

SECTION 5.0

CESIUM

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This section provides technical information on the sources, characteristics, and biokinetics of radiocesium and summarizes the technical basis used for its internal dosimetry at Hanford.

5.1 SOURCES AND CHARACTERISTICS OF RADIOCESIUM

The most important radionuclides of cesium at Hanford from an internal exposure standpoint are ^{134}Cs and ^{137}Cs . Cesium-137 ($T_{1/2} = 30.0$ yr), a fission product, is the primary cesium isotope of interest with respect to internal exposure. Cesium-134 ($T_{1/2} = 2.1$ yr), produced by neutron activation of ^{133}Cs (stable), is usually observed at activities on the order of less than 5% of the ^{137}Cs activity.

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 thus serves as a good indicator of internal exposure to fission products.

In addition to its presence in fission product mixtures, ^{137}Cs exists in relatively pure form at the waste fractionation facility (B-Plant) and the WESF. Encapsulation programs in 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 internal exposure situations involving ^{137}Cs and ^{90}Sr , ^{137}Cs will constitute the major component of intake. In cases where it is suspected that ^{90}Sr may be present along with ^{137}Cs but no radionuclide ratio information exists, it is prudent to consider the $^{137}\text{Cs}/^{90}\text{Sr}$ activity ratio to be 1.0 and to determine the need for specific assessment of strontium exposure accordingly.

5.2 BIOKINETIC BEHAVIOR OF RADIOCESIUM

ICRP 30 (1979) classifies all isotopes of cesium as 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 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. The soluble nature of cesium makes aerosol particle size of little importance from a bioassay and dosimetric standpoint. For purposes of biokinetic modeling, airborne particulates are assumed to have an AMAD of 1 μm .

ICRP 30 recommends the following equation for the retention of cesium following systemic uptake:

$$r_s^a(t) = 0.1 \exp\left(-\frac{0.693t}{2}\right) + 0.9 \exp\left(-\frac{0.693t}{110}\right) \quad (5.1)$$

where $r_s^a(t)$ is the fraction of the initial uptake that is present in the body at t days post uptake.

5.3 INTERNAL DOSIMETRY FOR RADIOCESIUM

Because cesium is assumed to be distributed evenly throughout soft tissues in the body, the stochastic dose equivalent (effective dose equivalent) will be limiting for compliance purposes. Dose conversion factors for the radiocesiums were developed by Snyder et al., and published in ORNL-5000 (1975). 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 computer code GENMOD is used for internal dose calculations at Hanford (Johnson and Carver 1981; see Appendix A). The

code employs the dose factors in ORNL-5000 for radiocesiums and the biokinetic model of the ICRP. In contrast, effective dose equivalents for radiocesiums calculated and published in supplements to ICRP 30 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 GENMOD and this difference is attributed to conventions used by the ICRP rather than to technical merit. Thus, the use of total body dose factors is considered to be more appropriate for assessing effective dose equivalent to radiocesiums. These dose factors, from ORNL-5000, are

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

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

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 yields the cumulated internal activity in activity-days, and multiplying this times the DCF and the initial uptake (U_0) yields the effective dose equivalent over the time period of interest:

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

where t = days post initial deposition

$$\lambda_{\text{eff1}} (134) = 0.35/\text{day}$$

$$\lambda_{\text{eff1}} (137) = 0.35/\text{day}$$

$$\lambda_{\text{eff2}} (134) = 0.0072/\text{day}$$

$$\lambda_{\text{eff2}} (137) = 0.0064/\text{day}$$

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 as described in Section 5.4.

Equations 5.1 and 5.2 are specifically for the calculation of internal dose equivalent following acute uptakes of ^{134}Cs or ^{137}Cs . 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 to the total body dose and can generally be ignored for dose assessment purposes. The exception to this is in cases where actual retention in the respiratory tract exceeds a few days. In these situations, and as a general application, the computer code GENMOD includes the lung in the effective dose equivalent.

Table 5.1 gives the first-year and 50-year committed effective dose equivalents following an intake or uptake of radiocesium calculated using Equation 5.2. About 90% of the 50-year committed effective dose equivalent is received within the first year after intake.

