5.0 Cesium

This chapter provides technical information on the sources, characteristics, and biokinetics of radiocesium and summarizes the technical basis used for its internal dosimetry at Hanford. Dosimetry methods used for radiocesium are based on the concepts of ICRP 30 (ICRP 1979a), as implemented using the CINDY computer code (Strenge et al. 1992). A summary of ^{137}Cs dosimetric data is tabulated in Table 5.1. Details are provided in the following sections.

Table 5.1. Summary of ^{137}Cs Hanford Dosimetric Data

Radiological Half-Life	30.0 years
Inhalation Model	Class D—all compounds (ICRP 30, ICRP 54)
GI Absorption (f_1)	1 for all compounds
Systemic Biokinetic Model	Uniform distribution in all body organs and tissues. Two component exponential compartment retention. Component / Fraction / Half-Time A / 0.1 / 2 d B / 0.9 / 110 d
Excretion Fractions	Urine 0.80 Feces 0.20
Dose ($H_{E,50}$) Coefficients[(a)] 1-μm AMAD Inhalation 5-μm AMAD Inhalation Soluble Ingestion	 0.032 mrem/nCi and 8.6E-09 Sv/Bq 0.046 mrem/nCi and 1.2E-08 Sv/Bq 0.050 mrem/nCi and 1.4E-08 Sv/Bq
Derived Air Concentration[(b)] **(DAC)**	7E-08 μCi/ml and 2E+03 Bq/m^3
Annual Limit on Intake Inhalation[(c)] Soluble Ingestion[(d)]	 168 μCi and 4.8 MBq 100 μCi and 4 MBq

(a) Calculated using CINDY and ICRP 30 methods for Reference Man.
(b) From 10 CFR 835 Appendix B, stochastic limit-based, class D, 1-μm AMAD.
(c) Calculated as 10 CFR 835 DAC x 2400 m^3.
(d) From EPA Federal Guidance Report No. 11 (EPA 1988).

5.1 Sources and Characteristics of Radiocesium

The most important radionuclide of cesium at Hanford from an internal exposure standpoint is ^{137}Cs ($T_{1/2}$ = 30.0 y), a fission product. Historically, ^{134}Cs ($T_{1/2}$ = 2.1 y, produced by neutron activation of stable ^{133}Cs) was observed at activities on the order of less than 5% of the ^{137}Cs activity during Hanford production operations. However, with the lack of production by new sources at

Hanford and the normal radiological decay process, ^{134}Cs is no longer a significant nuclide in Hanford fission product or waste mixtures. Further discussion for this technical basis is limited to ^{137}Cs.

Because of its relatively high fission yield and its long half-life, ^{137}Cs, along with ^{90}Sr, is one of the most abundant radionuclides in aged fission product mixtures. More volatile than most of the longer-lived fission product radionuclides, cesium is more apt to escape containment or confinement and is commonly the most abundant radionuclide found in fission product releases within a facility. As discussed later, ^{137}Cs is easily detected using in vivo bioassay techniques and can serve as a good indicator radionuclide for intakes of fission products, waste mixtures, and spent fuel.

In addition to its presence in mixtures, ^{137}Cs has existed in relatively pure form at the Waste Fractionation Facility (B-Plant, 221-B) and the Waste Encapsulation and Storage Facility (WESF, 225-B). Encapsulation programs at WESF have been terminated; however, cesium-bearing capsules and cesium-contaminated equipment are stored in the facility.

Cesium has been found to be more dispersible than strontium, and therefore in most intake situations involving ^{137}Cs and ^{90}Sr, ^{137}Cs will likely constitute the major component of intake. In cases where it is suspected that ^{90}Sr or other radionuclides may be present along with ^{137}Cs but no radionuclide ratio information exists, it is prudent to consider additional bioassay appropriate for the other radionuclides of concern.

5.2 Environmental Levels of ^{137}Cs

Cesium-137 is present throughout the world environment as a result of atmospheric testing of nuclear weapons and releases from the 1986 Chornobyl nuclear accident in Ukraine. Elevated levels of ^{137}Cs in caribou and reindeer have long been recognized as contributing to detectable levels in people who consume such meats, and fish have also been identified as concentrators of environmental cesium (NCRP 1977). Following the Chornobyl accident, whole body activity levels of ^{137}Cs in humans were widely reported in the literature (e.g., Tarroni et al. 1990; Strand et al. 1989; Lloyd 1990; and Kang 1989). Generally these levels were in the range of a few nanocuries, although Strand et al. indicated microcurie quantities in Lapps who breed reindeer.

