13.0 Europium

This chapter provides technical information on the sources, characteristics, biokinetics, and dosimetry of ^{152}Eu, ^{154}Eu, and ^{155}Eu, which are the principal europium radionuclides of concern from an internal exposure standpoint at Hanford.

13.1 Sources and Characteristics

Europium-154 and ^{155}Eu have been produced historically at Hanford by the N Reactor through neutron activation of samarium oxide marbles used in the reactor's safety system. The samarium oxide marbles were replaced in 1978 with marbles made of boron carbide; however, a few of the old samarium oxide marbles remained lodged in the graphite block moderator and continued to be activated during operation of the reactor until its shutdown in 1986.

Europium-152 has been found in coolant pipes of some of the old production reactors. Its exact source has not been determined, but it has been speculated that it might result from activation of stable ^{151}Eu from naturally occurring or fission-product sources. Data are provided for ^{152}Eu, although this has not historically been considered a major nuclide of concern in these facilities.

Radiological decay data for these isotopes are given in Table 13.1.

Table 13.1. Radiological Data for Hanford Europiums

Isotope	Half-Life (y)	Decay Constant (y^1)	Specific Activity (Ci/g)
^{152}Eu	13.33	0.052	176
^{154}Eu	8.8	0.079	263
^{155}Eu	4.96	0.14	463

Based on numerous measurements made at various N Reactor locations (Weetman and DeHaven 1982), a particle size of 0.5-µm-AMAD should be assumed, unless specific particle size data are available. This particle size is in contrast to the 1-µm-AMAD particle size assumed by ICRP publication 30 (1979) and the 5-µm-AMAD particle size recommended by ICRP publication 66 (1994a).

The principal locations where exposures to europium radionuclides may occur are the 100-N Area and the waste management facilities in the 200 Areas where contaminated waste from N Reactor is handled.

13.2 Biokinetic Behavior of Europium

The biokinetic behavior of europium is addressed in the following sections.

13.2.1 Transportability Class

ICRP 30 Part 3 (1981) recommends that all compounds of europium (including nitrates, chlorides, and oxides) be assigned to inhalation class W. Some experience at Hanford has suggested that europium oxide may occasionally be more tenaciously retained in the lung than would be expected for a class W material. However, at this time data are insufficient to establish a case for class Y europium at Hanford.

The new ICRP 66 lung model (ICRP 1994a) introduced the concept of lung absorption type as a replacement for the ICRP 30 inhalation class. Based on data tabulated in ICRP 68 (1994b), all forms of europium are assigned absorption type M.

The default assumption for Hanford europium exposures is inhalation class W, per the ICRP 30 recommendation.

13.2.2 Gastrointestinal Uptake to Blood (f_1 Factor)

Citing a range of 2E-04 to 3E-03, the GI uptake factor (f_1) for europium was taken by ICRP 30 (1981) to be 1E-03. More recently, ICRP 68 used 5E-04, without highlighting a reason for the change. This choice has been promulgated by the International Atomic Energy Agency in its Basic Safety Standards (IAEA 1996). Although a clear scientific justification for the change has not been identified, the HIDP uses the more recent ICRP recommendation of 5E-04. This value lies within the range originally cited, and it appears to be the current scientific consensus.

13.2.3 Biokinetic Model

According to the ICRP 30 Part 3 (1981) model, europium entering the bloodstream is deposited and tenaciously retained in the liver and on bone surfaces. The distribution of europium entering the blood is given by ICRP 30 as follows:

Organ/Tissue	Fraction Retained	Biological Half-Life (days)
Liver	0.4	3500
Bone Surfaces	0.4	3500
Kidney	0.06	10
Direct Excretion	0.14	

13.3 Internal Dosimetry Factors for Europium

This section contains factors that are useful in making internal dosimetry calculations. The factors included are derived from the CINDY computer code and incorporate the models and assumptions of the preceding sections. Their application is intended for circumstances where such assumptions are appropriate or more specific information is lacking. Variation from these factors is appropriate if sufficient data are available.

13.3.1 Retention of Europium

Selected retention fractions for ^{152}Eu and ^{154}Eu in the whole body and bone and ^{155}Eu in the lung and bone are listed in Table 13.2 for inhalation intakes and Table 13.3 for ingestion intakes. Fractions have been tabulated for a 0.5-µm-AMAD aerosol class W inhalation as the default Hanford assumption based on the previously described characterization work. Fractions are also tabulated for a 5-µm-AMAD aerosol inhalation as the standard ICRP inhalation aerosol. Although the larger particle size is not normally used for Hanford europium intakes, particle size growth with time is possible due to oxidation in the ambient environment. The organs and tissues selected for tabulation are those of greatest interest to routine and special bioassay measurements.

13.3.2 Dose Coefficients

Dose coefficients, expressed as committed dose equivalent per unit activity of intake (e.g., rem/nCi of intake), are a convenient shortcut to estimating doses based on standard assumptions when the magnitude of intake is known. Acute intake dose coefficients have been compiled in Table 13.4 for selected exposure scenarios, based on calculations using the CINDY code. The scenarios include the inhalation of class W 0.5-µm- and 5-µm-AMAD particles as the Hanford default and ICRP 66 default particle sizes, respectively, and ingestion. For all of these scenarios, the most limiting dose coefficients are for the committed effective dose equivalent. Dose coefficients for organs or tissues that contribute approximately 10% or more to the committed effective dose equivalent are also shown.

