

SECTION 4.0

STRONTIUM

4.0 STRONTIUM

This section summarizes the technical basis and provides some historical perspective for the internal dosimetry of strontium 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- μ Ci ICRP 2 maximum permissible body burden (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 in Table 4.1.

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 model, derived investigation levels were calculated for various times post intake, and these were documented by letter to the Hanford Radiation Protection Historical Files as referenced in Table 4.1.

This technical basis incorporates the ICRP 26 and 30 (1977, 1979) concepts of tissue and effective doses, the ICRP alkaline earth model (1973) as implemented using the GENMOD computer code (Johnson and Carver 1981; see Appendix A), and supersedes the previously documented techniques for assessing internal exposure to strontium at Hanford.

(a) Pacific Northwest Laboratory. 1982. Hanford Dosimetry Evaluation Manual. PNL-MA-575, Richland, Washington.

TABLE 4.1. Historical Documentation of the Hanford Strontium Model and Deposition Evaluation Techniques

<u>Date</u>	<u>Author</u>	<u>Title</u>
Pre 1966	Various	Deposition Evaluations ^(a)
11-66	Not Specified	Appendix I - ⁹⁰ Sr ^(a)
08-01-68	R. C. Henle	⁹⁰ Sr Calculation Factors ^(a)
07-26-76	R. D. Glenn	Appendix I - ⁹⁰ Sr ^(a)
09-17-80	D. P. Hickman	Appendix I - ⁹⁰ Sr Dose Evaluation ^(a)
11-82		PNL-MA-575 Appendix G - ⁹⁰ Sr Dose Evaluation
04-01-85	E. H. Carbaugh	Derived Investigation Levels - ⁹⁰ Sr ^(b)

- (a) Unpublished Hanford evaluation procedures, guides, and evaluations.
 (b) Carbaugh, E. H., and M. J. Sula. 1985. "Derived Investigation Levels--⁹⁰Sr." Letter to the Hanford Radiation Protection Historical Files, April 1, 1985, Pacific Northwest Laboratory, Richland, Washington.

For incidents involving potential intakes of mixed fission products, it is often a common practice to use ¹³⁷Cs as an indicator of ⁹⁰Sr. This can be a valid assumption, because both nuclides have comparable yields from the fissioning of ²³⁵U (see Table 4.2). However, it must be noted that some Hanford chemical processes have separated cesium from strontium. Thus, caution must

TABLE 4.2. Fission Product Yields^(a)

<u>Fissionable Nuclide</u>	<u>FP Mass 90, %</u>	<u>FP Mass 137, %</u>
²³³ U	6.9	6.81
²³⁵ U	5.91	6.22
²³⁹ Pu	2.11	6.70

- (a) From General Electric Co. (1983).

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

4.1 SOURCES AND CHARACTERISTICS OF STRONTIUM

This section provides general information on the isotopes of strontium and related decay products that can be found at Hanford. The information compiled in this section was taken directly from, or calculated based on, information in ICRP 30 and 38 (1979, 1983).

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 facility that deals with fission products. Most facilities that have strontium may also be expected to have other fission products present, notably cesium (^{137}Cs). However, at certain facilities, notably B-Plant (221-B Building) and the Waste Encapsulation and Storage Facility (WESF) (225-B Building), strontium may be found in an essentially pure form.

In facilities where freshly irradiated fuel is being handled or processed, ^{89}Sr may also be a concern. Due to its short radiological half-life, it is not likely to be found. At Hanford, N Reactor, fuel storage basins, FFTF, and the Plutonium Uranium Extraction (PUREX) Plant are considered the facilities most likely to have ^{89}Sr . Immediately after irradiation, there may be substantially more ^{89}Sr than ^{90}Sr , but by 1 year of decay the residual ^{89}Sr is insignificant compared to ^{90}Sr for internal dosimetry purposes. Selected decay data for these three nuclides are in Table 4.3.

TABLE 4.3. Decay Data for Strontium Isotopes

<u>Parameter</u>	<u>^{90}Sr</u>	<u>^{90}Y</u>	<u>^{89}Sr</u>
Half-life	29.12 yr	64.0 h	50.5 days
Decay constant	$6.5\text{E}-5 \text{ day}^{-1}$	0.26 day^{-1}	$1.4\text{E}-2 \text{ day}^{-1}$
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 to each other 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 would result 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 there would be equal quantities of both nuclides present.

Strontium-89 decays to a stable decay product and, due to its short (50-day) radiological half-life, is only a concern in facilities that handle freshly irradiated fuel or the associated wastes from processing freshly irradiated fuel. The ORIGEN computer code (Hedengren 1985) indicates that, for N Reactor, 6%, Mark IV (MKIV) fuel at discharge, there may be about 90 times as much ^{89}Sr as ^{90}Sr . Exposure to such material may be more limiting in terms of internal dose than exposure to ^{90}Sr . Because of the rapid decay of ^{89}Sr , within about 6 months ^{90}Sr becomes the dominant isotope of concern. At that time there may still be seven times as much ^{89}Sr as ^{90}Sr ; however, the potential first-year dose from the ^{89}Sr is only about 20% of that from the ^{90}Sr . Less than 1% of the ^{89}Sr produced in fuel remains at 1 year after exposure, and, for practical purposes, that nuclide ceases to be a dosimetric concern by that time.

4.2 BIOKINETIC BEHAVIOR OF STRONTIUM

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.

4.2.1 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. However, that compound of strontium is not present at Hanford.

