6.0 Strontium

This chapter provides technical information on the sources of radiostrontium and its characteristics, and summarizes the technical basis used for its internal dosimetry at Hanford. Dosimetry methods used are based on the concepts of ICRP 30 (1979), as implemented using the CINDY computer code (Strenge et al. 1992). Because of its long radiological half-life, ^{90}Sr (with its secular equilibrium progeny ^{90}Y) is now the strontium isotope of significance at Hanford. Some information for the short-lived ^{89}Sr is also included here for historical purposes. A summary of the ^{90}Sr dosimetric data is tabulated in Table 6.1. A brief history of the strontium evaluation methods used at Hanford is also provided. Details are provided in the following sections.

Table 6.1. Summary of ^{90}Sr Hanford Dosimetric Data

Systemic Excretion Fractions		
Urine:	0.8	
Feces:	0.2	
Chemical Form:	All Forms except Sr-Titanate	Titanate
Inhalation Model	Class D (default)	Class Y
GI Absorption (f_1)	0.3	0.01
Committed Effective Dose Coefficients		
1-μm AMAD Inhalation	0.22 mrem/nCi	1.3 mrem/nCi
5-μm AMAD Inhalation	0.27 mrem/nCi	0.48 mrem/nCi
Ingestion	0.13 mrem/nCi (soluble)	0.011 mrem/nCi (insoluble)
Transportable Injection	0.41 mrem/nCi	Not applicable

6.1 Sources and Characteristics of Strontium at Hanford

The isotopes of dominant concern for strontium internal dosimetry are ^{90}Sr and its decay product ^{90}Y. These nuclides may be found in almost any Hanford facility that deals with fission products or fission product waste mixtures. Most facilities that have strontium may also be expected to have other fission products present, notably ^{137}Cs, and it is a common practice to use ^{137}Cs as an indicator of potential ^{90}Sr. This can be a valid assumption, because both nuclides have comparable yields from the fissioning of ^{235}U (see Table 6.2). However, it must be noted that some Hanford chemical processes have separated cesium from strontium, and relatively pure ^{90}Sr may be associated with laboratories, waste separation facilities (notably B-Plant, [221-B]) and the Waste Encapsulation and Storage Facility (WESF, [225-B Building]), and waste storage tank sludge.

Table 6.2. ^{90}Sr Fission Product Yields[(a)]

Fissionable Nuclide	FP Mass 90,%	FP Mass 137,%
^{233}U	6.9	6.81
^{235}U	5.91	6.22
^{239}Pu	2.11	6.7
(a) From General Electric Co. (1983)		

Thus, caution must be exercised because the ^{90}Sr/^{137}Cs ratio is highly variable between and within facilities. This use of a ratio can be valid if the nature of facility contamination is known.

When Hanford reactors were operating, the potential existed for ^{89}Sr to also be a concern, most likely at N-Reactor, the fuel storage basins, FFTF, or the Plutonium-Uranium Extraction (PUREX) Plant. However, the short radiological half-life of ^{89}Sr (50 days) and the long time that has elapsed since reactors operated indicates that ^{89}Sr is no longer a concern at Hanford, unless a new source (e.g., material received from offsite) is established. The ORIGEN computer code (Hedengren 1985) indicated that, for N-Reactor, 6%, Mark IV (MKIV) fuel at discharge, there might have been about 90 times as much ^{89}Sr as ^{90}Sr. Exposure to such material would have been more limiting in terms of internal dose than exposure to just ^{90}Sr. But because of the rapid decay of ^{89}Sr, within about 6 months ^{90}Sr became the dominant isotope of concern. Less than 1% of the ^{89}Sr produced in fuel remained at 1 year after exposure, and, for practical purposes, that nuclide ceased to be a dosimetric concern by that time.

Selected decay data for ^{90}Sr, ^{90}Y, and ^{89}Sr are shown in Table 6.3.

Table 6.3. Decay Data for Strontium Isotopes

Parameter	^{90}Sr	^{90}Y	^{89}Sr
Half-Life	29.12 y	64.0 h	50.5 d
Decay Constant	6.5E-05 d^{-1}	0.26 d^{-1}	0.014 d^{-1}
Decay Mode	Beta (no gamma)	Beta (no gamma)	Beta (no gamma)

For most internal dosimetry purposes, ^{90}Sr and ^{90}Y are the nuclides of concern. These nuclides are found in equilibrium in virtually all circumstances under which exposure is likely. Although strontium separation operations have been performed in which pure ^{90}Sr might be obtained, the rapid ingrowth of the ^{90}Y decay product results in the secular equilibrium condition being achieved within about 2 weeks after separation. Thus, even if an exposure to pure ^{90}Sr

occurred involving significant metabolic uptake and internal deposition, within about 2 weeks of exposure equal quantities of both nuclides would be present in the body. Pure ^{90}Y was produced and packaged in the 325 Building during the 1990s (through 1999).

6.2 Environmental Levels of ^{90}Sr

Daily dietary intake of ^{90}Sr is estimated to range from 0.1 to 0.4 Bq/d (San Francisco to New York) according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1982, p. 231). Higher intakes of about 8 to 11 pCi/d were reported by Stroube, Jeline, and Baratta (1985). The concentration in milk may run from 0.04 to 0.2 Bq/l. A brief note by Irlweck and Streit (1979) indicated that normal background ^{90}Sr in urine levels for Austria ranged from 0.2 to 2 pCi/l, which would correspond to 0.6 to 6 dpm/day for an ICRP Reference Man excretion rate of 1.4 l/d. These levels were attributed to worldwide fallout and natural variability. They suggested a screening level of 5 pCi/l (15 dpm/d) as a basis for assuming intake from sources other than worldwide fallout. Correcting these levels for an additional 20 years of physical radiological decay suggests a current daily excretion range of 0.4 to 4 dpm/d with their proposed screening level for identifying an unusual intake of 10 dpm/d. A detailed study of background ^{90}Sr in the urine of unexposed Hanford workers is in progress.