Table 13.2. Fractional Retention of Inhalation Class W Europium

Particle Size: 0.5-mm						
Days Post Intake	**^{152}Eu Whole Body**	**^{152}Eu Bone[(a)]**	**^{154}Eu Whole Body**	**^{154}Eu Bone[(a)]**	**^{155}Eu Lung**	**^{155}Eu Bone[(a)]**
0	5.9E-01	2.1E-03	5.9E-01	2.1E-03	4.1E-01	2.1E-03
1	5.5E-01	2.1E-02	5.5E-01	2.1E-02	3.0E-01	2.1E-02
2	4.6E-01	2.3E-02	4.6E-01	2.3E-02	2.5E-01	2.3E-02
5	2.8E-01	2.4E-02	2.8E-01	2.4E-02	2.0E-01	2.4E-02
7	2.5E-01	2.4E-02	2.5E-01	2.4E-02	1.9E-01	2.4E-02
14	2.3E-01	2.6E-02	2.3E-01	2.6E-02	1.8E-01	2.6E-02
30	2.1E-01	3.0E-02	2.1E-01	3.0E-02	1.4E-01	3.0E-02
60	1.7E-01	3.5E-02	1.7E-01	3.5E-02	9.6E-02	3.5E-02
90	1.4E-01	3.9E-02	1.4E-01	3.9E-02	6.4E-02	3.8E-02
180	1.1E-01	4.4E-02	1.1E-01	4.4E-02	2.0E-02	4.2E-02
365	9.1E-02	4.5E-02	8.9E-02	4.3E-02	1.7E-03	4.1E-02
730	8.0E-02	4.0E-02	7.5E-02	3.8E-02	1.2E-05	3.3E-02
1825	5.5E-02	2.7E-02	4.8E-02	2.4E-02	insig.	1.8E-02
3650	2.9E-02	1.5E-02	2.3E-02	1.1E-02	insig.	6.1E-03
7300	8.5E-03	4.3E-03	5.0E-03	2.5E-03	insig.	7.3E-04
18250	2.0E-04	1.0E-04	5.3E-05	2.7E-05	insig.	1.3E-06
Particle Size: 5-mm						
Days Post Intake	**^{152}Eu Whole Body**	**^{152}Eu Bone[(a)]**	**^{154}Eu Whole Body**	**^{154}Eu Bone[(a)]**	**^{155}Eu Lung**	**^{155}Eu Bone[(a)]**
0	9.1E-01	4.4E-03	9.1E-01	4.4E-03	1.5E-01	4.4E-03
1	8.1E-01	4.3E-02	8.1E-01	4.3E-02	7.5E-02	4.3E-02
2	5.4E-01	4.6E-02	5.4E-01	4.6E-02	6.3E-02	4.6E-02
5	1.8E-01	4.6E-02	1.8E-01	4.6E-02	5.1E-02	4.6E-02
7	1.5E-01	4.6E-02	1.5E-01	4.6E-02	4.9E-02	4.6E-02
14	1.4E-01	4.6E-02	1.4E-01	4.6E-02	4.4E-02	4.6E-02
30	1.3E-01	4.7E-02	1.3E-01	4.7E-02	3.6E-02	4.7E-02
60	1.2E-01	4.8E-02	1.2E-01	4.8E-02	2.4E-02	4.7E-02
90	1.1E-01	4.9E-02	1.1E-01	4.8E-02	1.6E-02	4.8E-02
180	1.0E-01	4.9E-02	1.0E-01	4.8E-02	4.9E-02	4.7E-02
365	9.4E-02	4.7E-02	9.1E-02	4.5E-02	4.2E-04	4.3E-02
730	8.3E-02	4.1E-02	7.8E-02	3.9E-02	3.0E-06	3.5E-02
1825	5.7E-02	2.8E-02	5.0E-02	2.5E-02	insig.	1.8E-02
3650	3.1E-02	1.5E-02	2.3E-02	1.2E-02	insig.	6.4E-03
7300	8.3E-03	4.4E-03	5.2E-03	2.6E-03	insig.	7.6E-04
18250	2.1E-04	1.1E-04	5.5E-05	2.8E-05	insig.	1.3E-06

(a) Fractional retention in the liver is the same as the fractional retention in the bone.

Table 13.3. Fractional Retention of Ingested Europium

Days Post Intake	^{152}Eu Whole Body	^{152}Eu Bone[(a)]	^{154}Eu Whole Body	^{154}Eu Bone[(a)]	^{155}Eu Bone[(a)]
0	1.0E+00	2.4E-07	1.0E+00	2.4E-07	2.4E-07
1	7.1E-01	1.8E-04	7.1E-01	1.8E-04	1.8E-04
2	3.2E-01	2.0E-04	3.2E-01	2.0E-04	2.0E-04
5	1.9E-02	2.0E-04	1.9E-02	2.0E-04	2.0E-04
7	2.9E-03	2.0E-04	2.9E-03	2.0E-04	2.0E-04
14	4.1E-04	2.0E-04	4.1E-04	2.0E-04	2.0E-04
30	4.0E-04	2.0E-04	4.0E-04	2.0E-04	2.0E-04
60	3.9E-04	2.0E-04	3.9E-04	2.0E-04	1.9E-04
90	3.9E-04	1.9E-04	3.9E-04	1.9E-04	1.9E-04
180	3.8E-04	1.9E-04	3.7E-04	1.9E-04	1.8E-04
365	3.5E-04	1.8E-04	3.4E-04	1.7E-04	1.6E-04
730	3.1E-04	1.6E-04	3.0E-04	1.5E-04	1.3E-04
1825	2.1E-04	1.1E-04	1.9E-04	9.4E-05	6.9E-05
3650	1.2E-04	5.8E-05	8.8E-05	4.4E-05	2.4E-05
7300	3.3E-05	1.7E-05	1.9E-05	9.7E-06	2.9E-06
18250	8.0E-07	4.0E-07	2.1E-07	1.0E-07	5.0E-09

(a) Fractional retention in the liver is the same as fractional retention in bone.