Potential transfer of radioactivity through the food chain received world-wide attention following the Chornobyl accident. In 1989 the joint World Health Organization (WHO)/Food and Agriculture Organization (FAO) established a guideline level of 1000 Bq/kg (27 nCi/kg) for cesium contamination in foods moving in international trade (WHO 1989). As summarized by Woodman and Nisbet (1999), the European Union has established additional intervention levels for cesium marketed in human foodstuffs and animal feeds.

Mushrooms can also be a potentially significant source of radiocesium intake. The radiocesium content of mushrooms depends on the species, locality of growth, and radiocesium in the local soil. Nakajima et al. (1998) reported levels of 3 to 18 nCi/g in mushrooms grown in the contaminated areas near Chornobyl. Mushrooms imported to France from Austria were removed from the retail market in 1998 after levels as high as 135 nCi/kg were discovered.

The possible existence of ^{137}Cs at the foregoing levels complicates interpretation of the source of low-level cesium that might be detected in routine whole body examinations. An attempt should be made to ascertain whether the detected levels are most likely of occupational or environmental origin: if occupational, then dose assessment may be warranted; if environmental, then occupational dose assessment is not warranted.

For workers who regularly consume large wild game, it might be reasonable to conclude that a few nanocuries of ^{137}Cs may represent nonoccupational intake. This can be further investigated if samples of meat can be obtained for direct assessment. However, even then conclusions may be tenuous because only limited data are available regarding expected variation throughout the Pacific Northwest. These data, obtained by counting meat samples provided by Hanford workers showing detectable levels of ^{137}Cs in their periodic whole body exams, indicate over 3 orders of magnitude of variability (MacLellan et al. 1993).

Likewise, for a worker who has spent time in a location known to be potentially affected by elevated cesium levels (e.g., Ukraine, Europe, Scandinavian countries, or Russia), it may also be reasonable to assume environmental exposure. Such exposure would probably result from consumption of locally obtained meat, dairy products, or produce. Consideration should be given to the location where one was exposed, length of time there, food consumption, and elapsed time since exposure in determining the likelihood that environmental sources were responsible for cesium intake.

5.3 Biokinetic Behavior of Radiocesium

ICRP 30 (1979a) classifies all isotopes of cesium as inhalation class D, indicating that inhaled material will be absorbed rapidly from the respiratory tract into the circulatory system. This is consistent with observations at Hanford. From the blood, cesium is distributed uniformly in the body with no organ or tissues showing a higher concentration than muscle. For dose assessment purposes, cesium is assumed to be completely and rapidly absorbed into systemic circulation from both the respiratory tract and the GI tract (f_1 factor = 1). The retention of stable cesium is described as two compartments, with 10% exhibiting a clearance half-time of 2 days and 90% exhibiting a clearance half-time of 110 days. Mathematically, the systemic compartment biokinetic model for stable cesium is depicted as follows:

$$R(t) = 0.1 \exp\left[-\frac{0.693 \times t}{2}\right] + 0.9 \exp\left[-\frac{0.693 \times t}{110}\right] \qquad (5.1)$$

where R(t) is the fraction of the initial uptake that is present in the body at t days post uptake. This systemic retention function is used for Hanford dosimetry unless there are sufficient data on an individual to identify an alternate function. For systemic excretion, the ICRP 54 (1988) split of 80% to urine and 20% to feces is used as the normal assumption.

The ICRP 30 systemic model is also used in the more recent ICRP publications 68 (ICRP 1994a) and 78 (ICRP 1997). Publication 78 notes that the biological clearance half-time from the transfer compartment to the systemic compartment (i.e., the translocation to body tissues) is 0.25 days. That publication also notes that females may exhibit significantly shorter retention half-times in the long-term compartment than males.

The whole body retention fractions, urine excretion fractions, and feces excretion fractions for inhalation of class D particles of 1-μm, 5-μm AMAD, and for a soluble ingestion intake are shown in Tables 5.2, 5.3, and 5.4, respectively.