6.3 Biokinetic Behavior of Radiostrontium

The biokinetic behavior of strontium is a composite of the intake mode, the chemical form, the inhalation class, the internal distribution and retention, the excretion, and the radiological half-life of the strontium isotope. The basic models used for Hanford internal dosimetry are those of ICRP 30, as implemented using CINDY.

6.3.1 Inhalation Class

All intakes of strontium at Hanford are considered to be inhalation class D, in accordance with the recommendations of ICRP 30. It is noted that strontium titanate is the only compound identified by the ICRP as belonging to inhalation class Y (Anderson et al. 1999). However, that compound of strontium has not been used at Hanford.

Waste management practices involving strontium fluoride (SrF_2) are of particular interest from an internal dosimetry perspective, because SrF_2 was not specifically included in the ICRP lung model descriptions of strontium compounds. The waste fractionation process separated and purified ^{90}Sr at B-Plant, and then converted it into SrF_2 powder, which was encapsulated into welded cylinders at

WESF. The cylinders remain stored in a water pool at WESF. The SrF_2 powder was selected as the chemical form because of its chemical stability and only moderate solubility (i.e., its relative insolubility). This relative insolubility and lack of specific discussion in the ICRP lung model might be cause for considering SrF_2 to be a class W or Y material. However, this is not thought to be the case. While solubility studies for SrF_2 in simulated lung fluid have not been identified, SrF_2 is only moderately soluble on a large scale, having a solubility product of 3.5×10^{-4} mg/l. A different picture emerges upon consideration of the microscopic scale, as might be encountered in human intakes. Because of the very high specific activity of ^{90}Sr, dosimetrically significant quantities of SrF_2 powder have extremely small masses that come no where near the solubility product and thus are very quickly dissolved in a small volume of fluid as might be found in the lung or GI tract. Hence, $^{90}SrF_2$ would be expected to exhibit class D behavior upon intake.

6.3.2 Uptake to Blood

The absorption coefficient (f_1) used for the GI tract absorption of readily transportable (inhalation class D) forms of strontium is 0.3, which is consistent with the recommendations of ICRP publications 30 (1979), 56 (1989), 67 (1993), and 78 (1997). Those publications note that the normal range of the absorption coefficient is 0.15 to 0.45, and fasting for 24 hours can elevate it to 0.25 to 0.55. Suggested values for infants and children (age 1 to 15) are 0.6 and 0.4, respectively.

Where evaluation of poorly transportable (class Y) forms may be required, the ICRP 30 value of 0.01 will be used.

6.3.3 Internal Distribution and Retention

The biokinetic model used for the distribution, retention, and excretion of stable strontium is the ICRP alkaline earth model (1973; 1979) as implemented by the CINDY computer code. It is assumed that stable strontium is uniformly distributed throughout the bone volume, where it is retained and internally recycled according to a series of exponential terms modeled by Johnson and Myers (1981), which show good agreement with the ICRP alkaline earth model.

More recent models for strontium distribution have been developed by Leggett, Eckerman, and Williams (1982), Leggett et al. (1984), and Leggett (1992) and are featured in ICRP 56, 67, and 78. These models have different formulations that cannot be readily adapted to CINDY, and were developed to allow for age-dependent parameters

for assessment of doses for age groups ranging from infant to adult. The ICRP 30 approach used by CINDY is adequate at this time for assessment of occupational exposure to adult workers.

For dosimetry purposes, it is assumed that the intake is the pure isotope of ^{90}Sr. The dose contribution from any ^{90}Y present at the time of intake due to equilibrium with the ^{90}Sr parent makes no significant difference in the total dose.

6.3.4 Excretion of Strontium

The alkaline earth excretion model assumes that the fraction of excreted uptake occurring by the urinary pathway and by the fecal pathway is 0.8 and 0.2, respectively. This is consistent with past Hanford practices and the recommendations of ICRP 30, 56, 67, and 78. CINDY incorporates this pathway fractionation into its algorithms.

Urine sample analysis is the easiest and most common bioassay method for both ^{89}Sr and ^{90}Sr, and therefore the urinary excretion function becomes the key for internal dosimetry evaluations of strontium. The CINDY ^{90}Sr urinary excretion function is used in this technical basis for strontium evaluations. The CINDY urinary excretion function is identical to that of the GENMOD code formerly used by the Hanford Internal Dosimetry Program and similar to excretion derived from the Dolphin model, which was used prior to 1989 (Sula, Carbaugh, and Bihl 1989).

Urine and feces excretion fractions, respectively, are shown in Tables 6.4 and 6.5 for class D and Y inhalations of 1-μm- and 5-μm-AMAD particles, soluble ingestion, and transportable injection (wound) intakes. For readily transportable injection intakes (i.e., wounds), the total uptake to blood occurs very quickly. In these cases, the calculated intake and uptake are essentially synonymous. For a class D inhalation, the only significant difference from a transportable injection excretion function is the ratio of total uptake to total intake (0.52 for 1-μm, class D particles), where total uptake includes the contributions from both the respiratory and GI tracts. For class Y material, the uptake to blood occurs over a long period, nominally characterized by the clearance rate from the lung. Figure 6.1 illustrates the urine excretion fractions for inhalation of 5-μm class D and class Y particles. As is apparent in Figure 6.1, urinary excretion following an acute class Y intake can be expected to be relatively constant from about 50 to 1000 days post intake.