Table 13.4. Committed Dose Coefficients for Europium (rem/nCi acute intake)

Isotope	Organ	Class W Inhalation		Ingestion	Instant Uptake
		0.5-mm-AMAD	5-mm-AMAD	f_1 = 5E-04	
^{152}Eu	Effective	2.2E-04	2.1E-04	4.7E-06	1.6E-03
	Liver	1.3E-03	1.4E-03	insig.	1.0E-02
	Bone Surface	9.3E-04	9.8E-04	insig.	7.4E-03
	Red Marrow	3.1E-04	3.2E-04	insig.	2.4E-03
	Lung	2.7E-04	1.5E-04	insig.	insig.
	Lower Large Intestine	insig.	insig.	3.7E-05	insig.
	Upper Large Intestine	insig.	insig.	1.5E-05	insig.
^{154}Eu	Effective	3.0E-04	2.8E-04	7.5E-06	2.1E-03
	Liver	1.6E-03	1.7E-03	insig.	1.3E-02
	Bone Surface	2.0E-03	2.1E-03	insig.	1.6E-02
	Red Marrow	4.1E-04	4.3E-04	insig.	3.3E-03
	Lung	3.8E-04	1.7E-04	insig.	insig.
	Lower Large Intestine	insig.	insig.	6.7E-05	insig.
^{155}Eu	Effective	4.5E-05	4.2E-05	1.3E-06	3.0E-04
	Liver	1.8E-04	2.0E-04	insig.	1.5E-03
	Bone Surface	5.7E-04	6.0E-04	insig.	4.6E-03
	Red Marrow	5.6E-05	5.9E-05	insig.	4.5E-04
	Lung	6.1E-05	1.9E-05	insig.	insig.
	Lower Large Intestine	insig.	insig.	1.3E-05	insig.

13.3.3 Comparison of Published Dosimetry Factors

A comparison of selected dosimetry factors for ^{154}Eu, the most restrictive of the Hanford europium isotopes, is shown in Table 13.5.

Table 13.5. Comparison of Dosimetric Factors for ^{154}Eu

Reference Source	Class W Inhalation 0.5 or 1-mm AMAD	Class W Inhalation 5-mm-AMAD	Ingestion (f_1 = 5E-04)
Dose Coefficients			
CINDY ($h_{E,50}$)	3.0E-04 rem/nCi 8.1E-08 Sv/Bq (Based on 0.5-µm-AMAD particles)	2.8E-04 rem/nCi 7.6E-08 Sv/Bq	7.5E-06 rem/nCi 2.0E-09 Sv/Bq
EPA Federal Guidance Report No.11 ($h_{E,50}$)	7.73E-08 Sv/Bq (2.86E-04 rem/nCi) (Based on 1-µm-AMAD particles)	NA	2.58E-09 Sv/Bq (9.55E-06 rem/nCi)
ICRP 68 [e(50)]	5.0E-08 Sv/Bq (1.8E-04 rem/nCi) Type S, based on 1-µm-AMAD particles)	3.5E-08 Sv/Bq (1.3E-04 rem/nCi) Type M	2.0E-09 Sv/Bq (7.4E-06 rem/nCi)
Stochastic 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
Stochastic Annual Limit on Intake, ALI			
Calculated from 10 CFR 835 DAC	19 µCi and 7.2E+05 Bq	NA	NA
ICRP 30	7E+05 Bq	NA	2E+07 Bq
EPA Federal Guidance Report No. 11	0.7 MBq and 20 µCi	NA	20 MBq and 500 µCi
NA = not applicable.			

13.3.4 Derived Reference Levels

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

^{152}Eu, ^{154}Eu, and ^{155}Eu, as pure isotopes, for whole body and skeleton bioassays. Derived levels for ^{152}Eu are shown in Table 13.6, for ^{154}Eu in Table 13.7, and for ^{155}Eu in Table 13.8.

13.4 Bioassay for Europium

This section discusses bioassay methods, capabilities, and protocols for europium.

13.4.1 Bioassay Methods and Capabilities

The europium isotopes of concern at Hanford (^{152}Eu, ^{154}Eu, and ^{155}Eu) are readily measured by in vivo bioassay techniques. Europium intakes can also be detected and assessed through collection and analysis of urine and fecal samples. However, because in vivo measurements provide a direct and sensitive method for assessing internal depositions of europium radionuclides, excreta measurements are generally not necessary. The recommended bioassay programs for europium are based on in vivo measurements. Nominal minimum detectable activities for in vivo measurements are shown in Table 13.9.

Europium-154 is the predominant long-lived europium radioisotope in europium mixtures at Hanford. During the operating lifetime of N Reactor, the ^{154}Eu:^{155}Eu activity ratio was about 2.0. Since the 1986 shutdown of N Reactor, this ratio should gradually increase due to the longer half-life of ^{154}Eu, now that europium is no longer produced. Because ^{154}Eu is also more easily detectable in vivo than ^{155}Eu, it is the best indicator of an intake of europium radionuclides. Whole body counting for ^{154}Eu is conveniently performed using the NaI-detector preview counter, however the high-resolution large-volume coaxial germanium detector system should be used for quantitative determinations if detection is indicated on the NaI system.

Europium-155 is more difficult to detect in vivo because its predominant gamma emission falls in the low-energy noise region of the standard whole body count. It can be detected in the skeleton or lungs using the low-energy planar germanium detector systems. The total body content of ^{155}Eu cannot be directly measured with the Hanford whole body counter. It can be estimated by establishing a ^{155}Eu:^{154}Eu ratio, using chest or skeleton counts, and then applying that ratio to the ^{154}Eu whole body count result. Skeleton counting would provide a more sensitive ratio for ^{155}Eu estimation.