4.2.2 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 recommendation of ICRP 30. Where evaluation of poorly transportable (class Y) forms may be required, the ICRP 30 value of 0.01 will be used. These values have been incorporated into the GENMOD computer code used for derivation of many of the values and factors used in this technical basis.

4.2.3 Internal Distribution and Retention

The biokinetic model used for the distribution, retention, and excretion of stable strontium is the alkaline earth model of the ICRP (1973, 1979) as implemented by the GENMOD computer code (see Appendix A). 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. The uptake retention function of GENMOD is shown in Figure 4.1 along with the Dolphin model that has been used for Hanford strontium evaluations prior to this technical basis.

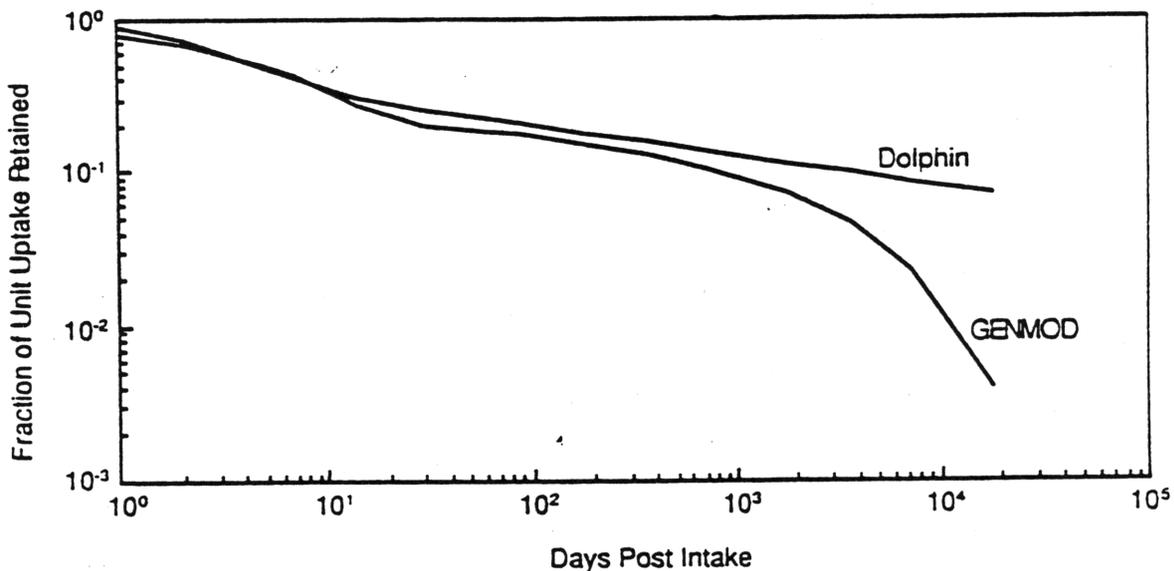


FIGURE 4.1. ⁹⁰Sr Retention Functions

The use of the GENMOD code marks a departure from the past Hanford use of the Dolphin model described previously. This departure is made to allow for the adoption of tools consistent with ICRP 30 recommendations and DOE 5480.11 radiation protection standards. Past ^{90}Sr evaluations compared the residual systemically retained quantity at 1 year post intake with the ICRP 2 (1959) MPBB as a measure of compliance and assumed that this retained quantity was permanent. In fact, the 29-year radiological half-life for ^{90}Sr combined with biological clearance results in a continuing decrease in the systemically retained quantity, which becomes significant with regard to the annual tissue and effective doses at long times post intake. The transition from the Dolphin to the ICRP alkaline earth model as implemented by GENMOD is noted here for historical purposes.

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.

4.2.4 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 represents generally accepted excretion fractionation.

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 GENMOD ^{90}Sr urinary excretion function is used in this technical basis for strontium evaluations. This function, expressed as the fractional excretion rate for an acute uptake of transportable ^{90}Sr , is plotted in Figure 4.2. Also shown is the excretion function derived from the Dolphin model that was formerly used for Hanford ^{90}Sr evaluations without correction for radiological decay.

Despite the differences in formulation and the lack of decay correction in the Dolphin-based function, it can be concluded from Figure 4.2 that the two models will provide roughly comparable estimates of an acute uptake, when