5.4 Internal Dosimetry for Radiocesium

Internal dosimetry for ^{137}Cs can be performed using hand calculations based on the fundamental principles of time-integrated concentration of radioactivity in the body or by using the CINDY

Table 5.2. ^{137}Cs Whole Body Retention Fractions

Days Post Intake	1-µm-AMAD Class D Inhalation	5-µm-AMAD Class D Inhalation	Soluble Ingestion
1	0.62	0.89	0.98
2	0.60	0.86	0.95
7	0.55	0.79	0.87
14	0.52	0.75	0.83
30	0.47	0.68	0.75
60	0.39	0.56	0.62
90	0.32	0.46	0.51
180	0.18	0.26	0.29
365	0.056	0.080	0.088
730	0.0055	0.0079	0.0087
1825	5.1E-06	7.4E-06	8.1E-06

Table 5.3. ^{137}Cs Urine Excretion Fractions

Days Post Intake	1-µm-AMAD Class D Inhalation	5-µm-AMAD Class D Inhalation	Soluble Ingestion
1	1.3E-02	2.1E-02	2.5E-02
2	1.3E-02	1.8E-02	2.0E-02
7	4.8E-03	6.6E-03	7.2E-03
14	2.8E-03	4.0E-03	4.4E-03
30	2.4E-03	3.4E-03	3.8E-03
60	2.0E-03	2.8E-03	3.1E-03
90	1.6E-03	2.3E-03	2.6E-03
180	9.1E-04	1.3E-03	1.4E-03
365	2.8E-04	4.0E-04	4.5E-04
730	2.8E-05	4.0E-05	4.4E-05
1825	2.6E-08	3.7E-08	4.1E-08

Table 5.4. ^{137}Cs Feces Excretion Fractions

Days Post Intake	1-µm-AMAD Class D Inhalation	5-µm-AMAD Class D Inhalation	Soluble Ingestion
1	3.2E-03	5.4E-03	6.2E-03
2	3.2E-03	4.6E-03	5.1E-03
7	1.2E-03	1.7E-03	1.8E-03
14	7.0E-04	1.0E-03	1.1E-03
30	5.9E-04	8.5E-04	9.4E-04
60	4.9E-04	7.1E-04	7.8E-04
90	4.0E-04	5.8E-04	6.4E-04
180	2.3E-04	3.3E-04	3.6E-04
365	7.0E-05	1.0E-04	1.1E-04
730	6.9E-06	9.9E-06	1.1E-05
1825	6.5E-09	9.3E-09	1.0E-08

computer code as an implementation of the ICRP 30 methodology. Similar approaches can be used for ^{134}Cs, if dosimetry for that radionuclide is required.

5.4.1 Fundamental Principles Method

Because cesium is assumed to be distributed evenly throughout all tissues in the body, the stochastic dose equivalent (effective dose equivalent) is limiting for compliance purposes. Dose conversion factors for the radiocesiums were developed by Snyder et al., and published in ORNL-5000 (1974). These factors include the "total body dose" from activity deposited in the total body. Dosimetrically, this represents the most straightforward and technically appropriate way to express the total dose equivalent to the body when a radionuclide is uniformly distributed. The effective dose equivalent is derived from the "total body dose" by using a weighting factor of 1.0 for the total body as an organ. That is, the effective dose equivalent is equal to the "total body dose." The total body dose conversion factors (DCFs) from ORNL-5000, are as follows:

$$DCF(^{134}Cs) = 5.1\ E\text{-}7\ rem/nCi\text{-}day$$

$$DCF(^{137}Cs) = 3.2\ E\text{-}7\ rem/nCi\text{-}day.$$

Because cesium distributes relatively uniformly in the body, the dose received by individual organs and tissues is about the same as the total body dose. Thus, the dose received by specific organs and tissues can be assumed to be equivalent to the total body dose equivalent.

Integrating the retention function (Equation 5.1) with respect to time and multiplying by the initial systemic uptake (U_o) yields the cumulated internal activity in activity-days (e.g., nCi-days). Multiplying this product by the DCF gives the effective dose equivalent over the time period of interest as follows:

$$H_{E,t} = DCF \text{ x } U_0 \times \left[0.1 \times \frac{1 - \exp^{-\lambda_{eff1} \times t}}{\lambda_{eff1}} + 0.9 \times \frac{1 - \exp^{-\lambda_{eff2} \times t}}{\lambda_{eff2}} \right] \quad (5.2)$$

where t = days post uptake

λ_{eff1} for both ^{134}Cs and ^{137}Cs = 0.35/day

λ_{eff2} (134) = 0.0072/day

λ_{eff2} (137) = 0.0064/day

The λ_{eff} values provided above are based on ICRP recommendations. However, for retrospective dose assessments, λ_{eff} values may be empirically determined from whole body counts.

