0	210	0.291	2,732	9,388

Column 1 is the sampling time (in days) after the exposure occurred.

Column 2 is the measured concentration of uranium in the urine samples in units of micrograms per liter. Decay correction is not necessary because of the long half-lives of ^{234}U , ^{235}U , and ^{238}U .

To obtain the IRFs for column 3 from Appendix B to NUREG/CR-4884, use the following procedure: Look in the alphabetical index to Appendix B (page B-814) to find the location of IRFs for uranium Class D compounds. The index indicates that the IRFs for Class D start on page B-158. Assume all the activity is ^{238}U . Find the IRFs listed under "Accumulated Urine" (page B-163) corresponding to the times following intake noted in column 1 of the table.

For column 4, calculate the amount of ^{238}U that would be present in accumulated urine. This can be calculated for each sample by using Regulatory Position 1, Equations 2, 3, and 4. The amount of uranium in the first sample would be calculated as follows:

$$\Delta A_i = C_i \times E \times (t_i - t_{i-1})$$

$$A_i = \Delta A_1 + \Delta A_2 + \dots + \Delta A_i$$

$$A_1 = \Delta A_1 = C_1 \times E \times (t_1 - t_0)$$

$$\begin{aligned}\Delta A_1 &= 6100 \frac{\mu\text{g}}{\text{L}} \times 1.4 \frac{\text{L}}{\text{day}} \times 0.2 \text{ day} \\ &= 1708 \mu\text{g}\end{aligned}$$

where:

- A_1 = Accumulated activity up to time t equals t_1
- ΔA_1 = Activity or amount of uranium in the first sample
- C_1 = Concentration of uranium in the first sample
- E = Daily excretion rate (1.4 L/day for urine for reference man)
- t_1 = Time (in days) after intake when the first sample was taken
- t_0 = Time (in days) after intake when the previous sample was taken (i.e., 0 days in this case)

The accumulation for the second sample is calculated in the following manner:

$$\begin{aligned}A_2 &= A_1 + C_2 \times E \times (t_2 - t_1) \\ &= 1708 \mu\text{g} + 990 \frac{\mu\text{g}}{\text{L}} \times 1.4 \frac{\text{L}}{\text{day}} \times (0.6 - 0.2 \text{ day}) \\ &= 2262 \mu\text{g}\end{aligned}$$

Accumulations for the remainder of the sample times are similarly calculated.

The intakes shown in column 5 are calculated by dividing the amount of uranium in accumulated urine (column 4) by the IRFs shown in column 3.

For example, the intake based on the first sample is calculated as follows.

$$\frac{1708}{0.05} = 34,160 \mu\text{g}$$

Ideally, the calculated intakes would be the same for each sample. However, individual differences in dietary habits, physical health, biological parameters, sample times, etc., can produce large variations in the intake estimated from each sample.

The actual intake is estimated using the minimized chi-square statistic in Regulatory Position 1, Equation 2, and the calculated A_i s (i.e., the uranium in accumulated urine, column 4 of the above table) as follows:

$$I = \frac{\sum_i IRF(i) A(i)}{\sum_i IRF(i)^2}$$

where:

- I = Best estimate of intake with units the same as A(i)
- IRF(i) = Intake retention fraction associated with the i^{th} measurement
- A(i) = Value of the i^{th} measurement with appropriate units, for example, μCi , Bq, or μg .

$$I = \left[\frac{(1708 \times 0.050) + (2262 \times 0.132) + (2438 \times 0.259) + (2732 \times 0.291)}{0.050^2 + (0.132)^2 + (0.259)^2 + (0.291)^2} \right]$$

= 10,545 μg V 10.5 mg

CASE 5: Comparison of Air Sampling and Bioassay Measurements and Results

A worker fabricating a ^{137}Cs source is exposed to airborne radioactive material. The work area is sampled by a low-volume continuous air sampler with an air flow rate of 2 ft³/minute (56.6 L/minute). At the end of the 8-hour shift, the health physicist counts the air sampler filter and measures 3.67 μCi of ^{137}Cs . Based on this level of activity on the filter, the health physicist calculates that the average air concentration of ^{137}Cs over the 8-hour shift was 0.135 pCi/ml (5000 Bq/m³). A 24-hour urine sample ordered by the health physicist contained 0.0046 μCi (170 Bq) of ^{137}Cs .