Table 6.4. ^{90}Sr Urine Excretion Fractions

Days Post Intake	1-µm-AMAD Class D Inhalation (f_1 = 0.3)	5-µm-AMAD Class D Inhalation (f_1 = 0.3)	Soluble Ingestion (f_1 = 0.3)	Transportable Injection (f_1 = 0.3)	1-µm-AMAD Class Y Inhalation (f_1 = 0.01)	5-µm-AMAD Class Y Inhalation (f_1 = 0.01)
1	4.8E-02	5.5E-02	2.6E-02	8.3E-02	8.4E-04	1.7E-03
2	3.8E-02	4.4E-02	2.0E-02	6.6E-02	6.4E-04	1.2E-03
7	1.5E-02	1.7E-02	7.9E-03	2.6E-02	2.5E-04	4.7E-04
14	4.8E-03	5.7E-03	2.6E-03	8.6E-03	9.1E-05	1.6E-04
30	5.5E-04	6.6E-04	3.0E-04	1.0E-03	2.1E-05	2.2E-05
60	1.6E-04	1.9E-04	8.9E-05	3.0E-04	1.5E-05	9.3E-06
90	1.2E-04	1.5E-04	7.1E-05	2.4E-04	1.5E-05	8.4E-06
180	7.6E-05	9.3E-05	4.3E-05	1.4E-04	1.4E-05	7.0E-06
365	3.8E-05	4.7E-05	2.2E-05	7.3E-05	1.4E-05	5.9E-06
730	1.6E-05	2.0E-05	9.4E-06	3.1E-05	1.3E-05	4.9E-06
1825	5.9E-06	7.3E-06	3.4E-06	1.1E-05	7.5E-06	2.8E-06
3650	3.1E-06	3.8E-06	1.8E-06	5.8E-06	2.4E-06	9.4E-07
7300	1.1E-06	1.3E-06	6.2E-07	2.1E-06	3.0E-07	1.3E-07
18250	1.4E-07	1.7E-07	8.1E-08	2.7E-07	1.8E-08	9.9E-09

Table 6.5. ^{90}Sr Fecal Excretion Fractions

Days Post Intake	1-µm-AMAD Class D Inhalation (f_1 = 0.3)	5-µm-AMAD Class D Inhalation (f_1 = 0.3)	Soluble Ingestion (f_1 = 0.3)	Transportable Injection (f_1 = 0.3)	1-µm-AMAD Class Y Inhalation (f_1 = 0.01)	5-µm-AMAD Class Y Inhalation (f_1 = 0.01)
1	6.3E-02	1.4E-01	3.4E-01	2.1E-02	1.3E-01	2.5E-01
2	4.0E-02	8.4E-02	2.0E-01	1.7E-02	1.5E-01	2.9E-01
7	3.9E-03	4.9E-03	3.6E-03	6.5E-03	5.4E-03	5.7E-03
14	1.2E-03	1.4E-03	6.6E-04	2.1E-03	1.9E-04	1.0E-04
30	1.4E-04	1.6E-04	7.6E-05	2.5E-04	1.4E-04	5.2E-05
60	3.9E-05	4.8E-05	2.2E-05	7.4E-05	1.4E-04	4.7E-05
90	3.1E-05	3.8E-05	1.8E-05	5.9E-05	1.2E-04	4.5E-05
180	1.9E-05	2.3E-05	1.1E-05	3.6E-05	1.1E-04	3.9E-05
365	9.5E-06	1.2E-05	5.5E-06	1.8E-05	8.4E-05	3.0E-05
730	4.1E-06	5.1E-06	2.3E-06	7.8E-06	5.1E-05	1.8E-05
1825	1.5E-06	1.8E-06	8.4E-07	2.8E-06	1.2E-05	4.1E-06
3650	7.6E-07	9.5E-07	4.4E-07	1.5E-06	1.3E-06	4.8E-07
7300	2.7E-07	3.3E-07	1.6E-07	5.2E-07	7.8E-08	3.5E-08
18250	3.5E-08	4.4E-08	2.0E-08	6.7E-08	4.4E-09	2.5E-09