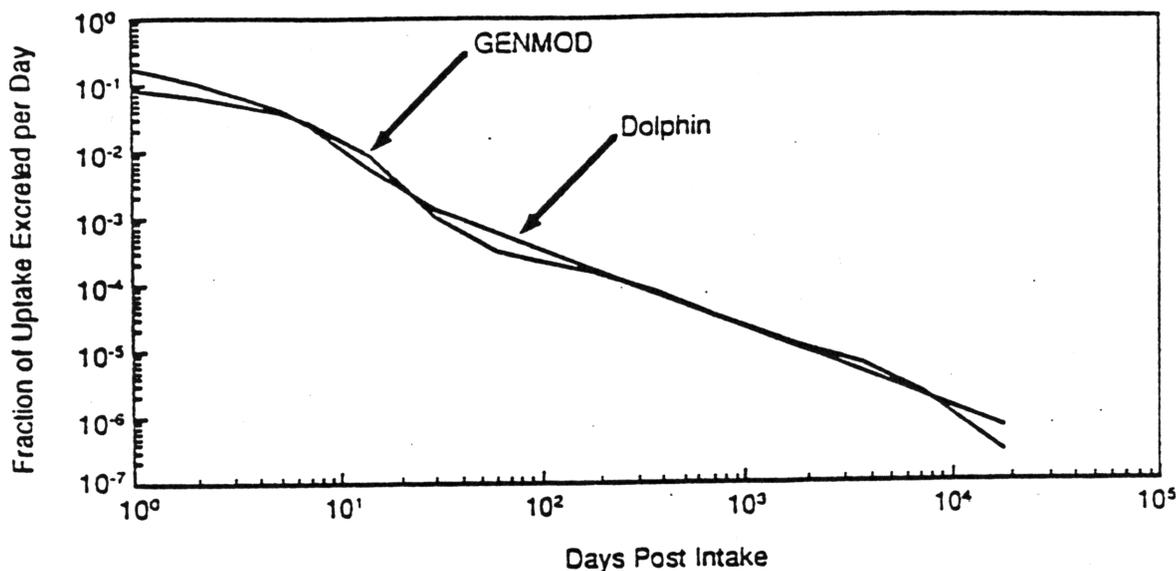


FIGURE 4.2. ^{90}Sr Excretion Functions for Urinary Excretion Following an Acute Uptake

evaluations are based on multiple data points spread over many days to weeks post intake and undue emphasis is not given to single data points. The excretion models are not significantly different between about 150 and several thousand days post uptake, and thus, where long-term data are available, the models should give comparable results. For evaluations based primarily on data from times less than 150 days post uptake, the uptake estimates based on GENMOD are likely to be more conservative than those based on the Dolphin model, because the GENMOD code predicts lower excretion rates for about two-thirds of that period. For the typical case, the data fits for the two models should not make an appreciable difference in the estimated uptake.

The GENMOD excretion function for ^{89}Sr uses the same stable element retention function with corrections based on the radiological decay of ^{89}Sr . This function is addressed in the next section.

4.3 STRONTIUM INTERNAL DOSIMETRY FACTORS

The following subsections detail factors useful for making internal dosimetry calculations. These factors are derived from the GENMOD computer code.

4.3.1 Intake Excretion Functions

The fractional intake excretion functions for transportable injection, class D inhalation, and class Y inhalation intakes of ^{90}Sr (as calculated by GENMOD) are shown in Figure 4.3. Selected values for these functions are listed in Table 4.4. 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 positioning of the curve relative to the y-axis. The difference is due simply to the ratio of total uptake to total intake (0.48 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. As is apparent in Figure 4.3, urinary excretion following an acute class Y intake can be expected to be relatively constant from about 50 to 1000 days post intake.

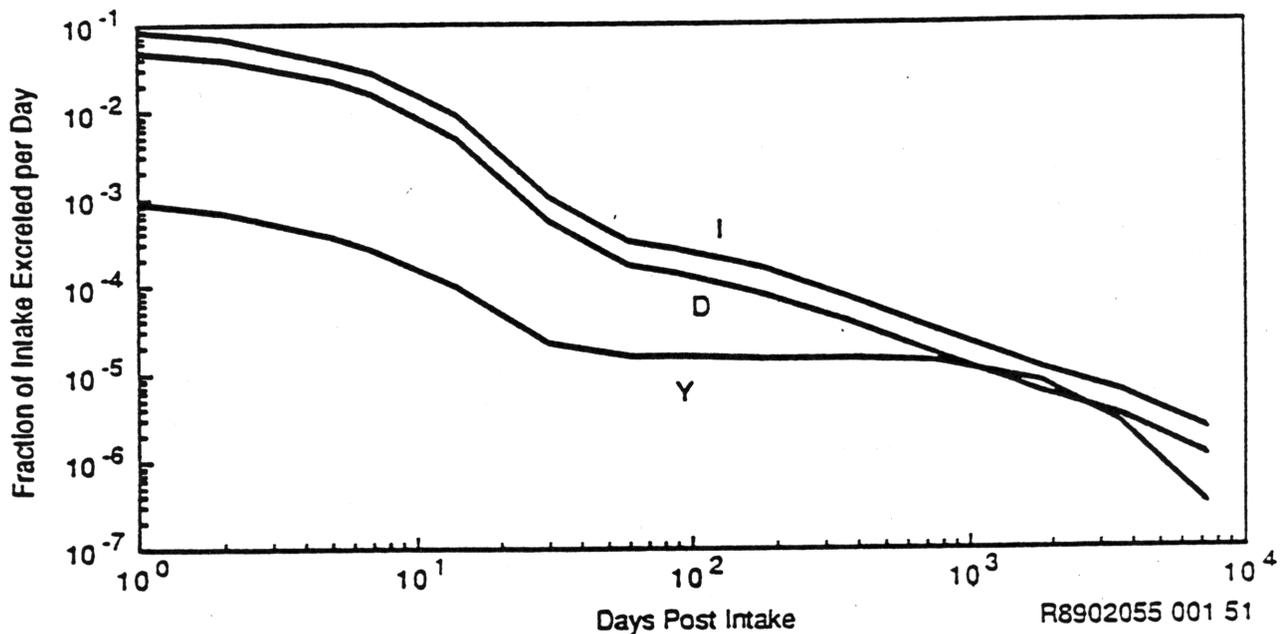


FIGURE 4.3. ^{90}Sr Intake Excretion Functions for the Urinary Excretion Pathway (Johnson and Carter 1981). I = transportable injection, D = class D inhalation, Y = class Y inhalation.