Table 5.2 gives the activity of ^{134}Cs and ^{137}Cs in the body following an uptake sufficient to result in a first-year effective dose equivalent of 10 mrem. The table also gives the internal activity of ^{137}Cs following an intake of equal activities of ^{137}Cs and ^{90}Sr resulting in a first-year

TABLE 5.1. Predicted Effective Dose Equivalent Resulting from an Inhalation^(a,b) or Uptake of Radiocesium, mrem/nCi

Nuclide	First-Year Effective Dose Equivalent		50-Year Committed Dose Equivalent	
	Inhalation		Inhalation	
	Intake	Uptake	Intake	Uptake
^{134}Cs	0.043	0.068	0.046	0.073
^{137}Cs	0.026	0.041	0.028	0.045

- (a) Assuming an inhalation of class D, 1- μm -AMAD aerosol.
 (b) Organ dose equivalents are assumed to be the same as the effective dose equivalent.

TABLE 5.2. Total Body Activity Following an Acute Uptake or Class D Inhalation Intake Resulting in a First-Year Effective Dose Equivalent of 10 mrem

<u>Days Post Uptake</u>	<u>Activity in Body, nCi</u>		
	<u>^{134}Cs (a)</u>	<u>^{137}Cs (b)</u>	<u>$^{137}\text{Cs} + ^{90}\text{Sr}$ (c)</u>
1	144	240	110
2	140	230	100
7	130	210	95
14	120	200	90
30	110	180	81
60	86	150	67
90	69	120	55
180	36	70	31
365	9.5	22	9.6
730	0.7	2.1	0.9

(a) Inhalation intake = 230 nCi ^{134}Cs .

(b) Inhalation Intake = 390 nCi ^{137}Cs .

(c) Total ^{137}Cs in body following an inhalation intake of 170 nCi $^{137}\text{Cs} + 170$ nCi ^{90}Sr .

effective dose equivalent of 10 mrem. This information is presented graphically in Figure 5.1. Because fission product mixtures may include ^{90}Sr , as well as ^{137}Cs , the detection of the presence of ^{137}Cs in the body should be regarded as an indication of a potential exposure to ^{90}Sr as well. Thus, if internal levels exceed those for cesium/strontium in Table 5.2, bioassay measurement and assessment for ^{90}Sr as described in Section 4.0 is recommended. Consideration should be given to the individual's routine bioassay monitoring schedule for ^{90}Sr when deciding action to be taken regarding ^{90}Sr bioassay following detection of ^{137}Cs in the body.

The ICRP 30 annual limits on intake (ALIs) for class D ^{137}Cs and ^{134}Cs are 200 μCi and 100 μCi , respectively.

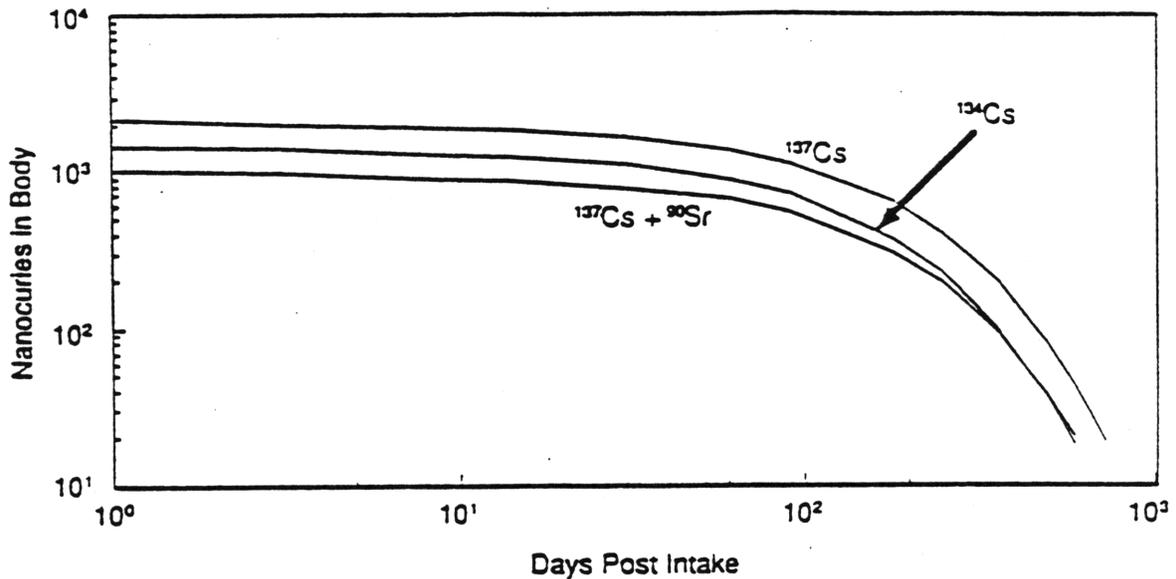


FIGURE 5.1. Activity in Body Following an Uptake Resulting in a First-Year Effective Dose Equivalent of 100 mrem

5.4 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 subsections.