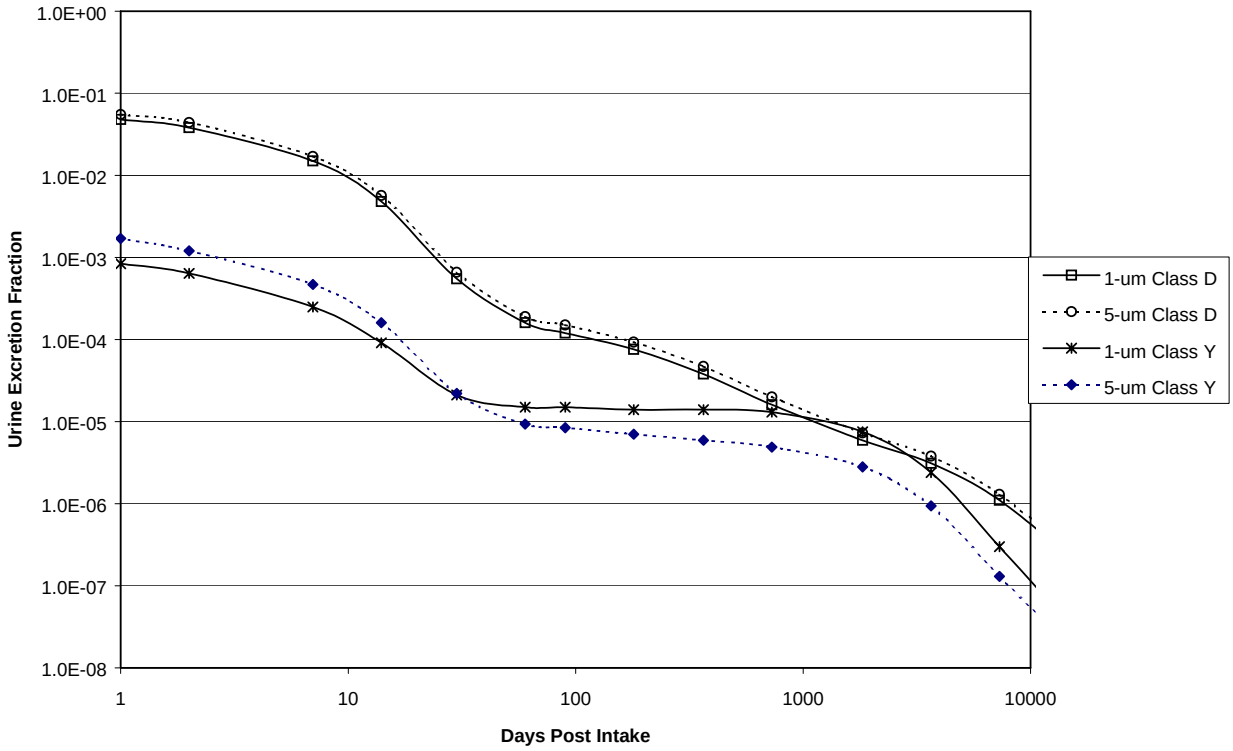

Figure 6.1. ^{90}Sr Urine Excretion Following an Acute Inhalation Intake

6.4 Internal Dosimetry Factors for Radiostrontium

The ^{90}Sr committed effective dose equivalent coefficients of greatest interest to Hanford internal dosimetry are for intakes of 1-µm- and 5-µm-AMAD particles. Values for these coefficients, as calculated by CINDY, are as follows:

- Class D inhalation 5-µm-AMAD particles: 0.27 mrem/nCi intake
- Class D inhalation 1-µm-AMAD particles: 0.22 mrem/nCi intake.

Committed dose coefficients for organs and tissues of significance to several different intake conditions are tabulated in Table 6.6. Committed dose coefficients for ^{90}Y are approximately 2 to 3 orders of magnitude lower than those for ^{90}Sr, hence the existence of ^{90}Y in secular equilibrium to ^{90}Sr at the time of intake does not add any significant dose to the intake beyond that resulting from the ^{90}Sr.

Selected internal dosimetry factors for ^{90}Sr cited by various scientific and regulatory bodies are shown in Table 6.7. The 1-µm values calculated by CINDY using the Hanford parameters are not significantly different from those tabulated by ICRP 54 (1988) and Federal Guidance Report No. 11 (EPA 1988). The difference

Table 6.6. Hanford ^{90}Sr Dose Coefficients for Significant Organs (mrem/nCi Intake[a, b])

Organ	Class D Inhalation		Class Y Inhalation		Soluble Ingestion	Transportable Injection
	1-µm	5-µm	1-µm	5-µm		
Effective	0.22	0.27	1.3	0.48	0.13	0.41
Bone Surfaces	2.4	3.0	[0.23]	[0.15]	1.4	4.6
Red Bone Marrow	1.1	1.3	[0.10]	[0.064]	0.61	2.0
Lung	[<0.01]	[<0.01]	11	3.8	[<0.01]	[<0.01]

(a) Bracketed values are considered insignificant contributors to effective dose equivalent and are shown for information only.
(b) The values for ^{90}Sr and ^{90}Sr+^{90}Y are not significantly different at the precision shown.

between these values and those of ICRP 68 (1994) is related to changes in the ICRP lung model, the new metabolic model, and the new organ and tissue weighting factors.

Derived reporting, investigation, and dose limit compliance levels (based on committed effective dose equivalents 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 daily urine excretion are shown in Tables 6.8 and 6.9 for inhalation class D, and Tables 6.10 and 6.11 for inhalation class Y. Although there is no reason to suspect class Y ^{90}Sr at Hanford, the dose coefficients and derived levels are provided for information purposes.

6.5 Bioassay for Radiostrontium

The general techniques and applicability of bioassay for strontium, urine and fecal sample bioassay, in vivo measurement of ^{90}Sr, bioassay monitoring program capability, a recommended program, and special monitoring needs are discussed in the following sections.

6.5.1 Excreta Bioassay Techniques for ^{90}Sr

The standard method of bioassay for strontium is by analysis of urine excreta samples. Because strontium at Hanford is a class D material, its rapid transport to the systemic compartment makes urine sampling an accurate, reliable, and convenient means for bioassay monitoring. In addition, the lack of any readily detectable gamma emissions makes in vivo detection somewhat ineffective, although if sufficient strontium is present, the bremsstrahlung can be detected by in vivo counting. Fecal samples can also be analyzed; however, their collection is more difficult, and analysis of fecal samples is more costly than analysis of urine samples. Hanford ^{90}Sr urinalysis analytical sensitivities prior to 1991 were summarized by Sula,

Carbaugh, and Bihl (1991). Since 1988, analytical sensitivities have been included in the various annual reports on Hanford radiological protection site support services (e.g., MacLellan et al. 1999).

Table 6.7. Comparison of Dosimetric Factors for Soluble ^{90}Sr (f_1 = 0.3)

Reference Source	Class D Inhalation 1-μm AMAD	Class D Inhalation 5-μm AMAD	Soluble Ingestion
Dose Coefficients			
CINDY [$h_{E,50}$]	0.22 mrem/nCi 5.8E-08 Sv/Bq	0.27 mrem/nCi 7.3E-08 Sv/Bq	0.13 mrem/nCi 3.5E-08Sv/Bq
ICRP-54 [$h_{E,50}$]	6.2E-08 Sv/Bq (0.23 mrem/nCi)	NA	NA
EPA Federal Guidance Report No.11 [$h_{E,50}$]	6.47E-08 Sv/Bq and 0.0239 mrem/nCi	NA	3.85E-08 Sv/Bq and 0.143 mrem/nCi
ICRP-68 [e(50)]	2.4E-08 Sv/Bq (0.089 mrem/nCi)	3.0E-08 Sv/Bq (0.11 mrem/nCi)	2.8E-08 Sv/Bq (0.10 mrem/nCi)
Bone Surface DAC			
10 CFR 835, App. A	8E-09 μCi/ml and 3E+02 Bq/m^3	NA	NA
EPA Federal Guidance Report No. 11	8E-09 μCi/ml and 3E-04 MBq/m^3	NA	NA
ICRP-30, ICRP-54	3E+02 Bq/ m^3	NA	NA
Annual Limit on Intake, ALI (Bone Surface)			
Calculated from 10 CFR 835 DAC	19 μCi and 7.2E+05 Bq	NA	NA
ICRP-30	7E+05 Bq	NA	1E+06 Bq
EPA Federal Guidance Report No. 11	0.7 MBq and 20 μCi	NA	1 MBq and 30 μCi
NA = not applicable			