TABLE 4.4. Selected ^{90}Sr Urinary Excretion Fractions
(expressed as fraction of intake)

<u>Days Post Intake</u>	<u>Transportable Injection</u>	<u>Class D Inhalation</u>	<u>Class Y Inhalation</u>
1	8.2E-2	4.8E-2	8.4E-4
2	6.5E-2	3.8E-2	6.4E-4
5	3.6E-2	2.1E-2	3.6E-4
7	2.6E-2	1.5E-2	2.5E-4
14	8.5E-3	4.8E-3	9.1E-5
30	1.0E-3	5.5E-4	2.1E-5
60	3.0E-4	1.6E-4	1.5E-5
90	2.4E-4	1.3E-4	1.5E-5
180	1.5E-4	7.6E-5	1.4E-5
365	7.3E-5	3.8E-5	1.4E-5
730	3.1E-5	1.6E-5	1.3E-5
1825	1.1E-5	5.9E-6	7.5E-6
3650	5.9E-6	3.1E-6	2.4E-6
7300	2.1E-6	1.1E-6	3.0E-7

Values of the intake excretion functions for days other than those indicated in Table 4.4 can be obtained directly from running the GENMOD code, or can be reasonably approximated by linear interpolation between the data points of Table 4.4.

Table 4.5 provides similar values for the ^{89}Sr urinary excretion function.

4.3.2 Source-to-Target-Organ Dose Conversion Factors

The DCFs used by the GENMOD computer code to calculate dose equivalent to a target organ from radioactive decay in a source organ are shown in Table 4.6. These factors agree with those of ICRP 30 to within a few percent, which is consistent with the expected rounding error.

TABLE 4.5. Selected ^{89}Sr Urinary Excretion Fractions
(expressed as fraction of intake)

<u>Days Post Intake</u>	<u>Transportable Injection</u>	<u>Class D Inhalation</u>	<u>Class Y Inhalation</u>
1	8.1E-2	4.9E-2	8.3E-4
2	6.3E-2	3.8E-2	6.2E-4
5	3.4E-2	2.0E-2	3.3E-4
7	2.3E-2	1.3E-2	2.3E-4
14	7.0E-3	4.0E-3	7.6E-5
30	6.7E-4	3.7E-4	1.4E-5
60	1.3E-4	6.9E-5	6.6E-6
90	7.0E-5	3.7E-5	4.3E-6
180	1.2E-5	6.5E-6	1.4E-6
365	5.0E-7	2.6E-7	1.1E-7

TABLE 4.6. Dose Conversion Factors for Strontium Dosimetry

<u>Organ of Concern</u>		<u>Dose Conversion Factor^(a)</u>			
<u>Target</u>	<u>Source</u>	<u>^{90}Sr</u>	<u>^{90}Y</u>	<u>$^{90}\text{Sr} + ^{90}\text{Y}$</u>	<u>^{89}Sr</u>
Lung	Lung	1.0E-7	4.8E-7	5.8E-7	3.0E-7
Gut	Gut	2.0E-7	9.6E-7	1.2E-6	6.0E-7
SI ^(b)	SI	1.2E-7	6.0E-7	7.2E-7	3.7E-7
ULI ^(c)	ULI	2.3E-7	1.1E-6	1.3E-6	6.8E-7
LLI ^(d)	LLI	3.7E-7	1.8E-6	2.1E-6	1.1E-6
BS ^(e)	Trabecular bone	2.1E-8	1.0E-8	1.2E-7	6.2E-8
BS	Cortical bone	1.2E-8	6.0E-8	7.2E-8	3.7E-8
BS	Bone surface	2.1E-7	8.0E-8	2.9E-7	5.0E-8
RM ^(f)	Trabecular bone	2.3E-8	1.1E-7	1.4E-7	7.0E-8
RM	Bone surface	1.7E-8	8.0E-8	9.7E-8	5.0E-8

(a) Units of rem(target)/nCi-day(source).

(b) SI = small intestine.

(c) ULI = upper large intestine.

(d) LLI = lower large intestine.

(e) BS = bone surface.

(f) RM = red marrow.

4.3.3 Intake Dose Equivalent Factors

Intake dose equivalent factors express the dose to an organ from a unit intake of radioactivity. Because of the mathematical formulation of the strontium retention function, with its incorporation of bone-to-blood recycling, these factors are difficult to derive by hand calculation, but they can be readily obtained from the GENMOD computer code. Tables 4.7 and 4.8 provide first-year and 50-year committed organ and effective dose equivalent factors for transportable injection, and inhalations of 1- μ m-AMAD class D and class Y particles. Intake dose equivalent factors for any year post intake can be obtained from the GENMOD code. For ^{90}Sr cases, it was assumed that the intake was pure ^{90}Sr with ^{90}Y rapidly growing to equilibrium. If the intake consisted of ^{90}Sr and ^{90}Y in equilibrium at the time of intake, the resulting factors would not be noticeably different.

4.3.4 Cumulative Dose Equivalents

The cumulative dose equivalent from an intake through various times post intake is frequently of interest with regard to tenaciously retained radionuclides. The most commonly referenced cumulative dose is the committed dose equivalent through a 50-year period following an intake. For ^{89}Sr , virtually all of this dose is received during the first year after intake, and the committed dose is essentially the same as the first-year dose. The dose from a ^{90}Sr intake is delivered over a much longer period of time, due to its long radiological and biological half-lives.

The cumulative effective dose equivalents (expressed as a percentage of the 50-year committed effective dose equivalent) through various times post intake are shown in Table 4.9 for transportable injection, class D inhalation, and class Y inhalation intakes. These values were derived from the GENMOD computer code.