Evaluation Procedure

Find the IRFs for ^{137}Cs in Appendix B to NUREG/CR-4884. Assume a 1- μm particle size. The appendix indicates the following:

- Cesium: Class D IRFs, starting on page B-109 (B-112)
- IRF (Inhalation) 1 day following intake = 1.35E-02

Obtain the ALI and DAC from Table 1 in Appendix B to §§ CFR 20.1001 - 20.2401.

$$\begin{aligned}\text{ALI } (^{137}\text{Cs, Inhalation}) &= 200 \mu\text{Ci} \\ \text{DAC } (^{137}\text{Cs}) &= 6\text{E-}8 \mu\text{Ci/ml } (0.06 \text{ pCi/ml})\end{aligned}$$

Since the air sample result is available immediately, the health physicist notes that the ^{137}Cs DAC of 0.06 pCi/ml has been exceeded by the air sampler filter result of 0.135 pCi/ml. The air sampler filter result is used to determine if the ALI has been exceeded.

As a first approximation, it is assumed that the worker was exposed to the average airborne ^{137}Cs concentration represented by the activity on the air sampler filter for the entire 8 hours of the work shift. A worker breathing rate of 1.2 m³/hour (light work activity) is also assumed. The following intake is calculated:

$$\begin{aligned}\text{Intake} &= 8 \text{ hours} \times 1.2 \frac{\text{m}^3}{\text{hour}} \times 0.135 \frac{\text{pCi}}{\text{ml}} \times 1\text{E}6 \frac{\text{ml}}{\text{m}^3} = 1.30\text{E}6 \text{ pCi} \\ &= 1.30 \mu\text{Ci } (4.8\text{E}4 \text{ Bq})\end{aligned}$$

The following day, the 24-hour urine sample is analyzed and the intake is calculated based on this bioassay measurement. Find the IRF value for ^{137}Cs (Class D, Inhalation) shown in the column "24-Hour Urine" in Appendix B to NUREG/CR-4884 for 1 day following intake. Determine the intake by dividing the measured 24-hour urine activity by the IRF.

$$\begin{aligned}\text{Intake} &= \frac{0.0046 \mu\text{Ci}}{1.35 \text{ E-}02} \\ &= 0.34 \mu\text{Ci } (12,580 \text{ Bq})\end{aligned}$$

The two calculated estimates of ^{137}Cs intake, while not identical, are within an order of magnitude. The differences between the two differently

calculated estimates of the ^{137}Cs intake may reflect any or all of the following:

- Differences between the metabolism of reference man and the worker
- Variability between the air breathed by the worker and the air collected by the low-volume air sampler
- An AMAD greater or less than $1\ \mu\text{m}$

In this example, the available data cannot resolve the differences between the results of air sampling and urinalysis. Collection of additional bioassay samples are needed to monitor the contaminated worker. However, it is possible that even with the collection, analysis, and interpretation of additional bioassay samples, the discrepancies between the results may not be resolved. If additional bioassay samples are collected, the best estimate of intake can be calculated using Regulatory Position 1, Equation 2. (See Example 1, Case 2, "Inhalation of P-32," or Example 1, Case 4, "Uranium Intake.") The licensee should, in the meantime, use the estimate of intake that, by evaluation, is shown to be more likely. In this case it is not the most conservative estimate. However, it is accepted that air sample results represent only an approximation of the level of radioactive material in the air breathed by the worker. The bioassay results are somewhat more indicative of actual intake. However, it is important to stress that more data is needed to properly evaluate this intake. When several 24-hour urine samples have been evaluated, the minimized chi-squared statistic (Equation 2, Regulatory Position 1) can be used to quantify intake more definitively.