Table 13.6. Reference Levels and Derived Reference Levels for ^{152}Eu

Days Post Intake	10-mrem $H_{E,50}$ Reporting Level			100-mrem $H_{E,50}$ Investigation Level			5,000-mrem $H_{t,50}$ Compliance Level		
	0.5-mm Inhalation	5-mm Inhalation	Ingestion	0.5-mm Inhalation	5-mm Inhalation	Ingestion	0.5-mm Inhalation	5-mm Inhalation	Ingestion
Intake (nCi)	4.5E+01	4.8E+01	2.1E+03	4.5E+02	4.8E+02	2.1E+04	2.3E+04	2.4E+04	1.1E+06
Whole Body Count Bioassay (nCi)									
0	2.7E+01	4.3E+01	2.1E+03	2.7E+02	4.3E+02	2.1E+04	1.3E+04	2.2E+04	1.1E+06
1	2.5E+01	3.9E+01	1.5E+03	2.5E+02	3.9E+02	1.5E+04	1.2E+04	1.9E+04	7.5E+05
2	2.1E+01	2.6E+01	6.8E+02	2.1E+02	2.6E+02	6.8E+03	1.0E+04	1.3E+04	3.4E+05
5	1.3E+01	8.6E+00	4.0E+01	1.3E+02	8.6E+01	4.0E+02	6.4E+03	4.3E+03	2.0E+04
7	1.1E+01	7.1E+00	6.2E+00	1.1E+02	7.1E+01	6.2E+01	5.7E+03	3.6E+03	3.1E+03
14	1.0E+01	6.7E+00	8.7E-01	1.0E+02	6.7E+01	8.7E+00	5.2E+03	3.3E+03	4.3E+02
30	9.5E+00	6.2E+00	8.5E-01	9.5E+01	6.2E+01	8.5E+00	4.8E+03	3.1E+03	4.2E+02
60	7.7E+00	5.7E+00	8.3E-01	7.7E+01	5.7E+01	8.3E+00	3.9E+03	2.9E+03	4.1E+02
90	6.4E+00	5.2E+00	8.3E-01	6.4E+01	5.2E+01	8.3E+00	3.2E+03	2.6E+03	4.1E+02
180	5.0E+00	4.8E+00	8.1E-01	5.0E+01	4.8E+01	8.1E+00	2.5E+03	2.4E+03	4.0E+02
365	4.1E+00	4.5E+00	7.4E-01	4.1E+01	4.5E+01	7.4E+00	2.1E+03	2.2E+03	3.7E+02
730	3.6E+00	4.0E+00	6.6E-01	3.6E+01	4.0E+01	6.6E+00	1.8E+03	2.0E+03	3.3E+02
Skeleton Bioassay (nCi)									
0	9.5E-02	2.1E-01	5.1E-04	9.5E-01	2.1E+00	5.1E-03	4.8E+01	1.0E+02	2.5E-01
1	9.5E-01	2.0E+00	3.8E-01	9.5E+00	2.0E+01	3.8E+00	4.8E+02	1.0E+03	1.9E+02
2	1.0E+00	2.2E+00	4.3E-01	1.0E+01	2.2E+01	4.3E+00	5.2E+02	1.1E+03	2.1E+02
5	1.1E+00	2.2E+00	4.3E-01	1.1E+01	2.2E+01	4.3E+00	5.4E+02	1.1E+03	2.1E+02
7	1.1E+00	2.2E+00	4.3E-01	1.1E+01	2.2E+01	4.3E+00	5.4E+02	1.1E+03	2.1E+02
14	1.2E+00	2.2E+00	4.3E-01	1.2E+01	2.2E+01	4.3E+00	5.9E+02	1.1E+03	2.1E+02
30	1.4E+00	2.2E+00	4.3E-01	1.4E+01	2.2E+01	4.3E+00	6.8E+02	1.1E+03	2.1E+02
60	1.6E+00	2.3E+00	4.3E-01	1.6E+01	2.3E+01	4.3E+00	7.9E+02	1.1E+03	2.1E+02
90	1.8E+00	2.3E+00	4.0E-01	1.8E+01	2.3E+01	4.0E+00	8.9E+02	1.2E+03	2.0E+02
180	2.0E+00	2.3E+00	4.0E-01	2.0E+01	2.3E+01	4.0E+00	1.0E+03	1.2E+03	2.0E+02
365	2.0E+00	2.2E+00	3.8E-01	2.0E+01	2.2E+01	3.8E+00	1.0E+03	1.1E+03	1.9E+02
730	1.8E+00	2.0E+00	3.4E-01	1.8E+01	2.0E+01	3.4E+00	9.1E+02	9.8E+02	1.7E+02