Equations 5.1 and 5.2 are specifically for the calculation of an internal dose equivalent following an acute uptake. In actuality, most uptakes occur following inhalation of airborne contamination and deposition in the lung precedes systemic uptake. Nevertheless, for exposures to readily transportable forms of cesium (class D), the dose received by the lung is negligible in comparison with the total body dose and can generally be ignored for dose assessment purposes. The exception to this is cases where actual retention in the respiratory tract exceeds a few days. In these situations, and as a general application, the CINDY computer code includes the lung in the effective dose equivalent.

5.4.2 Intake-Based Dosimetry Using the ICRP System and the CINDY Computer Code

In contrast to the "total body dose" approach described in the preceding section, the effective dose equivalents for radiocesiums published in the supplement to ICRP 30 (1979b) are based on the summing of weighted doses to specific organs meeting the ICRP criteria for inclusion in the effective dose equivalent (Watson and Ford 1980). Dose factors calculated in this way are slightly higher (about 10%) than those obtained using the total body dose approach, and this difference is attributed to conventions used by the ICRP rather than to technical merit.

The computer code CINDY (Strenge et al. 1992) is used for most internal dose calculations at Hanford. The code employs ICRP 30 methods, biokinetic models, and specific effective energies for radiocesiums. When bioassay data are available, CINDY calculates intake based on the bioassay data and the biokinetic models specified. To obtain internal doses, CINDY calculates the integrated retention for the interval of interest (e.g., 50 years), and then applies the SEE factors to give committed organ and tissue dose equivalents. The weighted organ and tissue doses are summed to give effective dose. Thus, as noted in the previous paragraph, the doses calculated by CINDY for radiocesium intakes are slightly higher than those that might be calculated using the "total body" approach. For a 1-nCi intake of ^{137}Cs, CINDY calculates the following dose coefficients:

Class D inhalation 5-μm-AMAD particles:	0.046 mrem/nCi
Class D inhalation 1-μm-AMAD particles:	0.032 mrem/nCi
Soluble ingestion:	0.050 mrem/nCi

Derived reporting, investigation, and compliance levels (based on $H_{E,50}$ of 10 mrem, 100 mrem, and 5,000 mrem, respectively) have been calculated for 1-µm and 5-µm particle sizes. The derived levels for whole body retention (as might be measured by whole body counting) are shown in Tables 5.5 and 5.6, and the derived levels for daily urine excretion are shown in Tables 5.7 and 5.8.

Table 5.5. ^{137}Cs Whole Body Reference Levels for 1-µm-AMAD Class D Inhalation

		10-mrem $H_{E,50}$ Reporting Level	**100-mrem $H_{E,50}$ Investigation Level**	**5-rem $H_{E,50}$ Compliance Level**
Inhalation Intake (nCi)		313	3,130	156,000
Days Post Intake	**Whole Body IRF(t)**	**Derived Reporting Level (nCi)**	**Derived Investigation Level (nCi)**	**Derived Compliance Level (nCi)**
1	0.62	194	1,940	96,900
2	0.60	188	1,980	93,700
7	0.55	172	1,720	85,900
14	0.52	163	1,630	81,200
30	0.47	147	1,470	73,400
60	0.39	122	1,220	60,900
90	0.32	100	1,000	50,000
180	0.18	56.3	563	28,100
365	0.056	17.5	175	8,750
730	0.0055	1.72	17.2	859
1825	5.1E-06	0.00160	0.0160	0.797

Table 5.6. ^{137}Cs Whole Body Reference Levels for 5-µm-AMAD Class D Inhalation

		10-mrem $H_{E,50}$ Reporting Level	**100-mrem $H_{E,50}$ Investigation Level**	**5-rem $H_{E,50}$ Compliance Level**
Inhalation Intake (nCi)		217	2,170	109,000
Days Post Intake	**Whole Body IRF(t)**	**Derived Reporting Level (nCi)**	**Derived Investigation Level (nCi)**	**Derived Compliance Level (nCi)**
1	0.89	193	1,930	96,700
2	0.86	187	1,870	93,500
7	0.79	172	1,720	85,900
14	0.75	163	1,630	81,500
30	0.68	148	1,480	73,900
60	0.56	122	1,220	60,900
90	0.46	100	1,000	50,000
180	0.26	56.5	565	28,300
365	0.080	17.4	174	8,700
730	0.0079	1.72	17.2	859
1825	7.4E-06	0.00160	0.0160	0.804