Table 6.8. ^{90}Sr Urine Excretion Reference Levels for Class D Inhalation of 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)		45.5	455	22,700
Days Post Intake	**Urine Excretion Fraction (f_1 = 0.3)**	**Derived Reporting Level (dpm)**	**Derived Investigation Level (dpm)**	**Derived Compliance Level (dpm)**
1	4.8E-02	4.8E+03	4.8E+04	2.4E+06
2	3.8E-02	3.8E+03	3.8E+04	1.9E+06
7	1.5E-02	1.5E+03	1.5E+04	7.6E+05
14	4.8E-03	4.8E+02	4.8E+03	2.4E+05
30	5.5E-04	5.6E+01	5.6E+02	2.8E+04
60	1.6E-04	1.6E+01	1.6E+02	8.1E+03
90	1.2E-04	1.2E+01	1.2E+02	6.0E+03
180	7.6E-05	7.7E+00	7.7E+01	3.8E+03
365	3.8E-05	3.8E+00	3.8E+01	1.9E+03
730	1.6E-05	1.6E+00	1.6E+01	8.1E+02
1825	5.9E-06	6.0E-01	6.0E+00	3.0E+02
3650	3.1E-06	3.1E-01	3.1E+00	1.6E+02
7300	1.1E-06	1.1E-01	1.1E+00	5.5E+01
18250	1.4E-07	1.4E-02	1.4E-01	7.1E+00

Table 6.9. ^{90}Sr Urine Excretion Reference Levels for Class D Inhalation of 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)		37	370	18,500
Days Post Intake	**Urine Excretion Fraction (f_1 = 0.3)**	**Derived Reporting Level (dpm)**	**Derived Investigation Level (dpm)**	**Derived Compliance Level (dpm)**
1	5.5E-02	4.5E+03	4.5E+04	2.3E+06
2	4.4E-02	3.6E+03	3.6E+04	1.8E+06
7	1.7E-02	1.4E+03	1.4E+04	7.0E+05
14	5.7E-03	4.7E+02	4.7E+03	2.3E+05
30	6.6E-04	5.4E+01	5.4E+02	2.7E+04
60	1.9E-04	1.6E+01	1.6E+02	7.8E+03
90	1.5E-04	1.2E+01	1.2E+02	6.2E+03
180	9.3E-05	7.6E+00	7.6E+01	3.8E+03
365	4.7E-05	3.9E+00	3.9E+01	1.9E+03
730	2.0E-05	1.6E+00	1.6E+01	8.2E+02
1825	7.3E-06	6.0E-01	6.0E+00	3.0E+02
3650	3.8E-06	3.1E-01	3.1E+00	1.6E+02
7300	1.3E-06	1.1E-01	1.1E+00	5.3E+01
18250	1.7E-07	1.4E-02	1.4E-01	7.0E+00

Table 6.10. ^{90}Sr Urine Excretion Reference Levels for Class Y Inhalation of 1-µm-AMAD Particles

		10-mrem Reporting Level	100-mrem Investigation Level	5-rem Compliance Level
Inhalation Intake (nCi)		7.69	76.9	3,850
Days Post Intake	**Urine Excretion Fraction (f_1 = 0.01)**	**Derived Reporting Level (dpm)**	**Derived Investigation Level (dpm)**	**Derived Compliance Level (dpm)**
1	8.4E-04	1.4E+01	1.4E+02	7.2E+03
2	6.4E-04	1.1E+01	1.1E+02	5.5E+03
7	2.5E-04	4.3E+00	4.3E+01	2.1E+03
14	9.1E-05	1.6E+00	1.6E+01	7.8E+02
30	2.1E-05	3.6E-01	3.6E+00	1.8E+02
60	1.5E-05	2.6E-01	2.6E+00	1.3E+02
90	1.5E-05	2.6E-01	2.6E+00	1.3E+02
180	1.4E-05	2.4E-01	2.4E+00	1.2E+02
365	1.4E-05	2.4E-01	2.4E+00	1.2E+02
730	1.3E-05	2.2E-01	2.2E+00	1.1E+02
1825	7.5E-06	1.3E-01	1.3E+00	6.4E+01
3650	2.4E-06	4.1E-02	4.1E-01	2.1E+01
7300	3.0E-07	5.1E-03	5.1E-02	2.6E+00
18250	1.8E-08	3.1E-04	3.1E-03	1.5E-01

Table 6.11. ^{90}Sr Urine Excretion Reference Levels for Class Y Inhalation of 5-µm-AMAD Particles