Table 13.7. Reference Levels and Derived Reference Levels for ^{154}Eu

Days Post Intake	10-mrem $H_{E,50}$ Reporting Level			100-mrem $H_{E,50}$ Investigation Level			5,000-mrem $H_{t,50}$ Compliance Level		
	0.5-mm Inhalation	5-mm Inhalation	Ingestion	0.5-mm Inhalation	5-mm Inhalation	Ingestion	0.5-mm Inhalation	5-mm Inhalation	Ingestion
Intake (nCi)	3.3E+01	3.6E+01	1.3E+03	3.3E+02	3.6E+02	1.3E+04	1.7E+04	1.8E+04	6.7E+05
Whole Body Count Bioassay (nCi)									
0	2.0E+01	3.2E+01	1.3E+03	2.0E+02	3.2E+02	1.3E+04	9.9E+03	1.6E+04	6.7E+05
1	1.8E+01	2.9E+01	9.5E+02	1.8E+02	2.9E+02	9.5E+03	9.2E+03	1.4E+04	4.7E+05
2	1.5E+01	1.9E+01	4.3E+02	1.5E+02	1.9E+02	4.3E+03	7.7E+03	9.7E+03	2.1E+05
5	9.3E+00	6.4E+00	2.5E+01	9.3E+01	6.4E+01	2.5E+02	4.7E+03	3.2E+03	1.3E+04
7	8.3E+00	5.4E+00	3.9E+00	8.3E+01	5.4E+01	3.9E+01	4.2E+03	2.7E+03	1.9E+03
14	7.7E+00	5.0E+00	5.5E-01	7.7E+01	5.0E+01	5.5E+00	3.8E+03	2.5E+03	2.7E+02
30	7.0E+00	4.6E+00	5.3E-01	7.0E+01	4.6E+01	5.3E+00	3.5E+03	2.3E+03	2.7E+02
60	5.7E+00	4.3E+00	5.2E-01	5.7E+01	4.3E+01	5.2E+00	2.8E+03	2.1E+03	2.6E+02
90	4.7E+00	3.9E+00	5.2E-01	4.7E+01	3.9E+01	5.2E+00	2.3E+03	2.0E+03	2.6E+02
180	3.7E+00	3.6E+00	4.9E-01	3.7E+01	3.6E+01	4.9E+00	1.8E+03	1.8E+03	2.5E+02
365	3.0E+00	3.2E+00	4.5E-01	3.0E+01	3.2E+01	4.5E+00	1.5E+03	1.6E+03	2.3E+02
730	2.5E+00	2.8E+00	4.0E-01	2.5E+01	2.8E+01	4.0E+00	1.3E+03	1.4E+03	2.0E+02
Skeleton Bioassay (nCi)									
0	7.0E-02	1.6E-01	3.2E-04	7.0E-01	1.6E+00	3.2E-03	3.5E+01	7.9E+01	1.6E-01
1	7.0E-01	1.5E+00	2.4E-01	7.0E+00	1.5E+01	2.4E+00	3.5E+02	7.7E+02	1.2E+02
2	7.7E-01	1.6E+00	2.7E-01	7.7E+00	1.6E+01	2.7E+00	3.8E+02	8.2E+02	1.3E+02
5	8.0E-01	1.6E+00	2.7E-01	8.0E+00	1.6E+01	2.7E+00	4.0E+02	8.2E+02	1.3E+02
7	8.0E-01	1.6E+00	2.7E-01	8.0E+00	1.6E+01	2.7E+00	4.0E+02	8.2E+02	1.3E+02
14	8.7E-01	1.6E+00	2.7E-01	8.7E+00	1.6E+01	2.7E+00	4.3E+02	8.2E+02	1.3E+02
30	1.0E+00	1.7E+00	2.7E-01	1.0E+01	1.7E+01	2.7E+00	5.0E+02	8.4E+02	1.3E+02
60	1.2E+00	1.7E+00	2.7E-01	1.2E+01	1.7E+01	2.7E+00	5.8E+02	8.6E+02	1.3E+02
90	1.3E+00	1.7E+00	2.5E-01	1.3E+01	1.7E+01	2.5E+00	6.5E+02	8.6E+02	1.3E+02
180	1.5E+00	1.7E+00	2.5E-01	1.5E+01	1.7E+01	2.5E+00	7.3E+02	8.6E+02	1.3E+02
365	1.4E+00	1.6E+00	2.3E-01	1.4E+01	1.6E+01	2.3E+00	7.2E+02	8.1E+02	1.1E+02
730	1.3E+00	1.4E+00	2.0E-01	1.3E+01	1.4E+01	2.0E+00	6.3E+02	7.0E+02	1.0E+02

Table 13.8. Reference Levels and Derived Reference Levels for ^{155}Eu

Days Post Intake	10-mrem $H_{E,50}$ Reporting Level			100-mrem $H_{E,50}$ Investigation Level			5,000-mrem $H_{t,50}$ Compliance Level		
	0.5-mm Inhalation	5-mm Inhalation	Ingestion	0.5-mm Inhalation	5-mm Inhalation	Ingestion	0.5-mm Inhalation	5-mm Inhalation	Ingestion
Intake (nCi)	2.2E+02	2.4E+02	7.7E+03	2.2E+03	2.4E+03	7.7E+04	1.1E+05	1.2E+05	3.9E+06
Skeleton Bioassay (nCi)									
0	4.7E-01	1.0E+00	1.8E-03	4.7E+00	1.0E+01	1.8E-02	2.3E+02	5.2E+02	9.2E-01
1	4.7E+00	1.0E+01	1.4E+00	4.7E+01	1.0E+02	1.4E+01	2.3E+03	5.1E+03	6.9E+02
2	5.1E+00	1.1E+01	1.5E+00	5.1E+01	1.1E+02	1.5E+01	2.6E+03	5.5E+03	7.7E+02
5	5.3E+00	1.1E+01	1.5E+00	5.3E+01	1.1E+02	1.5E+01	2.7E+03	5.5E+03	7.7E+02
7	5.3E+00	1.1E+01	1.5E+00	5.3E+01	1.1E+02	1.5E+01	2.7E+03	5.5E+03	7.7E+02
14	5.8E+00	1.1E+01	1.5E+00	5.8E+01	1.1E+02	1.5E+01	2.9E+03	5.5E+03	7.7E+02
30	6.7E+00	1.1E+01	1.5E+00	6.7E+01	1.1E+02	1.5E+01	3.3E+03	5.6E+03	7.7E+02
60	7.8E+00	1.1E+01	1.5E+00	7.8E+01	1.1E+02	1.5E+01	3.9E+03	5.6E+03	7.3E+02
90	8.4E+00	1.1E+01	1.5E+00	8.4E+01	1.1E+02	1.5E+01	4.2E+03	5.7E+03	7.3E+02
180	9.3E+00	1.1E+01	1.4E+00	9.3E+01	1.1E+02	1.4E+01	4.7E+03	5.6E+03	6.9E+02
365	9.1E+00	1.0E+01	1.2E+00	9.1E+01	1.0E+02	1.2E+01	4.6E+03	5.1E+03	6.2E+02
730	7.3E+00	8.3E+00	1.0E+00	7.3E+01	8.3E+01	1.0E+01	3.7E+03	4.2E+03	5.0E+02