Table 5.7. ^{137}Cs Urine Excretion Reference Levels for 1-µm-AMAD Particles

		10-mrem $H_{E,50}$ Reporting Level	100-mrem $H_{E,50}$ Investigation Level	5-rem $H_{E,50}$ Compliance Level
Inhalation Intake (nCi)		313	3,130	156,000
Days Post Intake	**Urine IRF(t)**	**Derived Reporting Level (dpm)**	**Derived Investigation Level (dpm)**	**Derived Compliance Level (dpm)**
1	1.3E-02	9,020	90,200	4,510,000
2	1.3E-02	9,020	90,200	4,510,000
7	4.8E-03	3,330	33,300	1,670,000
14	2.8E-03	1,940	19,400	971,000
30	2.4E-03	1,670	16,700	832,000
60	2.0E-03	1,390	13,900	694,000
90	1.6E-03	1,110	11,100	555,000
180	9.1E-04	631	6,310	316,000
365	2.8E-04	194	1,940	97,100
730	2.8E-05	19	194	9,710
1825	2.6E-08	0.02	0.18	9.02

Table 5.8. ^{137}Cs Urine Excretion Reference Levels for 5-µm-AMAD Particles

		10-mrem $H_{E,50}$ Reporting Level	100-mrem $H_{E,50}$ Investigation Level	5-rem $H_{E,50}$ Compliance Level
Inhalation Intake (nCi)		217	2,170	109,000
Days Post Intake	**Urine IRF(t)**	**Derived Reporting Level (dpm)**	**Derived Investigation Level (dpm)**	**Derived Compliance Level (dpm)**
1	2.1E-02	10,100	101,000	5,070,000
2	1.8E-02	8,690	86,900	4,340,000
7	6.6E-03	3,190	31,900	1,590,000
14	4.0E-03	1,930	19,300	965,000
30	3.4E-03	1,640	16,400	820,000
60	2.8E-03	1,350	13,500	676,000
90	2.3E-03	1,110	11,100	555,000
180	1.3E-03	627	6,270	314,000
365	4.0E-04	193	1,930	96,500
730	4.0E-05	19.3	193	9,650
1825	3.7E-08	0.02	0.18	8.9

5.4.3 Comparison of Dosimetric Factors

The HIDP uses the dose factors of CINDY as the basis for most internal dosimetry applications. However, it is recognized that compilations of dosimetric factors have been made by various scientific and governmental bodies, based on different calculational methods or models. The dose coefficient for unit intake, DAC, and ALI calculated using CINDY, and as tabulated by DOE in 10 CFR 835, Appendix A (DOE 1998), the ICRP in publication 54 (ICRP 1988), the EPA in Federal Guidance Report No. 11 (EPA 1988), and the ICRP in publication 68 (ICRP 1994a) are shown in Table 5.9. Generally speaking, the differences in these tabulated values (with the exception of ICRP 68 inhalation values) are not significant and can be attributed to slightly different computer code algorithms and rounding practices. The ICRP 68 inhalation values, based on the ICRP 66 lung model (ICRP 1994b) and different organ/tissue weighting factors, are approximately a factor of 2 lower than those calculated using the ICRP 30 model. These values are tabulated for information and as a simple reference for the potential impact of dosimetry under different systems.

5.5 Bioassay for Radiocesium

The bioassay techniques, the recommended routine program, and the measurements required for monitoring radiocesium after an acute intake are discussed in the following sections.

5.5.1 Bioassay Method

The presence of ^{137}Cs is detected by gamma spectroscopy using the 0.661-MeV photon of ^{137m}Ba, which is the short half-life ($T_{1/2}$ = 2.5 min) progeny that exists in secular equilibrium with ^{137}Cs. Gamma spectroscopy can be either for in vivo measurements or for excreta analysis. In vivo whole body counting is the preferred method for ^{137}Cs bioassay, due to its simplicity. Urine sample gamma spectroscopy can also be highly effective if in vivo measurements cannot be readily obtained. Fecal sampling is not normally recommended due to the high absorption (theoretically, 100%) in the GI tract. (An exception might occur if a person was being treated with Prussian blue, whereby fecal results would aid in determining efficacy of the treatment.)