		10-mrem Reporting Level	100-mrem Investigation Level	5-rem Compliance Level
Inhalation Intake (nCi)		20.8	208	10,400
Days Post Intake	**Urine Excretion Fraction (f_1 = 0.01)**	**Derived Reporting Level (dpm)**	**Derived Investigation Level (dpm)**	**Derived Compliance Level (dpm)**
1	1.7E-03	7.8E+01	7.8E+02	3.9E+04
2	1.2E-03	5.5E+01	5.5E+02	2.8E+04
7	4.7E-04	2.2E+01	2.2E+02	1.1E+04
14	1.6E-04	7.4E+00	7.4E+01	3.7E+03
30	2.2E-05	1.0E+00	1.0E+01	5.1E+02
60	9.3E-06	4.3E-01	4.3E+00	2.1E+02
90	8.4E-06	3.9E-01	3.9E+00	1.9E+02
180	7.0E-06	3.2E-01	3.2E+00	1.6E+02
365	5.9E-06	2.7E-01	2.7E+00	1.4E+02
730	4.9E-06	2.3E-01	2.3E+00	1.1E+02
1825	2.8E-06	1.3E-01	1.3E+00	6.5E+01
3650	9.4E-07	4.3E-02	4.3E-01	2.2E+01
7300	1.3E-07	6.0E-03	6.0E-02	3.0E+00
18250	9.9E-09	4.6E-04	4.6E-03	2.3E-01

The minimum detectable intakes and committed effective dose equivalents associated with various urinalysis sampling times post intake, based on a 10-dpm/d minimum detectable activity for ^{90}Sr in urine for 1-µm- and 5-µm AMAD particle sizes are shown for inhalation intakes of class D and class Y material in Tables 6.12 and 6.13, respectively. Corresponding values for transportable injection intakes of soluble material are shown in Table 6.14.

6.5.2 In Vivo Measurement of ^{90}Sr

Direct in vivo measurement of ^{90}Sr in the skeleton is possible by counting the bremsstrahlung from its decay. This procedure is subject to substantial interference by any other gamma- and beta-emitting nuclides that might be present. Indications are that a retained quantity in the skeleton of about 100 nCi might be detectable by head counting, however, there is no calibration for this measurement.

If isotope activity relationships are known, in vivo whole body counting can be an effective indicator for the potential presence of strontium. Cesium-137 is frequently used as the indicator, because its fission product yield is comparable to that of ^{90}Sr. However, this method is not conclusive and caution must be exercised because there are processes at Hanford where strontium and cesium have undergone chemical separation from each other. Use of ^{137}Cs as an indicator of ^{90}Sr is more fully described in Chapter 5.0. Radiochemistry analyses for ^{137}Cs and ^{90}Sr in media representative of an intake may be used in lieu of supplemental bioassay measurements. This method is most appropriate when dealing with intakes of small dosimetric consequence.

It is generally recommended that in vivo measurements be used only as indicators of the potential for strontium being present, and that evaluations of any strontium intake be based on urine samples.

6.5.3 Recommended Periodic Bioassay Monitoring Protocol

Workers potentially exposed to ^{90}Sr should be on an annual or biennial urinalysis bioassay program. Such programs should be easily capable of detecting class D intakes resulting in committed effective dose equivalents less than 100 mrem. Similar monitoring programs applied to inhalation class Y are capable of detecting committed effective dose equivalents below 200 mrem. For most Hanford applications, a whole body exam for high-energy gamma-emitting nuclides can also be used as a screening measurement for

Table 6.12. Hanford Bioassay Program Capability for ^{90}Sr in Urine for Class D Inhalation (MDA = 10 dpm/d)

Days Post Intake	1-µm-AMAD Urine Excretion Fraction (f_1 = 0.3)	1-µm-AMAD Minimum Detectable Intake (nCi)	1-µm-AMAD Minimum Detectable Dose ($H_{E,50}$, mrem)	5-µm-AMAD Urine Excretion Fraction (f_1 = 0.3)	5-µm-AMAD Minimum Detectable Intake (nCi)	5-µm-AMAD Minimum Detectable Dose ($H_{E,50}$, mrem)
1	4.8E-02	9.4E-02	2.1E-02	5.5E-02	8.2E-02	2.1E-02
2	3.8E-02	1.2E-01	2.6E-02	4.4E-02	1.0E-01	2.8E-02
7	1.5E-02	3.0E-01	6.6E-02	1.7E-02	2.6E-01	7.2E-02
14	4.8E-03	9.4E-01	2.1E-01	5.7E-03	7.9E-01	2.1E-01
30	5.5E-04	8.2E+00	1.8E+00	6.6E-04	6.8E+00	1.8E+00
60	1.6E-04	2.8E+01	6.2E+00	1.9E-04	2.4E+01	6.4E+00
90	1.2E-04	3.8E+01	8.3E+00	1.5E-04	3.0E+01	8.1E+00
180	7.6E-05	5.9E+01	1.3E+01	9.3E-05	4.8E+01	1.3E+01
365	3.8E-05	1.2E+02	2.6E+01	4.7E-05	9.6E+01	2.6E+01
730	1.6E-05	2.8E+02	6.2E+01	2.0E-05	2.3E+02	6.1E+01
1825	5.9E-06	7.6E+02	1.7E+02	7.3E-06	6.2E+02	1.7E+02
3650	3.1E-06	1.5E+03	3.2E+02	3.8E-06	1.2E+03	3.2E+02
7300	1.1E-06	4.1E+03	9.0E+02	1.3E-06	3.5E+03	9.4E+02
18250	1.4E-07	3.2E+04	7.1E+03	1.7E-07	2.6E+04	7.2E+03

Table 6.13. Hanford Bioassay Program Capability for ^{90}Sr in Urine for Class Y Inhalation (MDA = 10 dpm/d)