EXAMPLE 2

Correcting Intake Estimates for Particle Size Difference

This example illustrates the correction of intake retention fractions (IRFs) for particle size. Rarely (if ever) is an air sample composed of only a single particle size. Therefore, the sample is described in terms of its characteristics relative to a theoretical sample consisting of particles of a single size. Samples are described in terms of the activity median aerodynamic

diameter (AMAD). In this example, the sample is composed of a variety of sizes that will result in a deposition similar to a sample containing only particles of 2 μm . This is referred to as 2 μm AMAD.

A worker is exposed to a ^{60}Co Class Y compound with an AMAD of 2.0 μm . The circumstances indicate that the intake occurred 20 days before the bioassay measurements were made.

Evaluation Procedure

An IRF is adjusted for a 2.0- μm AMAD particle size using Equation 7 of Regulatory Position 3, which shows the approximate relationship among the total body IRFs for different aerosol sizes between 0.2 μm and 10 μm .

Values for D_{N-P} , D_{T-B} , and D_p derived from the data in Part 1 of ICRP Publication 30 (pages 24 and 25) and as presented in NUREG/CR-4884 (page B-801) are given in the following table:

Aerosol AMAD				
	0.2 μm	0.5 μm	0.7 μm	1.0 μm
D_{N-P}	0.05	0.16	0.23	0.30
D_{T-B}	0.08	0.08	0.08	0.08
D_p	0.50	0.35	0.30	0.25
Total Deposition	0.63	0.59	0.61	0.63
	2.0 μm	5.0 μm	7.0 μm	10.0 μm
D_{N-P}	0.50	0.74	0.81	0.87
D_{T-B}	0.08	0.08	0.08	0.08
D_p	0.17	0.09	0.07	0.05
Total Deposition	0.75	0.91	0.96	1.00

The values of f_{N-P} , f_{T-B} , and f_p needed for Equation 7 are listed in the Supplement to Part 1 of ICRP Publication 30 (page 40). These values, as presented in ICRP Publication 30, are given as percentages and must be converted to decimal fractions before they are used in Equation 7. The decimal

fractions for each tissue, along with its weighting factor and committed dose equivalent factor, are presented in the following table.

Input Values					
Tissue	f_{N-P}	f_{T-B}	f_P	W_2^*	$H_{50,T}^{**}$ (Sv/Bq)
Gonads	0.35	0.21	0.44	0.25	4.0E-09
Breast	0.19	0.17	0.64	0.15	4.2E-09
Red Marrow	0.20	0.17	0.63	0.12	4.2E-09
Lungs	0.02	0.02	0.96	0.12	3.6E-08
LLI Wall	0.45	0.15	0.40	0.06	8.2E-09
Liver	0.21	0.19	0.60	0.06	9.2E-09
Remainder	0.01	0.09	0.81	0.06	8.7E-09

Equation 7 in Regulatory Position 3 is used to estimate the IRF for 0.2 μm particles.

$$\begin{aligned}
 \text{IRF (AMAD)} = \text{IRF (1 } \mu\text{m)} \sum_T \left[f_{N-P,T} \frac{H_{50T} W_T}{\sum_T H_{50T} W_T} \frac{D_{N-P}(\text{AMAD})}{D_{N-P}(1 \mu\text{m})} + \right. \\
 f_{T-B,T} \frac{H_{50T} W_T}{\sum_T H_{50T} W_T} \frac{D_{T-B}(\text{AMAD})}{D_{T-B}(1 \mu\text{m})} + \\
 \left. f_{P,T} \frac{H_{50T} W_T}{\sum_T H_{50T} W_T} \frac{D_P(\text{AMAD})}{D_P(1 \mu\text{m})} \right]
 \end{aligned}$$

Substituting into the above equation from the table of input values results in the following:

$$\text{IRF}(2.0 \mu\text{m}) = 8.5 \text{ E-02}$$

*Tissue weighting factors from 10 CFR 20.1003.