The ICRP 30 annual limits on intakes (ALIs) for ^{90}Sr are 19,000 nCi and 2700 nCi for class D and class Y inhalations, respectively. These intakes correspond to a 50-year committed effective dose equivalent of 5 rem.

TABLE 4.7. $^{90}\text{Sr} + ^{90}\text{Y}$ Intake Dose Equivalent Factors^(a)
for First-Year and 50-Year Committed Doses

<u>Tissue</u>	<u>Transportable^(b) Injection</u>	<u>Class D^(c) Inhalation</u>	<u>Class Y^(c) Inhalation</u>
Effective			
First-year	5.9E-5	3.2E-5	3.2E-4
50-year	4.1E-4	2.2E-4	1.3E-3
Bone Surface			
First-year	5.5E-4	2.9E-4	7.0E-6
50-year	4.6E-3	2.4E-3	2.3E-4
Red Marrow			
First-year	3.1E-4	1.6E-4	3.9E-6
50-year	2.0E-3	1.1E-3	1.0E-4
Lung			
First-year	NA ^(d)	3.9E-6	2.6E-3
50-year	NA ^(d)	4.1E-6	1.1E-2
Gut			
First-year	NA ^(d)	2.1E-7	9.1E-7
50-year	NA ^(d)	2.1E-7	1.2E-6
Small Intestine			
First-year	NA ^(d)	4.0E-7	2.4E-6
50-year	NA ^(d)	4.0E-7	3.1E-6
Upper Large Intestine			
First-year	NA ^(d)	3.1E-6	1.8E-5
50-year	NA ^(d)	3.1E-6	2.2E-5
Lower Large Intestine			
First-year	NA ^(d)	1.2E-5	6.3E-5
50-year	NA ^(d)	1.2E-5	7.5E-5
Other			
First-year	2.1E-6	1.3E-6	3.9E-8
50-year	2.4E-6	1.3E-6	1.7E-7

(a) Units are rem/nCi of acute intake.

(b) Assumes all strontium and yttrium is readily transportable.

(c) Assumes 1- μm -AMAD particle size.

(d) Not applicable.

TABLE 4.8. ^{89}Sr Intake Dose Equivalent Factors^(a) for First-Year and 50-Year Committed Doses

<u>Tissue</u>	<u>Transportable^(b) Injection</u>	<u>Class D^(c) Inhalation</u>	<u>Class Y^(c) Inhalation</u>
Effective			
First-year	7.0E-6	6.2E-6	4.2E-5
50-year	8.7E-6	6.3E-6	4.2E-5
Bone Surface			
First-year	6.5E-5	3.4E-5	6.4E-7
50-year	6.6E-5	3.4E-5	6.5E-7
Red Marrow			
First-year	4.1E-5	2.1E-5	4.1E-7
50-year	1.1E-6	2.2E-5	4.1E-7
Lung			
First-year	NA ^(d)	6.4E-6	3.1E-4
50-year	NA ^(d)	6.4E-6	3.1E-4
Gut			
First-year	NA ^(d)	3.8E-7	1.2E-6
50-year	NA ^(d)	3.8E-7	1.2E-6
Small Intestine			
First-year	NA ^(d)	6.7E-7	3.0E-6
50-year	NA ^(d)	6.7E-7	3.0E-6
Upper Large Intestine			
First-year	NA ^(d)	4.0E-6	1.8E-5
50-year	NA ^(d)	4.0E-6	1.8E-5
Lower Large Intestine			
First-year	NA ^(d)	1.1E-5	5.1E-5
50-year	NA ^(d)	1.1E-5	5.1E-5
Other			
First-year	1.4E-6	7.1E-7	1.4E-8
50-year	1.4E-6	7.1E-7	1.4E-8

(a) Units are rem/nCi of acute intake.

(b) Assumes all strontium is readily transportable.

(c) Assumes 1- μm -AMAD particle size.

(d) Not applicable.

TABLE 4.9. Cumulative Effective Dose Equivalent^(a) for ⁹⁰Sr Intakes

Cumulative Time		Mode of Intake		
Post Intake, days	years	Transportable Injection	Class D Inhalation	Class Y Inhalation
90	0.25	7%	5.5%	4.8%
180	0.50	13%	8.9%	8.2%
365	1	24%	15%	14%
730	2	41%	25%	25%
1,825	5	67%	48%	48%
3,650	10	81%	71%	71%
7,300	20	90%	89%	89%
18,250	50	100%	100%	100%

(a) Expressed as a percentage of $H^C_{E,50}$.

4.4 BIOASSAY TECHNIQUES FOR STRONTIUM

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

4.4.1 General Techniques and Applicability

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.

4.4.2 Urine and Fecal Sample Bioassay

Minimum detectable activities for radiostrontium analyses from 1980 through 1991 are shown in Table 4.10. Other procedures have been available, however their actual use has been quite limited.

Prior to the June 1990 termination of the analytical support laboratory contract, the laboratory performed a strontium chemical separation followed by a total radiostrontium ($^{89+90}\text{Sr}$) count. If the result was below 1 dpm, then no further analysis was performed and the result was reported as either total strontium or ^{90}Sr depending on the request. For ^{90}Sr analyses in which the first count exceeded 1 dpm, the sample preparation would be aged to allow ^{90}Y ingrowth to occur. Chemical separation and measurement of the ^{90}Y would then be used to determine the ^{90}Sr present.