Days Post Intake	1-µm-AMAD Urine Excretion Fraction (f_1 = 0.01)	1-µm-AMAD Minimum Detectable Intake (nCi)	1-µm-AMAD Minimum Detectable Dose ($H_{E,50}$, mrem)	5-µm-AMAD Urine Excretion Fraction (f_1 = 0.01)	5-µm-AMAD Minimum Detectable Intake (nCi)	5-µm-AMAD Minimum Detectable Dose ($H_{E,50}$, mrem)
1	8.4E-04	5.4E+00	7.0E+00	1.7E-03	2.6E+00	1.3E+00
2	6.4E-04	7.0E+00	9.1E+00	1.2E-03	3.8E+00	1.8E+00
7	2.5E-04	1.8E+01	2.3E+01	4.7E-04	9.6E+00	4.6E+00
14	9.1E-05	5.0E+01	6.4E+01	1.6E-04	2.8E+01	1.4E+01
30	2.1E-05	2.1E+02	2.8E+02	2.2E-05	2.0E+02	9.8E+01
60	1.5E-05	3.0E+02	3.9E+02	9.3E-06	4.8E+02	2.3E+02
90	1.5E-05	3.0E+02	3.9E+02	8.4E-06	5.4E+02	2.6E+02
180	1.4E-05	3.2E+02	4.2E+02	7.0E-06	6.4E+02	3.1E+02
365	1.4E-05	3.2E+02	4.2E+02	5.9E-06	7.6E+02	3.7E+02
730	1.3E-05	3.5E+02	4.5E+02	4.9E-06	9.2E+02	4.4E+02
1825	7.5E-06	6.0E+02	7.8E+02	2.8E-06	1.6E+03	7.7E+02
3650	2.4E-06	1.9E+03	2.4E+03	9.4E-07	4.8E+03	2.3E+03
7300	3.0E-07	1.5E+04	2.0E+04	1.3E-07	3.5E+04	1.7E+04
18250	1.8E-08	2.5E+05	3.3E+05	9.9E-09	4.6E+05	2.2E+05

Table 6.14. Hanford Bioassay Program Capability for ^{90}Sr in Urine for Transportable Injection and Soluble Ingestion Intakes (MDA = 10 dpm/d; f_1 = 0.3)

	Transportable Injection Intake			Soluble Ingestion Intake		
Days Post Intake	**Urine Excretion Fraction (f_1 = 0.3)**	**Minimum Detectable Intake (nCi)**	**Minimum Detectable Dose ($H_{E,50}$, mrem)**	**Urine Excretion Fraction (f_1 = 0.3)**	**Minimum Detectable Intake (nCi)**	**Minimum Detectable Dose ($H_{E,50}$, mrem)**
1	8.3E-02	5.4E-02	2.2E-02	2.6E-02	1.7E-01	2.3E-02
2	6.6E-02	6.8E-02	2.8E-02	2.0E-02	2.3E-01	2.9E-02
7	2.6E-02	1.7E-01	7.1E-02	7.9E-03	5.7E-01	7.4E-02
14	8.6E-03	5.2E-01	2.1E-01	2.6E-03	1.7E+00	2.3E-01
30	1.0E-03	4.5E+00	1.8E+00	3.0E-04	1.5E+01	2.0E+00
60	3.0E-04	1.5E+01	6.2E+00	8.9E-05	5.1E+01	6.6E+00
90	2.4E-04	1.9E+01	7.7E+00	7.1E-05	6.3E+01	8.2E+00
180	1.4E-04	3.2E+01	1.3E+01	4.3E-05	1.0E+02	1.4E+01
365	7.3E-05	6.2E+01	2.5E+01	2.2E-05	2.0E+02	2.7E+01
730	3.1E-05	1.5E+02	6.0E+01	9.4E-06	4.8E+02	6.2E+01
1825	1.1E-05	4.1E+02	1.7E+01	3.4E-06	1.3E+03	1.7E+02
3650	5.8E-06	7.8E+02	3.2E+02	1.8E-06	2.5E+03	3.3E+02
7300	2.1E-06	2.1E+03	8.8E+02	6.2E-07	7.3E+03	9.4E+02
18250	2.7E-07	1.7E+04	6.8E+03	8.1E-08	5.6E+04	7.2E+03

potential intake of mixed fission products. A worker scheduled only for a whole body exam may not be recognized as having potential exposure to radiostrontium.

If gamma-emitting nuclides such as ^{137}Cs are also of potential concern, the impact of mixtures on potentially undetected effective dose equivalent must also be addressed. If other means (e.g., in vivo measurements) are used to monitor for other nuclides, then annual or biennial urine samples should be sufficient to monitor the ^{90}Sr contribution to dose.

6.5.4 Special Monitoring for Suspected Exposures

If exposure to ^{90}Sr has occurred or is suspected to have occurred, one or more urine samples should be scheduled for investigation purposes. Because of the high sensitivity of the urine sample analysis, even slight intakes of ^{90}Sr resulting in small fractions of a millirem committed effective dose equivalent can be detected if prompt sampling is performed. This also permits the use of less sensitive analytical procedures (i.e., expedite or emergency processing analyses) for reasonably accurate dose estimates.

As is apparent from Table 6.8 and 6.9, for class D inhalation of either 1-µm or 5-µm particles, a urine sample result of 5 dpm/d obtained within 30 days following the intake would imply a committed

effective dose equivalent of less than 1 mrem, which could be rounded to zero. Thus, although some indications exist to suggest that 5 dpm/d may be above the normal background levels for urinary excretion, the dosimetric consequence for incident evaluation is insignificant and no confirmation of intake is made based on results of 5 dpm/d or less.

Isotopic strontium analyses should be considered for any potential exposures to ^{89}Sr. However, if more than 1 year has elapsed since the production of ^{89}Sr, that isotope is unlikely to be a dosimetric concern due to its short radiological half-life.

In vivo measurements should also be considered following potential ^{90}Sr exposures, because generally ^{90}Sr is likely to be mixed with other nuclides.

For relatively small intakes, fecal samples for strontium are not likely to be warranted because of the high degree of systemic uptake and the ease of detection by urine sampling. If major intakes are suspected, fecal samples combined with urine samples may provide more accurate estimates of intake, particularly if the intake is thought to contain some nontransportable strontium.