**Committed dose equivalent. Example data taken from ICRP Publication 30, Supplement to Part 1.

This IRF could be used to estimate intakes, determine the time of exposure, etc., as illustrated in the above examples.

This method for revising the IRF for different particle sizes is applicable for the total body IRF. Revised IRFs for other tissues and excreta may be derived based on the modeling of ICRP Publication 30. However, this determination is very detailed, requiring an understanding of the interrelationship of the interlinking differential equations that describe the lung model. Refer to the Appendix to ICRP Publication 30 and Section 2.5 of NUREG/CR-4884 for additional information on evaluating IRFs for different particle size distributions.

EXAMPLE 3

Adjusting Intake Estimates for Multiple and Continual Intakes

This example shows how to adjust intake estimates for multiple and continual intakes.

Whole body counting for Worker 1 and urinalysis for Worker 2, performed March 1, 1988, reveal deposits of ^{60}Co . It is determined that the workers were continually exposed to ^{60}Co between January 15 and December 31, 1987. Results of whole body counting reveal $0.33 \mu\text{Ci}$ ($1.22\text{E}4 \text{ Bq}$) of ^{60}Co , and results of the urinalysis reveal 0.91 nCi (33.7 Bq) of ^{60}Co .

Evaluation Procedure

Equation 6 in Regulatory Position 2 can be used to estimate the intakes.

$$\langle q(t) \rangle = \frac{A}{T} \int_{t-T}^t \text{IRF}(u) \, du \quad \text{for } t \geq T$$

where:

$\langle q(t) \rangle$ = Amount of activity in compartment at time t following onset of intake

In this case, the values are:

T = 350 days (period of intake)
 t = 420 days (number of days following onset of intake)

A table of the IRFs can be constructed. For IRF values not indicated in NUREG/CR-4884, interpolate between the IRFs over the appropriate time interval. (See Example 1, Case 1, "Inhalation of Soluble ¹³⁷Cs and Insoluble ⁶⁰Co (In Vivo).") A table of the IRFs for these days would show the following:

Time Post-intake (Days)	Worker 1 IRF (Total Body)	Worker 2 IRF (24-hr Urine)
70	7.87E-2	2.50E-4
120	5.10E-2	1.62E-4
170	3.44E-2	1.04E-4
220	2.23E-2	6.03E-5
270	1.71E-2	3.95E-5
320	1.33E-2	2.41E-5
370	1.14E-2	1.70E-5
420	9.94E-3	1.17E-5

Note: If a greater degree of accuracy is desired, the time may be divided into smaller intervals. Standard error analysis for numerical integration may be used to determine the allowable error in establishing the number of intervals. For all practical purposes, 8 to 10 increments may provide an acceptable analysis error.

For the total body, substituting the IRFs and the interval length into Equation 7 yields the following:

$$\int_{70}^{420} \text{IRF}(u)du = 50x \left[\frac{7.87 + 0.99}{2} + 5.10 + 3.44 + 2.23 + 1.71 + 1.33 + 1 \right]$$

$$= 9.69$$

For 24-hour urine, substitution yields the following:

$$\int_{70}^{420} \text{IRF}(u)du = 50x \left[\frac{2.50 + 1.17}{2} + 16.2 + 10.4 + 6.03 + 3.95 + 2.41 + 1 \right]$$

$$= 2.69 \text{ E-2}$$

The whole body counting data for Worker 1 and the value of the integral, as determined above, can be substituted into Equation 6 of Regulatory Position 3, as shown below:

$$\langle q(u) \rangle = \frac{A}{T} \int_{70}^{420} \text{IRF}(u) \, du$$

Rearranging yields the following:

$$A = \frac{\langle q(t) \rangle T}{\int_{70}^{420} \text{IRF}(u) \, du} = \frac{(0.33 \, \mu\text{Ci}) (350)}{9.69} = 11.92 \, \mu\text{Ci} \, (4.41\text{E}5 \, \text{Bq})$$

Thus, the intake for Worker 1 is 11.9 μCi (4.4E5 Bq).