Table 13.9. Hanford In Vivo Measurement Detection Capability for ^{152}Eu, ^{154}Eu, and ^{155}Eu, nCi

Measurement Type	Organ/Tissue	^{152}Eu	^{154}Eu	^{155}Eu
NaI Preview Count	Whole Body	20[a]	3.7[b]	NA
Coaxial Germanium Count	Whole Body	5.5[a]	1.7[b]	NA
Chest Count	Lung	0.4[a]	0.3[a]	0.6[a]
Skull Count	Skeleton	0.8[a]	0.5[a]	1.0[a]

(a) Not part of routine library. Estimated based on peak search algorithm.
(b) From *In Vivo Monitoring Project Manual*, PNL-MA-574.
NA = not applicable.

Europium-152 is not part of the routine whole body count library search algorithm, but is detectable by the peak search algorithm at whole body count levels of about 20 nCi.

Special measurements of lung, skeleton, or liver content may be desired to establish individual-specific patterns of distribution and retention. Because europium is a liver- and bone-seeking radionuclide, chest counts performed more than several weeks after intake may be detecting activity in the liver, the bones of the chest, and the lung, in any combination. Therefore, any quantification of lung activity should consider the contribution from the bones and the liver. Skeleton activity is estimated from a head count. A correction factor can then be derived for obtaining lung activity from a chest count. These calculations are performed by the In Vivo Measurement Program staff. Likewise, the presence of europium in the liver must also be considered for its potential impact on a chest count.

Minimum detectable committed effective dose equivalents for ^{154}Eu, based on whole body counting, are shown in Table 13.10 (0.5-µm-AMAD inhalation), Table 13.11 (5-µm-AMAD inhalation), and 13.12 (ingestion). Corresponding values for ^{152}Eu are shown in Tables 13.13, 13.14, and 13.15.

13.4.2 Routine Bioassay Monitoring Protocol

Routine bioassay monitoring for europium at Hanford can be accomplished by whole body counting. From Table 13.10, it is apparent that annual whole body counting for ^{154}Eu using the NaI preview counter provides sufficient sensitivity for detecting inhalation intakes resulting in doses well below 100 mrem, even when an equal amount of ^{155}Eu is included with ^{154}Eu at the time of intake. The minimum detectable dose from ingestion of a mixture of ^{154}Eu

Table 13.10. ^{154}Eu Minimum Detectable Intakes and Doses ($H_{E,50}$) for 0.5-µm-AMAD Class W Inhalation

Days Post Intake	NaI System[(a)] Minimum Detectable		Coax Ge System[(b)] Minimum Detectable	
	Intake (nCi)	Dose (mrem)	Intake (nCi)	Dose (mrem)
0	6.3	1.9	2.9	0.9
1	6.7	2.0	3.1	0.9
2	8.0	2.4	3.7	1.1
5	13	4.0	6.1	1.8
7	15	4.4	6.8	2.0
14	16	4.8	7.4	2.2
30	18	5.3	8.1	2.4
60	22	6.5	10	3.0
90	26	7.9	12	3.6
180	34	10	15	4.6
365	42	12	19	5.7
730	49	15	23	6.8
1825	77	23	35	11
3600	161	48	74	22
7300	740	220	340	100

(a) Based on MDA of 3.7 nCi.
(b) Based on MDA of 1.7 nCi.

Table 13.11. ^{154}Eu Minimum Detectable Intakes and Doses ($H_{E,50}$) for 5-µm-AMAD Class W Inhalation

Days Post Intake	NaI System[(a)] Minimum Detectable		Coax Ge System[(b)] Minimum Detectable	
	Intake (nCi)	Dose (mrem)	Intake (nCi)	Dose (mrem)
0	4.1	1.1	1.9	0.5
1	4.6	1.3	2.1	0.6
2	6.9	1.9	3.1	0.9
5	21	5.8	9.4	2.6
7	25	6.9	11	3.2
14	26	7.4	12	3.4
30	28	8.0	13	3.7
60	31	8.6	14	4.0
90	34	9.4	15	4.3
180	37	10	17	4.8
365	41	11	19	5.2
730	47	13	22	6.1
1825	74	21	34	10
3600	160	45	74	21
7300	710	200	330	92

(a) Based on MDA of 3.7 nCi.
(b) Based on MDA of 1.7 nCi.

Table 13.12. ^{154}Eu Minimum Detectable Intakes and Doses ($H_{E,50}$) for Ingestion

Days Post Intake	NaI System[(a)] Minimum Detectable		Coax Ge System[(b)] Minimum Detectable	
	Intake (nCi)	Dose (mrem)	Intake (nCi)	Dose (mrem)
0	3.7E+00	<0.1	1.7E+00	<0.1
1	5.2E+00	<0.1	2.4E+00	<0.1
2	1.2E+01	0.1	5.3E+00	<0.1
5	1.9E+02	1.5	8.9E+01	0.7
7	1.3E+03	10	5.9E+02	4.4
14	9.0E+03	68	4.1E+03	31
30	9.3E+03	69	4.3E+03	32
60	9.5E+03	71	4.4E+03	33
90	9.5E+03	71	4.4E+03	33
180	1.0E+04	75	4.6E+03	34
365	1.1E+04	82	5.0E+03	38
730	1.2E+04	93	5.7E+03	43
1825	1.9E+04	150	8.9E+03	67
3600	4.2E+04	320	1.9E+04	140
7300	1.9E+05	1500	8.9E+04	670

(a) Based on MDA of 3.7 nCi.
(b) Based on MDA of 1.7 nCi.