Following the June 1990 contract termination, arrangements were made for ^{90}Sr analyses to be provided by an interim analytical laboratory pending

TABLE 4.10. Contractual Detection Levels for Strontium

<u>Sample Media</u>	<u>Analysis</u>	<u>Detection Level, dpm/sample</u>
Urine	Pre-June 1990	
	Routine and priority ^{90}Sr	2.0
	Expedite ($^{89+90}\text{Sr}$)	10
	Emergency ($^{89+90}\text{Sr}$)	80
	Post-June 1990	
	Routine ^{90}Sr	30 (a)
Expedite ($^{89+90}\text{Sr}$)	40	
Emergency ($^{89+90}\text{Sr}$)	400	
Feces	Pre-June 1990	
	Priority (^{90}Sr or $^{89+90}\text{Sr}$)	10
	Expedite ($^{89+90}\text{Sr}$)	150
	Emergency ($^{89+90}\text{Sr}$)	450
	Post-June 1990	
	Expedite ($^{89+90}\text{Sr}$)	400
Emergency ($^{89+90}\text{Sr}$)	2000	

(a) Results greater than the critical level (L_C) of 15 dpm are considered to be positive detection and are investigated.

completion of the bidding process for a permanent replacement laboratory. As of this writing (June 1991) these arrangements are continuing. The interim laboratory provides a minimum detection level of 30 dpm, and any results greater than the 15 dpm critical level (L_C) are investigated.

4.4.3 In Vivo Measurement of ^{90}Sr

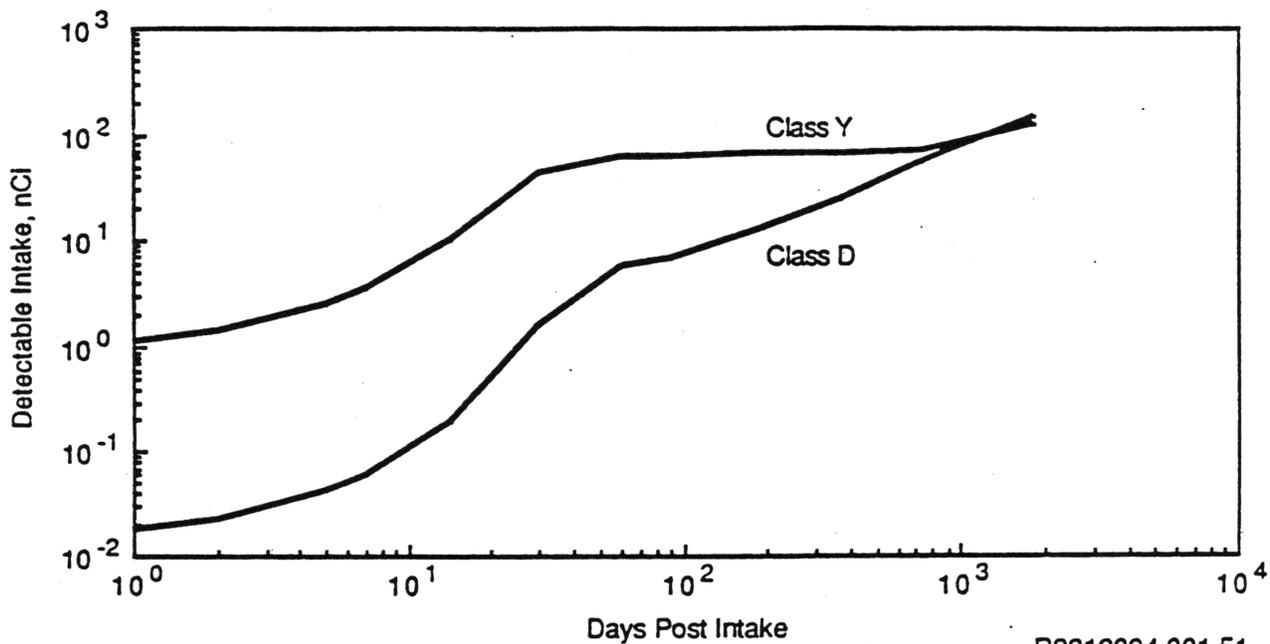
Direct in vivo measurement of ^{90}Sr in the skeleton is possible by counting the bremsstrahlung from its decay. This procedure is subject to substantial interference by any other gamma- and beta-emitting nuclides that might be present. Indications are that a retained quantity in the skeleton of about 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 the nuclide frequently used as the indicator, because its fission product yield is comparable to that of ^{90}Sr . For some circumstances, it can be assumed that ^{90}Sr is present at intake in amounts equal to ^{137}Cs . However, this method is not conclusive and caution must be exercised in its use as a rule-of-thumb, because there are processes at Hanford where strontium and cesium undergo chemical separation from each other. Use of ^{137}Cs as an indicator of ^{90}Sr is more fully described in Section 5.0.

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 uptake be based on urine samples.

4.4.4 Bioassay Monitoring Program Capability

The ^{90}Sr class D and Y acute inhalation intakes (for 1- μm -AMAD particles) that are potentially detectable using the 2 dpm/sample analytical procedure sensitivity are shown in Figure 4.4. This assumes that the samples represent 24-hour excretion. Capabilities for selected times post intake are shown in Table 4.11, and include the magnitudes of intake, first-year effective dose equivalent, and committed effective dose equivalents.



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FIGURE 4.4. ⁹⁰Sr Inhalation Intakes Detectable by Urine Sampling (D = class D inhalation, Y = class Y inhalation. Assumes 1- μ m-AMAD particles and a 2-dpm/day detection level.)