The 1-day urine data for Worker 2 and the value of the integral, as determined above, can be substituted into Equation 6 of Regulatory Position 2, as shown below.

$$A = \frac{\langle q(t) \rangle T}{\int_{70}^{420} \text{IRF}(u) \, du} = \frac{(0.91 \, \text{nCi}) (350)}{2.69 \, \text{E}-2} = 11,840 \, \text{nCi} \, (4.38\text{E}5 \, \text{Bq})$$

Thus, the intake for Worker 2 is 11.8 μCi (4.38E5 Bq).

APPENDIX B

DEFINITIONS

Airborne radioactive material means radioactive material dispersed in the air in the form of dusts, fumes, particulates, mists, vapors, or gases.

Airborne radioactivity area means a room, enclosure, or area in which airborne radioactive materials, composed wholly or partly of licensed material, exist in concentrations--

- (1) In excess of the derived air concentrations (DACs) specified in Appendix B to §§ 20.1001 through 20.2401, or
- (2) To such a degree that an individual present in the area without respiratory protective equipment could exceed, during the hours an individual is present in a week, an intake of 0.6 percent of the annual limit on intake (ALI) or 12 DAC-hours.

Annual limit on intake (ALI) means 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 rems (0.05 Sv) or a committed dose equivalent of 50 rems (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 §§ 20.1001 - 20.2401.)

Bioassay (radiobioassay) means 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.

Committed dose equivalent (H_T) means the dose equivalent to organs or tissues of reference (T) that will be received from an intake of radioactive material by an individual during the 50-year period following intake.

Committed effective dose equivalent ($H_{E,50}$) is 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 ($H_{E,50} = \sum W_T H_{T,50}$).

Deep-dose equivalent (H_d), which applies to external whole-body exposure, is the dose equivalent at a tissue depth of 1 cm (1000 mg/cm²).

Deposition means the quantity of a radionuclide deposited, e.g., in the respiratory tract following an inhalation or in the stomach following an ingestion intake.

Derived air concentration (DAC) means 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 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 §§ 20.1001 - 20.2401.

Derived air concentration-hour (DAC-hour) is 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-hours to represent one ALI, equivalent to a committed effective dose equivalent of 5 rems (0.05 Sv).

Dose or radiation dose is a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent, as defined in 10 CFR 20.1003.

External dose means that portion of the dose equivalent received from radiation sources outside the body.

Intake means the quantity of a radionuclide taken into the body by inhalation, ingestion, injection, or absorption.

Intake retention fraction (IRF) means the fraction of initial intake of a radionuclide remaining in an organ, a group of tissues, the whole body, or an excretion compartment, at some time after an intake.

Licensee means the holder of a license.

Occupational dose means the dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.

Survey means an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present.

Total effective dose equivalent (TEDE) means the sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

Uptake means the quantity of a radionuclide taken up by the systemic circulation, e.g., by injection into the blood, by absorption from compartments in the respiratory or GI tracts, or by absorption near the site of the wound.

Whole body means, for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knee.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this regulatory guide. The regulatory analysis prepared for 10 CFR Part 20, "Standards for Protection Against Radiation" (56 FR 23360), provides the regulatory basis for this guide and examines the costs and benefits of the rule as implemented by the guide. A copy of the "Regulatory Analysis for the Revision of 10 CFR Part 20" (PNL-6712, November 1988), is available for inspection and copying for a fee at the NRC Public Document Room, 2120 L Street NW., Washington, DC, as an enclosure to Part 20.

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