Table 13.13. ^{152}Eu Minimum Detectable Intakes and Doses ($H_{E,50}$) for 0.5-µm-AMAD Class W Inhalation

Days Post Intake	NaI System[(a)] Minimum Detectable		Coax Ge System[(b)] Minimum Detectable	
	Intake (nCi)	Dose (mrem)	Intake (nCi)	Dose (mrem)
0	3.4E+01	7.5	9.3E+00	2.1
1	3.6E+01	8.0	1.0E+01	2.2
2	4.3E+01	9.6	1.2E+01	2.6
5	7.1E+01	16	2.0E+01	4.3
7	8.0E+01	18	2.2E+01	4.8
14	8.7E+01	19	2.4E+01	5.3
30	9.5E+01	21	2.6E+01	5.8
60	1.2E+02	26	3.2E+01	7.1
90	1.4E+02	31	3.9E+01	8.6
180	1.8E+02	40	5.0E+01	11
365	2.2E+02	48	6.0E+01	13
730	2.5E+02	55	6.9E+01	15
1825	3.6E+02	80	1.0E+02	22
3600	6.9E+02	1.5E+02	1.9E+02	42
7300	2.4E+03	5.2E+02	6.5E+02	1.4E+02

(a) Based on MDA of 20 nCi.
(b) Based on MDA of 5.5 nCi.

Table 13.14. ^{152}Eu Minimum Detectable Intakes and Doses ($H_{E,50}$) for 5-µm-AMAD Class W Inhalation

Days Post Intake	NaI System[(a)] Minimum Detectable		Coax Ge System[(b)] Minimum Detectable	
	Intake (nCi)	Dose (mrem)	Intake (nCi)	Dose (mrem)
0	2.2E+01	4.6	6.0E+00	1.3
1	2.5E+01	5.2	6.8E+00	1.4
2	3.7E+01	7.8	1.0E+01	2.1
5	1.1E+02	23	3.1E+01	6.4
7	1.3E+02	28	3.7E+01	7.7
14	1.4E+02	30	3.9E+01	8.3
30	1.5E+02	32	4.2E+01	8.9
60	1.7E+02	35	4.6E+01	9.6
90	1.8E+02	38	5.0E+01	11
180	2.0E+02	42	5.5E+01	12
365	2.1E+02	45	5.9E+01	12
730	2.4E+02	51	6.6E+01	14
1825	3.5E+02	74	9.6E+01	20
3600	6.5E+02	140	1.8E+02	37
7300	2.4E+03	510	6.6E+02	140

(a) Based on MDA of 20 nCi.
(b) Based on MDA of 5.5 nCi.

Table 13.15. ^{152}Eu Minimum Detectable Intakes and Doses ($H_{E,50}$) for Ingestion

Days Post Intake	NaI System[(a)] Minimum Detectable		Coax Ge System[(b)] Minimum Detectable	
	Intake (nCi)	Dose (mrem)	Intake (nCi)	Dose (mrem)
0	2.0E+01	0.1	5.5E+00	<0.1
1	2.8E+01	0.1	7.7E+00	<0.1
2	6.3E+01	0.3	1.7E+01	0.1
5	1.1E+03	4.9	2.9E+02	1.4
7	6.9E+03	32	1.9E+03	8.9
14	4.9E+04	230	1.3E+04	63
30	5.0E+04	240	1.4E+04	65
60	5.1E+04	240	1.4E+04	66
90	5.1E+04	240	1.4E+04	66
180	5.3E+04	250	1.4E+04	68
365	5.7E+04	270	1.6E+04	74
730	6.5E+04	300	1.8E+04	83
1825	9.5E+04	450	2.6E+04	120
3600	1.7E+05	780	4.6E+04	220
7300	6.1E+05	2800	1.7E+05	780

(a) Based on MDA of 20 nCi.
(b) Based on MDA of 5.5 nCi.

and ^{155}Eu, as monitored by an annual whole body count, is also less than 100-mrem, assuming a ratio of ^{154}Eu:^{155}Eu of 4.7 in 2000. Annual whole body counting with the NaI preview counter is also sufficient for ^{152}Eu, even though that nuclide would be found by the less sensitive peak search routine rather than a library search. The fact that the source of ^{152}Eu appears to be different from ^{154,155}Eu suggests that concurrent exposure to all three nuclides seems unlikely. Routine bioassay monitoring for ^{155}Eu is not required because its presence can be inferred from the detection of ^{154}Eu, which is the more predominant nuclide due to its longer radioactive half-life.

A supplemental skeleton count to establish the ^{155}Eu:^{154}Eu ratio would allow determination of the total body content of ^{155}Eu. This measurement is warranted for an initial detection of ^{154}Eu on a whole body count, but need not be a routine bioassay.

Routine measurements in which a europium radionuclide is detected should be confirmed by follow-up in vivo measurements. The recommended protocol is to use high-resolution germanium detector whole body counting to confirm the identity and magnitude of activity indicated by the preview counter. Because of the adequate sensitivity of whole body counting, routine chest and skeleton measurements are not generally warranted for intake or dose assessment unless unusual retention or distribution is suspected.

13.4.3 Special Bioassay for Suspected Intakes

An in vivo whole body examination should be performed following a suspected intake. However, unless the exposure appears to be of such magnitude that actions to hasten the removal of the material from the body are considered, the initial examination can be at the earliest convenient time during normal working hours. A measurement of the chest or skeleton is warranted to establish the ^{155}Eu:^{154}Eu ratio.

Because there is much movement of inhaled material in the body during the first hours following an inhalation intake, early in vivo measurements should be considered semi-quantitative. Where early measurements suggest that the committed effective dose equivalent might exceed 100 mrem, follow-up measurements should be performed after about 5 days to allow for early clearance of material via the GI tract. Likewise, specialized measurements to estimate clearance rates from specific organs (i.e., chest counts and skeleton counts) should also be delayed until early GI tract clearance is complete.