5.4.1 Bioassay Methods

The presence of radiocesium is detected by in vivo measurements and in some cases excreta analysis.

In Vivo Measurements

Whole body counting using the 5-NaI detector preview counter for a 3-minute count will detect the presence of 3 nCi of ¹³⁷Cs in the body of a male subject of average size (Palmer et al. 1990).

Table 5.3 summarizes the capability of a standard whole body count for various times after a single acute intake. From the table, it is evident that an annual in vivo measurement with a detection level of 3 nCi for ¹³⁴Cs or ¹³⁷Cs would be capable of detecting an intake resulting in an annual or a committed effective dose equivalent of less than 4 mrem. Similarly, an intake

TABLE 5.3. Bioassay Detection Capability for an Acute Intake of ^{134}Cs or ^{137}Cs (a)

Days Post Intake	First-Year and Fifty-Year Committed Effective Dose Eq., mrem					
	^{134}Cs		^{137}Cs		$^{137}\text{Cs} + ^{90}\text{Sr}$ (b)	
	$H_{E,1}$	$H_{E,50}^C$	$H_{E,1}$	$H_{E,50}^C$	$H_{E,1}$	$H_{E,50}^C$
30	0.27	0.29	0.17	0.19	0.37	1.6
90	0.43	0.47	0.24	0.26	0.54	2.3
180	0.83	0.90	0.43	0.46	0.96	4.1
365	3.2	3.4	1.4	1.5	3.1	13.0
730	43.0	46.0	14	15	32	14

(a) Detectable dose for a single intake of class D, 1- μm -AMAD particles based on an MDA of 3 nCi.

(b) Assuming equal intakes of ^{137}Cs and ^{90}Sr .

involving a 1:1 mixture of ^{137}Cs and ^{90}Sr would be detectable at the 13-mrem committed effective dose equivalent level.

Excreta Analysis

Urine measurements may be used to detect internal cesium; however, because of the sensitivity of in vivo detection methods, there are no likely circumstances where urine sampling will improve the sensitivity or accuracy of internal dose assessment. Urine sampling for ^{90}Sr should be considered if there is reason to suspect its presence along with cesium.

5.4.2 Routine Bioassay Monitoring Program

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 frequency (see Table 5.3), 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 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, confirmatory measurements are technically capable of detecting a 100-mrem first-year effective dose equivalent for up to 3 years following the intake.

Follow-up in vivo measurements using high-resolution germanium detectors are preferred in order to identify other radionuclides possibly associated with the exposure and because the germanium detectors are considered to provide a more precise and accurate measurement. Detection capabilities for the germanium detectors are comparable to those obtained using the preview counter (Palmer et al. 1990). In addition to follow-up in vivo measurements, urinalysis for ^{90}Sr should be considered if internal levels of ^{137}Cs exceed those shown for the cesium/strontium mixture in Table 5.2.

5.4.3 Bioassay Measurements Following an Acute Intake

An in vivo examination should be performed following any indication of an intake of radiocesium. Unless the exposure appears to be of such magnitude that medical treatment to aid removal is considered, the exam may be scheduled as convenient within several days of the intake. All radionuclides potentially involved in the exposure should be considered in the follow-up investigation. Urinalysis for ^{90}Sr should also be considered.

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 100 mrem/yr (considering all radionuclides contributing), long-term follow-up bioassay measurements should be considered to monitor internal radioactivity levels and establish individual retention characteristics.

For the purposes of determining the dose from a radiocesium intake, excreta analysis is generally not necessary.