Table 5.9. Comparison of ^{137}Cs Dosimetric Factors

Reference Source	Class D Inhalation 1-μm AMAD	Class D Inhalation 5-μm AMAD	Soluble Ingestion
Dose Coefficients			
CINDY ($H_{E,50}$)	0.032 mrem/nCi 8.6E-09 Sv/Bq	0.046 mrem/nCi 1.2E-08 Sv/Bq	0.050 mrem/nCi 1.4E-08Sv/Bq
ICRP 54 ($H_{E,50}$)	8.7E-09 Sv/Bq (0.0322 mrem/nCi)	NA	NA
EPA Federal Guidance Report No.11 ($H_{E,50}$)	8.63E-09 Sv/Bq and 0.0319 mrem/nCi	NA	1.35E-08 Sv/Bq and 0.050 mrem/nCi
ICRP 68 [e(50)]	4.8E-09 Sv/Bq (0.0178 mrem/nCi)	6.7E-09 Sv/Bq (0.0248 mrem/nCi)	1.3E-08 Sv/Bq (0.0481 mrem/nCi)
Stochastic DAC			
10 CFR 835, App. A	7E-08 μCi/ml and 2E+03 Bq/m^3	NA	NA
EPA Federal Guidance Report No. 11	6E-08 μCi/ml and 2E-03 MBq/m^3	NA	NA
ICRP 30, ICRP 54	2E+03 Bq/m^3	NA	NA
Annual Limit on Intake, ALI			
Calculated from 10 CFR 835 DAC	168 μCi and 4.8 MBq	NA	NA
ICRP 30	6 MBq	NA	4 MBq
EPA Federal Guidance Report No. 11	6 MBq and 200 μCi	NA	4 MBq and 100 μCi
NA = not applicable.			

5.5.2 In Vivo Measurements

Hanford whole body counting using a 3-minute count on the 5-NaI detector preview counter currently provides an MDA of 1.3 nCi ^{137}Cs in the body of a male subject of average size. A 10-minute count using the coaxial germanium scanning detector system gives an MDA of about 1.0 nCi. The associated minimum detectable doses for class D inhalation of 1-μm and 5-μm particles are shown in Tables 5.10 and 5.11. Comparing these tables with the derived reference levels of Tables 5.12 and 5.13 shows that whole body counting provides excellent sensitivity for pure ^{137}Cs. For the pure nuclide, an annual whole body count is appropriate bioassay monitoring.

Cesium-137 is also often used as an indicator for other nuclides because of its isotopic abundance in Hanford waste mixtures. For such circumstances, ^{137}Cs whole body counting can be used as an effective monitor for other nuclides (notably ^{90}Sr and plutonium). The dosimetric significance of ^{137}Cs compared with the other nuclides is highly variable, depending on the mixture ratios. Statements of minimum detectable dose for mixtures are beyond the scope of this chapter, and are treated elsewhere in the technical basis documentation (see Appendix E of this manual and the exhibits in Chapter 5.0 of PNL-MA-552).[(a)]

5.5.3 Excreta Analysis

Urine sample gamma spectroscopy can also be used to detect internal radiocesium; however, because of the ease and sensitivity of in vivo detection methods, it is not commonly used for Hanford monitoring. As shown in the minimum detectable dose compilations of Tables 5.14 and 5.15, urinalysis gamma spectrometry can provide excellent bioassay monitoring sensitivity. This sensitivity makes offsite urine sample collection a viable alternative for follow-up measurement of former workers who left the area without obtaining a termination whole body count.

5.5.4 Routine Bioassay Monitoring Protocol

Annual in vivo measurements are recommended for periodic retrospective bioassay monitoring of workers potentially exposed to mixtures of radionuclides containing radiocesium. Even though in vivo measurement capabilities are sufficiently sensitive for a biennial

(a) Pacific Northwest National Laboratory (PNNL). *Hanford Internal Dosimetry Project Manual*. PNNL-MA-552, Richland, Washington. (Internal manual.) Available URL: http://www.pnl.gov/eshs/pub/pnnl552.html

Table 5.10. Minimum Detectable Intakes and Doses ($H_{E,50}$) for 1-µm-AMAD Inhalation Using the NaI Detector System (MDA = 1.3 nCi)

Days Post Intake	Whole Body IRF(t)	Minimum Detectable Intake (nCi)	Minimum Detectable Dose (mrem)
1	0.62	2.1	0.07
2	0.60	2.2	0.07
7	0.55	2.4	0.08
14	0.52	2.5	0.08
30	0.47	2.8	0.09
60	0.39	3.3	0.11
90	0.32	4.1	0.13
180	0.18	7.21	0.23
365	0.056	23	0.74
730	0.0055	240	7.6
1825	5.1E-06	250,000	8,2000

Table 5.11. Minimum Detectable Intakes and Doses ($H_{E,50}$) for 5-µm-AMAD Inhalation Using the NaI Detector System (MDA = 1.3 nCi)