4.4.5 Recommended Routine Bioassay Monitoring Program

Workers potentially exposed to radiostrontium should be on an annual bioassay program including urine sample analysis for radiostrontium and whole body counting for high-energy gamma-emitting nuclides as additional indicators of 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.

Extrapolating Table 4.11 to the present 30-dpm urine sample analysis sensitivity indicate that a routine bioassay monitoring program with an annual urine sampling frequency will be capable of detecting an approximate 80-mrem committed effective dose equivalent for class D ⁹⁰Sr, with the first-year effective dose equivalent being about 11 mrem. For class Y material, such

TABLE 4.11. Bioassay Detection Capability for an Acute ^{90}Sr Intake^(a)
Based on a 2-dpm Urine Sample Analysis Sensitivity

Days Post Intake	Class D Inhalation			Class Y Inhalation		
	I nCi	H _{E,1'} mrem	H _{E,50'} ^C mrem	I nCi	H _{E,1'} mrem	H _{E,50'} ^C mrem
1	0.018	6.1E-4	4.0E-3	1.1	0.35	1.4
2	0.023	7.4E-4	5.1E-3	1.4	0.45	1.8
5	0.043	1.4E-3	9.5E-3	2.5	0.80	3.3
7	0.060	1.9E-3	0.013	3.6	1.2	4.7
14	0.19	6.0E-3	0.041	9.9	3.2	13
30	1.6	0.053	0.36	43	14	56
60	5.6	0.18	1.2	60	19	78
90	6.9	0.22	1.5	60	19	78
180	12	0.38	2.6	64	21	83
365	24	0.76	5.2	64	21	84
730	56	1.8	12	69	22	90
1830	153	4.9	34	120	38	156

(a) Assumes 1- μm -AMAD particle size.

a program would only be capable of detecting a 1300-mrem committed effective dose equivalent and a 310-mrem first-year effective dose equivalent. Although some increase in the program capability can be achieved by more frequent sampling, the relatively small improvements so indicated in Table 4.11 imply that a more sensitive analytical procedure might be more cost effective than changes in sampling frequency. A biennial sampling frequency for Class D material would be capable of detecting a 50-year committed effective dose equivalent of 230 mrem with a first-year dose of 27 mrem.

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 urine samples should be sufficient to monitor the ^{90}Sr contribution to dose.

4.4.6 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 annual or 50-year committed effective dose equivalent can be detected if prompt sampling is performed. This also permits the use of less sensitive analytical procedures (i.e., rapid processing analyses) for reasonably accurate dose estimates.

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.

4.5 INTERNAL DOSE ASSESSMENT FOR STRONTIUM INTAKES

The following subsections discuss the general approach to strontium internal dosimetry, including how to estimate intake based on urine excretion data, specification of organs of concern, and dose equivalent calculations.

4.5.1 General Approach

For Hanford applications, ^{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. This section outlines a general approach for any strontium dosimetry evaluation. Estimates of the magnitude of a strontium intake can be made using urine data and the excretion function. However, because of the sophistication of the

strontium retention function, hand calculation of doses is quite complex, requiring the integration of simultaneous differential equations. Therefore, for practical purposes the organ and effective dose equivalent calculations are made using factors obtained from the GENMOD computer code.

Both ^{89}Sr and ^{90}Sr -Y are essentially pure beta-emitters; therefore, the dosimetry for them must generally be based on excreta sample analysis. In vivo measurements can be of some use if the activity relationship relative to a gamma-emitter, such as ^{137}Cs , is known, or if sufficient strontium activity is present to produce measurable bremsstrahlung radiation.

The general protocol for strontium dosimetry proceeds as follows:

- Estimate the intake based on urine excreta analyses and the appropriate intake excretion function.
- Estimate annual tissue and effective doses using factors from the GENMOD computer code.

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.

4.5.2 Estimating Intake

The intake for strontium is estimated by fitting the urinary excretion data to the appropriate intake excretion function, using manual or computerized techniques. For single data points, the intake can be estimated by dividing the measured excretion by the value of the intake excretion function on the day post intake that the sample represents, as shown in Equation (4.1):

$$I = M_u(t)/e_u^i(t) \quad (4.1)$$

where I is the intake, $M_u(t)$ is the observed urinary excretion of strontium on day t , and $e_u^i(t)$ is the fractional intake excretion function (for urine) on day t (obtained from Figure 4.3, Table 4.4, or directly from the GENMOD

computer code). For multiple data points, a least-squares fit of the data to the expected excretion function should be used, as described in Appendix C.

In addition to their use for dose calculations, class D or Y inhalation intakes calculated by the above techniques may also be compared with the ICRP Annual Limits on Intake (ALIs) or intake estimates based on air sample results.

4.5.3 Calculating Organ and Effective Dose Equivalents

Dose assessments include calculation of annual and 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) (See also Appendix B.)

Doses to the organs of interest can be calculated for any given time post intake by multiplying the intake by the appropriate intake dose equivalent factor. The intake dose equivalent factors may be those in Tables 4.7 or 4.8, or may be obtained directly from the GENMOD computer code.