5.5 ASSESSMENT OF INTERNAL DOSE EQUIVALENT

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

Table 5.2 provides whole body count levels for several routine in vivo monitoring frequencies that could be expected following an inhalation intake resulting in a first-year effective dose equivalent of 100 mrem. The values in the table were calculated assuming a single acute inhalation intake. The table provides values for ^{134}Cs , ^{137}Cs , and a mixture of ^{137}Cs and ^{90}Sr ; and it was assumed that the inhaled aerosol consisted entirely of class D particulate with an AMAD of 1 μm . Because ^{137}Cs is often associated with mixtures of fission product radionuclides, it is prudent, upon the initial review of bioassay measurement results, to assume that the intake consisted of a mixture of ^{137}Cs and ^{90}Sr with an activity ratio of 1.0. Assessment of internal deposition of ^{90}Sr using urinalysis is recommended when ^{137}Cs levels are above those shown in Figure 5.1 for intakes of cesium/strontium mixtures. This conservative approach is not necessary when it is known that only ^{137}Cs is available for intake or when actual ^{90}Sr urinalysis results are available.

Equations 5.3a and 5.3b give the 50-year committed effective dose equivalent, $H_{E,50}^C$ for ^{134}Cs and ^{137}Cs as a function of total body activity, $Q(t)$, at time t post intake.

$$H_{E,50}^C(^{134}\text{Cs}) = 0.073 \cdot Q(t) / r_s^a(t) \text{ mrem} \quad (5.3a)$$

$$H_{E,50}^C(^{137}\text{Cs}) = 0.045 \cdot Q(t) / r_s^a(t) \text{ mrem} \quad (5.3b)$$

where $r_s^a(t)$ is the retention function given by Equation 5.1.

The equation is appropriate for use to assess internal dose equivalents for radiocesium intakes that do not exceed 100 mrem/yr. It is also appropriate for the assessment to assume, in the absence of a known date of intake, that the intake was an acute inhalation occurring at the midpoint of the

period during which an intake is considered to be possible. Thus, for an annual routine in vivo measurement, a positive ^{137}Cs result would be assessed assuming the intake occurred 6 months prior to the measurement. For assessments involving intake times not shown in the table, doses may be calculated using the GENMOD code.

Assessments of internal dose equivalent that potentially exceed an annual effective dose equivalent of 100 mrem/yr should be based on observed retention to the extent practicable. The ICRP 30 model for uptake and retention of cesium has been 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. Cumulated activity, obtained by integrating the observed retention curve based on repeated in vivo measurements, is multiplied by the DCF given for Equation 5.2 to obtain the effective dose equivalent for the period covered. As an alternative approach, default biokinetic assumptions regarding 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 is then used to calculate annual dose equivalents. The computer code GENMOD is used for this type of assessment.

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 annual effective dose equivalent, which is the weighted composite organ dose equivalent, and the total body dose equivalent, which is the dose received by any organ. The total body dose equivalent is numerically equal to the effective dose equivalent. The "total body" designation thus serves as a surrogate for any specific organ or tissue in the body.

5.6 MANAGEMENT OF INTERNAL CONTAMINATION CASES

Although one of the most prevalent radionuclides at Hanford, historically ^{137}Cs has not contributed significantly to internal exposures.

Cesium-134+137 are easily detected by whole body counting and therefore early measurement and assessment of internal depositions can be made readily. Primary considerations for interpretation of initial in vivo measurements are possible external contamination on the subject and the rapid translocation and elimination that occurs shortly after intake.

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 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 is dependent on how soon after exposure it is started (NCRP 1980).

5.7 ENVIRONMENTAL LEVELS OF CESIUM

Cesium-137 is present throughout the world environment as a result of atmospheric testing of nuclear weapons and releases from the 1986 Chernobyl nuclear accident in the 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 Chernobyl accident, levels of ^{137}Cs were widely reported in the literature (for example, 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 wide attention following the Chernobyl accident. In 1989 the joint World Health Organization/Food and Agriculture Organization established a guideline level of 1000 Bq/kg (27 nCi/kg) for cesium contamination in foods moving in international trade (Health Physics 1989).

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 consume large wild game on a regular basis 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 and these data indicate over 3 orders of magnitude of variability.

Likewise, for a worker who has spent time in a location known to be potentially affected by elevated cesium levels (e.g., Europe, the 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.

For unknown sources of intake and circumstances where occupational intake seems unlikely, it may be prudent to estimate a dose as a matter of interest for the worker but not to assign it as an occupational dose. However, it should be emphasized that nonoccupational estimates based on measurements likely to be available through a routine occupational monitoring program are subject to large uncertainties regarding onset, duration, and nature of intake, and that standard assumptions used for occupational assessment are not necessarily applicable. Any in-depth assessment of nonoccupational exposure is usually beyond the scope of an occupational monitoring program.