13.5 Assessment of Internal Dose

The assessment of internal dose equivalent from europium is accomplished by evaluating in vivo measurement results. Assessments must consider the contribution of all radionuclides present in the mixture. For mixtures of ^{154}Eu and ^{155}Eu, the activity ratio should be established based on in vivo (e.g., skeleton) measurements of the two nuclides or determined from an isotopic analysis of a characteristic sample of the material. If the intake occurred many years before the measurements, decay correction must be made to determine the composition at the time of intake. Alternatively, if ^{155}Eu measurement data are not available, the amount of ^{155}Eu can be approximated from ^{154}Eu by back-calculating the ^{154}Eu value by radioactive decay correction from the time of intake to the reactor shutdown calendar year 1986 (a time when the ^{154}Eu:^{155}Eu ratio was approximately 2:1 [Weetman and DeHaven, 1982]), dividing the ^{154}Eu 1986 value by 2 (to account for the 2:1 ratio), and then decaying the resulting ^{155}Eu 1982 activity value to the time of intake.

The committed effective dose equivalent is calculated for confirmed occupational intakes from incidents discovered promptly in the workplace. A 10-mrem screening level is applied to possible detections as part of routine bioassay monitoring. Committed dose equivalents to specific organs and tissues are determined based on the criteria also presented in the *Hanford Internal Dosimetry Program Manual*.[(a)] Several methods exist to evaluate in vivo results in order to assess the internal dose equivalent. The simplest method, and the one recommended for initial evaluation of in vivo results, as well as for final evaluations when doses are low, involves fitting the in vivo measurement data to the expected internal activity using the biokinetic model prescribed by the ICRP in publication 30. This model is implemented using CINDY. For this evaluation, it is assumed that the material is in its most insoluble form; that the intake date, if unknown, is the midpoint of the period during which the intake could have occurred; and that the intake consisted of an inhalation of a class W aerosol with 0.5-µm-AMAD particles. Data-fitting is performed using CINDY. Alternatively, a hand calculation can be performed using the factors tabulated in this chapter.

If the intake could potentially result in a committed effective dose equivalent exceeding 100 mrem, then an investigation should be performed to determine the radionuclide composition of the involved mixture and to assess the dose equivalent from all radionuclides

(a) Pacific Northwest National Laboratory. 1999. *Hanford Internal Dosimetry Program Manual*. PNL-MA-552, Richland, Washington. (Internal manual.) Available URL: http://www.pnl.gov/eshs/pub/pnnl552.htm

present in the mixture. Additional in vivo measurements to confirm the assumed retention function, or to develop a case-specific retention function, should also be performed.

Observed in vivo retention of europium should be used in place of the ICRP biokinetic model for evaluations of internal doses that potentially exceed 100 mrem or when sufficient in vivo data are available for such an analysis. This can be accomplished by modifying distribution and retention parameters in CINDY to achieve better agreement between the model and the observed in vivo measurement data. Modifications to default model parameters must be documented in the internal dose assessment report.

13.6 Management of Internal Contamination Cases

Although, historically, there have been intakes involving europium radionuclides at Hanford, in no case have the intakes resulted in significant internal doses relative to occupational exposure limits. Because europium radionuclides are no longer produced, the concentrations of europium radionuclides at Hanford are slowly diminishing.

In vivo measurements performed following a potential intake provide an initial indication of the significance of an intake, although external contamination and rapid translocation of the material through the body may interfere with the accuracy of the measurement. If a significant intake is indicated, then various mitigative actions are possible (NCRP 1980; Bhattacharyya et al. 1992). Purgatives or laxatives, as well as enemas or colonic irrigations, may reduce the residence time of the radionuclide in the GI tract, thereby reducing absorption by the blood. Antacids may reduce the absorption rate from the GI tract. Once absorbed, diethylene triamine penta acetate (DTPA) may be considered as a chelating agent. All of these mitigative actions require prescription by medical authority. HEHF Occupational Medicine should be notified immediately upon indication of a severe intake potentially requiring mitigative action.

13.7 References

Bhattacharyya, M. H., B. D. Breitenstein, H. Metivier, B. A. Muggenburg, G. N. Stradling, and V. Volf. 1992. “Guidebook for the treatment of accidental internal radionuclide contamination of workers.” *Rad. Prot. Dosim.* 41:1.

International Atomic Energy Agency (IAEA). 1996. *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources*. Safety Series No. 115, Vienna, Austria.

International Commission on Radiological Protection (ICRP). 1979. "Limits for intakes of radionuclides by workers." (ICRP publication 30, part 1). *Annals of the ICRP*, 2:3-4, Pergamon Press, New York.

International Commission on Radiological Protection (ICRP). 1981a. "Limits for intakes of radionuclides by workers." (ICRP publication 30, part 3). *Annals of the ICRP*, 6:2-3, Pergamon Press, New York.

International Commission on Radiological Protection (ICRP). 1994a. "Human respiratory tract model for radiological protection." (ICRP publication 66). *Annals of the ICRP*, 24:1-3, Pergamon Press, New York.

International Commission on Radiological Protection (ICRP). 1994b. "Dose coefficients for intakes of radionuclides by workers." (ICRP publication 68). *Annals of the ICRP*, 24:4, Pergamon Press, New York.

National Council on Radiation Protection and Measurements (NCRP). 1980. *Management of Persons Accidentally Contaminated with Radionuclides*. NCRP Report No. 65, Bethesda, Maryland.

Weetman, R. A. and H. W. DeHaven. 1982. *Characterization of Airborne Radionuclides in UNC Facilities*. UNI-2164, UNC Nuclear Industries, Richland, Washington.