4.5.4 Systemic Deposition Estimate

With the advent of the new requirements for organ and effective dose equivalent assessment, the calculation and reporting of strontium systemic depositions for comparison to the ICRP 2 (1959) MPBB is no longer required. By using the intake excretion function technique described in this section, the calculation of systemic deposition is bypassed. Previous evaluations of systemic deposition performed using the previously discussed Dolphin technique can be converted to a readily transportable injection intake (or total uptake) by dividing the long-term (or permanent) systemic deposition by 0.15. If the mode of intake was inhalation, then the total uptake must also be divided by the ratio of total uptake to class D inhalation intake (0.48, for 1- μ m-AMAD particles).

(a) Pacific Northwest Laboratory. 1989. Hanford Internal Dosimetry Program Manual. PNL-MA-552, Richland, Washington.

4.5.5 Simplified Dose Assessments

Simplified dose assessments use the techniques and biokinetic models described previously and assume ICRP 23 (1974) Reference Man parameters, 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. In addition, the excretion associated with simplified assessments can be used as a trigger point for more in-depth measurements or dose assessments.

The procedure for performing a simplified dose assessment is as follows:

1. Normalize the result to daily excretion rate.
2. Select the intake date (known or assumed).
3. Estimate intake by fitting the data to excretion model.
4. Calculate dose equivalents by multiplying the estimated intake by the appropriate intake dose equivalent factor from GENMOD.

Intakes and the associated urinary excretions have been evaluated using simplified dose assessments on a prospective basis for class D and Y inhalations of ^{90}Sr resulting in the following doses:

- First-year effective dose equivalent of 10 mrem. Below this level the annual organ dose equivalents for each organ of concern are less than 100 mrem, and the 50-year committed effective dose equivalent is also less than 100 mrem.
- First-year effective dose equivalent of 100 mrem. Doses that exceed this level may merit attention to the individual-specific circumstances of the exposure. As higher doses are evaluated, the importance of these individual-specific details increases.
- 50-year committed effective dose equivalent of 100 mrem. Below this level it may be reasonable for compliance monitoring and record-keeping purposes to record the committed dose in the year of intake rather than the year in which it is actually incurred. Such recording is unlikely to significantly impact a worker's standing with regard to the stochastic and nonstochastic radiation protection limits.

The intakes associated with these doses are shown in Table 4.12. These intakes were then multiplied by the appropriate excretion function value

TABLE 4.12. Simplified Dose Assessment Intakes for a ⁹⁰Sr Inhalation Intake, nCi

<u>Associated Dose Equivalent</u>	<u>Class D</u>	<u>Class Y</u>
10 mrem First-Year Effective	310	31
100 mrem First-Year Effective	3100	310
100 mrem 50-Year Committed	460	77

from Table 4.4 to calculate the expected urinary excretion. The anticipated urinary excretions resulting from these intakes are shown for selected times post intake in Tables 4.13 and 4.14.

Based on the preceding discussions, action levels for tailoring dose assessments based on individual-specific characteristics can be established for routine bioassay monitoring. By assuming that an inhalation intake occurs immediately following a routinely scheduled sample, the number of days post intake becomes the same as the number of days between samples.

TABLE 4.13. Excretion Associated with ⁹⁰Sr Class D Acute Inhalation of 1- μ m-AMAD Particles

<u>Days Post Intake</u>	<u>Effective Dose Equivalent</u>		
	<u>10 mrem First Year, dpm/day</u>	<u>100 mrem First Year, dpm/day</u>	<u>100 mrem Committed 50-Year, dpm/day</u>
1	35,000	350,000	50,000
2	27,000	270,000	39,000
5	15,000	150,000	21,000
7	10,000	100,000	15,000
14	3,300	33,000	4,800
30	380	3,800	560
60	110	1,100	160
90	90	900	130
180	53	530	77
365	26	260	38
730	11	110	17
1825	4.1	41	6.0

TABLE 4.14. Excretion Associated with ^{90}Sr Class Y
Acute Inhalation of 1- μm -AMAD Particles

Days Post Intake	Effective Dose Equivalent		
	10 mrem First Year, dpm/day	100 mrem First Year, dpm/day	100 mrem Committed 50-Year, dpm/day
1	58	580	140
2	45	450	100
5	25	250	62
7	17	170	43
14	6.3	63	16
30	1.5	15	3.6
60	1.0	10	2.6
90	1.0	10	2.6
180	1.0	9.7	2.4
365	1.0	9.7	2.4
730	0.90	9.0	2.2
1825	0.52	5.2	1.3

The class D inhalation is suitable for monitoring potential transportable injection uptakes because the excretions associated with identical doses are not significantly different.

4.6 MANAGEMENT OF POTENTIAL INTERNAL CONTAMINATION CASES

The diagnostic procedures, therapeutic actions, and long-term monitoring of internal deposition are discussed in the following subsections on the management of potential internal contamination cases.

4.6.1 Diagnostic Procedures

A worker who may have received an internal contamination of strontium should be scheduled for a whole body count and a single voiding or an overnight urine sample. These initial measurements can be used to confirm an intake and provide preliminary estimates of the magnitude of potential doses. 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 potential intake of ^{90}Sr is best indicated by the results of the overnight or single voiding sample.

The evaluation of the magnitude of a ^{90}Sr intake should be based on two or more urine samples (representing actual or simulated 24-hour periods) collected over several days or weeks following the intake. The sample results should be evaluated using the techniques of Section 4.5.

4.6.2 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 are addressed in NCRP 65 (1980) and require administration under medical supervision. Aluminum phosphate gel and sodium alginate are the drugs identified by NCRP 65 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 at the direction of HEHF Occupational Medicine.

4.6.3 Long-Term Monitoring of Internal Deposition

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.