Days Post Intake	Whole Body IRF(t)	Minimum Detectable Intake (nCi)	Minimum Detectable Dose (mrem)
1	0.89	1.5	0.07
2	0.86	1.5	0.07
7	0.79	1.6	0.08
14	0.75	1.7	0.08
30	0.68	1.9	0.09
60	0.56	2.3	0.11
90	0.46	2.8	0.13
180	0.26	5.0	0.23
365	0.08	16	0.75
730	0.0079	170	7.6
1825	7.4E-06	180,000	8,100

Table 5.12. Minimum Detectable Intakes and Doses ($H_{E,50}$) for 1-µm-AMAD Inhalation Using the Coaxial Germanium Detector System (MDA = 1.0 nCi)

Days Post Intake	Whole Body IRF(t)	Minimum Detectable Intake (nCi)	Minimum Detectable Dose (mrem)
1	0.62	1.6	0.05
2	0.60	1.7	0.05
7	0.55	1.8	0.06
14	0.52	1.9	0.06
30	0.47	2.1	0.07
60	0.39	2.6	0.08
90	0.32	3.1	0.10
180	0.18	5.6	0.18
365	0.056	18	0.57
730	0.0055	180	5.8
1825	5.1E-06	200,000	6,300

Table 5.13. Minimum Detectable Intakes and Doses ($H_{E,50}$) for 5-µm-AMAD Inhalation Using the Coaxial Germanium Detector System (MDA = 1.0 nCi)

Days Post Intake	Whole Body IRF(t)	Minimum Detectable Intake (nCi)	Minimum Detectable Dose (mrem)
1	0.89	1.1	0.05
2	0.86	1.2	0.05
7	0.79	1.3	0.06
14	0.75	1.3	0.06
30	0.68	1.5	0.07
60	0.56	1.8	0.08
90	0.46	2.2	0.10
180	0.26	3.8	0.18
365	0.08	13	0.58
730	0.0079	130	5.8
1825	7.4E-06	140,000	6,200

Table 5.14. Minimum Detectable Intakes and Doses ($H_{E,50}$) for 1-µm-AMAD Inhalation Using Urinalysis Gamma Spectrometry (MDA = 15 dpm/1)

Days Post Intake	Urine IRF(t)	Minimum Detectable Intake (nCi)	Minimum Detectable Dose (mrem)
1	1.3E-02	0.7	0.02
2	1.3E-02	0.7	0.02
7	4.8E-03	2.0	0.06
14	2.8E-03	3.4	0.11
30	2.4E-03	3.9	0.13
60	2.0E-03	4.7	0.15
90	1.6E-03	5.9	0.19
180	9.1E-04	10.4	0.33
365	2.8E-04	34	1.08
730	2.8E-05	338	10.8
1825	2.6E-08	364,000	11,600

Table 5.15. Minimum Detectable Intakes and Doses ($H_{E,50}$) for 5-µm-AMAD Inhalation Using Urinalysis Gamma Spectrometry (MDA = 15 dpm/1)

Days Post Intake	Urine IRF(t)	Minimum Detectable Intake (nCi)	Minimum Detectable Dose (mrem)
1	2.1E-02	0.5	0.02
2	1.8E-02	0.5	0.02
7	6.6E-03	1.4	0.07
14	4.0E-03	2.4	0.11
30	3.4E-03	2.8	0.13
60	2.8E-03	3.4	0.16
90	2.3E-03	4.1	0.19
180	1.3E-03	7	0.33
365	4.0E-04	24	1.1
730	4.0E-05	236	11
1825	3.7E-08	256,000	11,800

frequency, the longer time between measurements makes investigation of potential exposures more difficult, and thus a minimum annual frequency is recommended.

If radiocesium is detected through a routine measurement, then follow-up measurements to confirm the initial indication should generally be performed. Follow-up measurements can usually be most conveniently performed immediately following the initial measurement, while the subject is at the In Vivo Radioassay and Research Facility (IVRRF). Follow-up measurements should be performed as promptly as practical following an indication of an intake in order to facilitate any health physics investigation associated with the potential exposures. However, because of the high sensitivity of the in vivo measurement, verification measurements for cesium are not appreciably affected by delays of a few days to a month in obtaining them.

Follow-up in vivo measurements using high-resolution germanium detectors are preferred for identifying other radionuclides possibly associated with the exposure, to discriminate against interference from radon progeny, and because the germanium detectors provide a more precise and accurate measurement. In addition to follow-up in vivo measurements, special bioassay should be considered for other significant nuclides (e.g., ^{90}Sr or plutonium urinalysis, plutonium fecal analysis), if ^{137}Cs is a mixture indicator nuclide.