6.6 Assessment of Internal Dose Equivalent

Internal dosimetry for radiostrontium is usually performed at Hanford using an intake assessment methodology and urine bioassay data. The method may use either tabulated values for the excretion fractions or the CINDY computer code for curve fitting or determining excretion fractions at specific times post intake. Doses may be calculated using either an intake value and tabulated dose coefficients or by using CINDY. For Hanford sources, ^{90}Sr and its ^{90}Y decay product have generally been the isotopes of greatest concern for strontium dosimetry. As noted in the previous sections, ^{89}Sr may also be a concern under some conditions.

The general protocol for strontium dosimetry is as follows:

- Estimate the intake based on urine excreta analyses and the appropriate intake excretion function using CINDY or the appropriate equation and technique described in Chapter 2.0.

- Estimate doses using CINDY or tabulated dose coefficients. This includes committed effective dose equivalents, as well as dose equivalents to specific organs of concern based on criteria presented in the *Hanford Internal Dosimetry Program Manual*.[a]

When estimated intakes and associated doses are a relatively small fraction of the applicable radiation protection limit, direct application of the biokinetic models and dosimetry factors without modification for individual-specific considerations is appropriate. As intakes and doses become more significant, it is appropriate to give correspondingly greater attention to those individual-specific details. Urine data normalization is the factor most likely to be adjusted for an individual-specific modification.

Dose assessments use the techniques and biokinetic models described previously and assume ICRP 23 (1974) Reference Man parameters, usually without correction for individual-specific characteristics. These assessments provide a basis for prospective bioassay program design and retrospective evaluation of doses that are small relative to the occupational exposure limits.

6.7 Management of Internal Contamination Cases

The diagnostic procedures, therapeutic actions, and long-term monitoring following an intake of ^{90}Sr are discussed in the following sections on the management of potential internal contamination cases.

6.7.1 Diagnostic Procedures

A worker who may have received an intake of strontium should be scheduled for a whole body count and a urine sample. These initial measurements can be used to confirm an intake and provide preliminary estimates of the magnitude of potential doses. Suitable urine samples can include a single voiding, overnight, or simulated 24-hour sample, depending on the potential severity of intake (the higher the severity, the more important prompt information becomes). However, as noted in previous sections, the in vivo measurements are for the detection of gamma-emitting nuclides, which may or may not be indicative of ^{90}Sr.

(a) Pacific Northwest Laboratory. 1997. *Hanford Internal Dosimetry Program Manual*. PNL-MA-552, Richland, Washington. (Internal manual.) Available URL: http://www.pnl.gov/eshs/pub/pnnl552.html

A potential intake of ^{90}Sr is best indicated by the results of the urine sample. Where the indicated dose is small (e.g., less than tens of millirem), a single urine sample is adequate for dosimetry. For more significant intakes, getting two or more urine samples (representing actual or simulated 24-hour periods) collected over several days or weeks following the intake is preferred. In general, less credence for dosimetry is placed on a sample taken within the first couple of days after an intake compared with one taken several days or more after the intake.

6.7.2 Therapeutic Actions

Therapeutic actions to prevent the uptake of strontium are based primarily on reducing GI tract absorption and accelerating the passage of material through the GI tract. These measures require administration under medical supervision and are addressed in NCRP 65 (1980) and the "Guidebook for Treatment of Accidental Internal Radionuclide Contamination of Workers" (Bhattacharyya et al. 1992). Aluminum phosphate gel and sodium alginate are the drugs identified as being potentially effective in reducing the GI tract uptake of strontium. Accelerating the passage of material through the GI tract can be accomplished by use of laxatives and enemas. These measures can only be taken under the supervision of Hanford Environmental Health Foundation (HEHF) Occupational Medicine. Frequent sampling should be used during treatment to provide information on treatment efficiencies. However, standard models should not be used on these samples for dosimetry.

6.7.3 Long-Term Bioassay Follow-Up Monitoring After an Intake

Long-term monitoring of urinary excretion following a ^{90}Sr intake may be required to validate the excretion model or to ensure that potential additional intakes do not go undetected. The establishment of a sampling frequency for such monitoring is dependent upon the nature of the exposure, magnitude of deposition, and likelihood for additional exposure. Appropriate long-term follow-up monitoring should be determined as part of the exposure evaluation.

6.8 Historical ^{90}Sr Internal Dosimetry Practices at Hanford

Historically, Hanford internal dosimetry for strontium was based on estimating the long-term systemic deposition, using urine data and Dolphin's excretion model (Dolphin and Eve 1963a; 1963b), and comparing it with the 2-μCi ICRP 2 MPBB (ICRP 1959). The long-term (formerly referred to as "permanent") deposition was defined as the amount remaining in the body at 1 year post intake, which was calculated to be 15% of the initial systemic uptake. This evaluation

technique was described in several short explanations, the most recent being Appendix G of *the Hanford Dosimetry Evaluation Manual* (PNL-MA-575).[a] Earlier versions are listed by Sula et al. (1991).

In April 1985, the practice of investigating all positive ^{90}Sr results regardless of their dose implication was discontinued, and only results potentially indicating long-term systemic depositions in excess of 1% of the above-described level were investigated. This change in practice was made due to increased sensitivity of the analytical procedure and the indication of potential background levels in the range of the minimum detection level for the analytical procedure. Using the above method, derived investigation levels were calculated for various times post intake, and these were documented by letter to the Hanford Radiation Protection Historical Files as cited by Sula et al. (1991).

With the issuance of *Technical Basis for Internal Dosimetry at Hanford* (Sula et al. 1989), the ICRP 30 (1979) dosimetry concepts of committed organ and tissue dose equivalents, and committed effective dose equivalent were adopted, along with the ICRP alkaline earth model (1973) as implemented using the GENMOD computer code (Johnson and Carver 1981). The CINDY computer code effectively replaced GENMOD at Hanford in 1992.

6.9 References

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