5.5.5 Bioassay Measurements Following an Acute Intake

An in vivo examination should be performed after any indication of an intake of radiocesium. Unless the exposure appears to be of such magnitude that medical treatment to aid its removal is considered, the exam may be scheduled as convenient within several days of the intake, without significantly compromising the dosimetric sensitivity of the measurement. Appropriate bioassay for all significant radionuclides potentially involved in the exposure should be considered in the follow-up investigation. Because of the wide range of waste mixtures in Hanford facilities, a standard default mixture is no longer used for general internal dosimetry. In the event of an exposure, the composition of the source mixture should be determined by appropriate analysis of a representative sample of the material, or alternatively, special bioassay for the appropriate specific nuclides should be performed.

The interpretation of in vivo measurements performed shortly after intake may be complicated by early transport of material through the lung and GI tract. Measurements performed after about 5 days post intake are more appropriate for dose evaluation. For intakes

potentially above a 100-mrem committed effective dose equivalent (considering all radionuclides contributing), long-term follow-up bioassay measurements should be considered to monitor internal radioactivity levels and establish individual retention characteristics.

5.6 Assessment of Internal Dose Equivalent

The assessment of the internal dose equivalent from ^{137}Cs is normally accomplished by evaluation of in vivo measurement results. Committed dose equivalents are assessed for any confirmed internal exposure not attributed to environmental or other nonoccupational sources.

Assessed committed effective dose equivalents below 100 mrem may be based on a single bioassay measurement and the standard biokinetic models described in this chapter. Assessments of internal dose equivalent that potentially exceed a committed effective dose equivalent of 100 mrem should be based on observed retention to the extent practicable. The ICRP 30 model for uptake and retention of cesium was described previously. The rapidly clearing compartment has little effect on the total dose equivalent received from an intake and can be ignored in retrospective dose assessments based on observed in vivo retention. As an alternative approach, default biokinetic assumptions about internal deposition and retention of cesium can be modified to obtain a better fit between the observed retention data and the model. The modified model can then be used to calculate dose equivalents. CINDY can be used for this intake and dose assessment, or if based on limited bioassay data, the tabulated values of this chapter can be used in conjunction with the basic formulas of Chapter 2.0.

Because cesium distributes relatively uniformly in the body, the dose received by individual organs and tissues is about the same as the effective dose equivalent. To simplify the recording of doses to specific organs and tissues, the dose to uniformly distributed radionuclides is ascribed to a single organ category called “total body.” That is, assessments of exposure to radiocesium will include the committed effective dose equivalent, which is equivalent to the total body dose equivalent, which, in turn, is equivalent to the dose received by any organ. The “total body” designation thus serves as a surrogate for any specific organ or tissue in the body.

5.7 Management of Internal Contamination Cases

Although one of the most abundant radionuclides at Hanford, historically ^{137}Cs has not contributed significantly to internal doses. Cesium-137 is easily detected by whole body counting and therefore

early measurements can result in fairly rapid intake and dose assessments. Primary considerations that might cause some difficulty for interpretation of initial in vivo measurements are possible external contamination on the subject, the rapid translocation and elimination that occurs shortly after intake, and the possibility of a nonoccupational source.

Being a major fission product radionuclide, ^{137}Cs is often accompanied by other fission product radionuclides. Thus, investigation of internal exposures involving ^{137}Cs should also consider that other radionuclides may be involved.

The most effective measure for removal of cesium from the body is by oral administration of Prussian blue. Prussian blue is a drug that must be administered by competent medical authorities. Prussian blue is not absorbed from the intestine and it binds the cesium ions that are enterically cycled into the GI tract, so that the cesium is not reabsorbed. The treatment can reduce the biological half-life to about one-third of its usual value. The effectiveness of the treatment depends on how soon after exposure it is started (NCRP 1980). Bhattacharyya et al. (1992) recommended administrations of 3 to 4 g of Prussian blue in water orally divided over three doses per day, continued for as long as effective. Significant human experience with Prussian blue therapy resulted from the Goiania, Brazil accident in which several members of the public incurred very high ^{137}Cs intakes when a medical therapy machine was stolen for salvage and the source was unknowingly opened (IAEA 1988). Dunstana et al. (1994) reported dose reductions of 51 to 84% based on orally administered dosages of Prussian blue from 3 to 10 g/d. An excellent case study of this accident, the associated dosimetry, and the medical case management is described by the International Atomic Energy Agency (IAEA 1998). The IAEA report includes a large citation of references appropriate for case management.

5.8 References

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