

SECTION 6.0

IODINE

6.0 IODINE

Radioiodines generated or used at Hanford include isotopes with half-lives ranging from minutes to millions of years in various physical and chemical forms. Internal radiation protection is achieved through the use of containment, ventilation, radioactive decay, and respiratory protection. Thus, exposures to radioiodines should only occur as a result of accident situations. This section provides information on the sources, characteristics and biokinetics of radioiodine and summarizes the technical basis used for its internal dosimetry at Hanford.

6.1 SOURCES AND CHARACTERISTICS OF RADIOIODINE

At Hanford the radioiodines of principal interest are ^{131}I , associated with reactor operations, and ^{125}I , associated with biological experimentation.

Although historically radioiodines were generated in large quantities during the operation of production reactors, the FFTF is currently the only generator of fission product radioiodine at Hanford. Iodine-131 is considered the most significant iodine radionuclide from an internal exposure standpoint. Several other radioactive isotopes of iodine are generated by the fission process; however, with the exception of the long-lived ^{129}I , the others are short-lived and of potential interest only during or within several days of reactor operation. Iodine-129 has, for practical purposes, an infinite half-life and is contained in irradiated fuel and associated separations and waste management facilities. However, unless concentrated by some means such as in the PUREX air treatment system, it is present in negligibly small quantities.

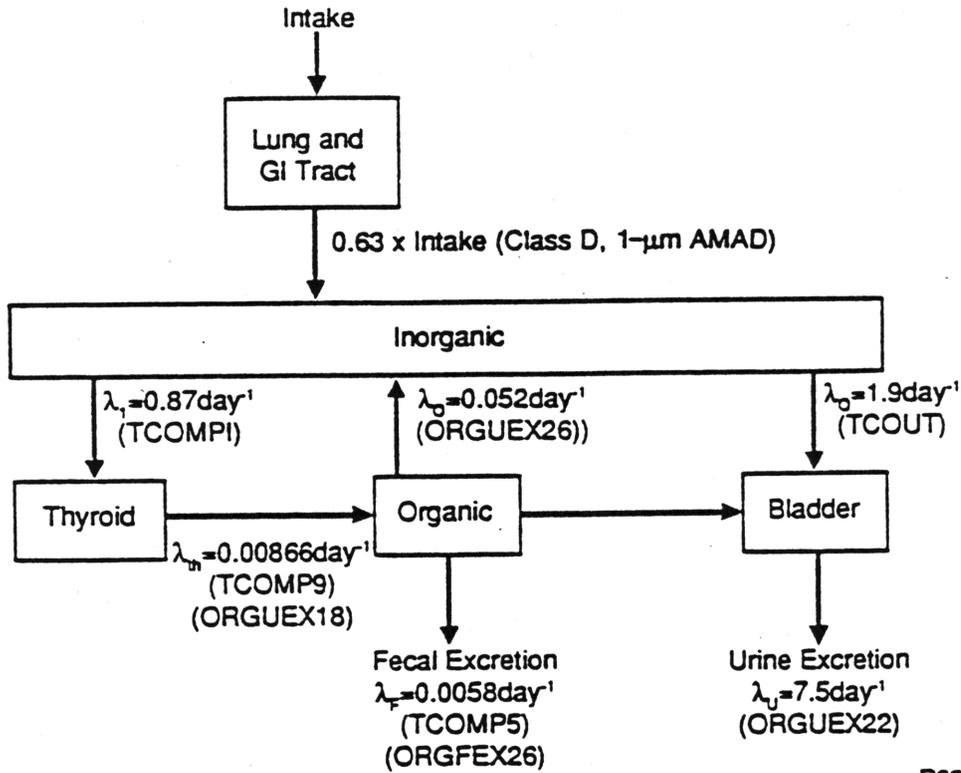
Iodine-125 is not generated at Hanford, but it is purchased for use in various biological research experiments. Thus, its use is generally limited to biology laboratories operated by PNL. Quantities of the isotope in use at one time are generally limited to amounts that could not result in significant internal exposures.

6.2 BIOKINETIC BEHAVIOR OF RADIOIODINE

The distribution and retention model described in ICRP 30 (1979) and ICRP 54 (1988) can be used to predict the uptake, retention, and resulting doses following an intake of a radioiodine. Using the ICRP assumptions for iodine intakes (class D transportability and 100% solubility in the GI tract), it is assumed that, for a 1- μm -AMAD aerosol, 63% of the intake is taken up into the circulatory system. The ICRP metabolic model, essentially the same one described by Riggs (1952), describes the deposition and retention of iodine in systemic compartments of the body. Of the iodine entering the systemic compartment, a fraction, 0.3, is assumed to be translocated to the thyroid, while the remainder is assumed to go directly to excretion. Iodine in the thyroid is assumed to be retained with a biological half-life of 80 days and to be lost from the thyroid in the form of organic iodine. Organic iodine is assumed to be uniformly distributed among all organs and tissues of the body other than the thyroid and to be retained there with a biological half-life of 12 days. One-tenth of this organic iodine is assumed to go directly to fecal excretion and the rest is assumed to be returned to the transfer compartment as inorganic iodine so that the effective half-life in the thyroid is 120 days.

The above model was implemented using the computer code GENMOD (Johnson and Carver 1981; see Appendix A). Several modifications to the iodine "default" compartment parameters in the Iodine Model of GENMOD 3.2 were made to provide for better agreement with dose values in ICRP 30 and retention values in ICRP 54 (1988). Figure 6.1 diagrams the iodine model employed by GENMOD and shows the model setup parameters used for the calculations in this section. The GENMOD variables that are set to the model parameters are provided in parentheses. The ICRP's lung and GI tract models are incorporated without change into GENMOD and, for simplicity, are represented by a single box in Figure 6.1.

As shown in Figure 6.1, material leaving the inorganic compartment is split 30/70 between the thyroid and bladder by setting the stable iodine removal rates to 1.9 day^{-1} and 0.87 day^{-1} , respectively. The material leaving the organic compartment is either recycled back to the inorganic



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FIGURE 6.1. Stable Iodine Retention Model

compartment or it goes directly to the feces. ICRP recommends a 90/10 split for this material, and this is achieved by setting the stable iodine removal rates in the organic compartment to 0.052 day^{-1} for removal to the inorganic compartment and 0.0058 day^{-1} for removal via fecal excretion. The recycling of the iodine back to the thyroid, along with stable iodine's fundamental half-life of 80 days in the thyroid, results in an apparent effective half-life of 120 days in the thyroid. Use of GENMOD allows for comparison of thyroid to total body iodine at various times after intake. However, for simplicity, ICRP 54 (1988) provides a thyroid retention function that effectively provides expected thyroid quantities following uptake:

$$\begin{aligned}
 r_{\text{thy}}^a(t) = & -0.33 \exp(-0.693t/0.24) + 0.018 \exp(-0.693t/11) \\
 & + 0.31 \exp(-0.693t/120)
 \end{aligned}
 \tag{6.1}$$

where t is in days post uptake.

For class D material, translocation from the lung to the blood is rapid and the above equation will provide an accurate thyroid retention value for the model after several days after acute inhalation.

6.3 INTERNAL DOSIMETRY FOR RADIOIODINE

The thyroid is the principally exposed organ following an intake of radioiodine and can be considered to be the only organ contributing to the effective dose equivalent for radioiodines with half-lives greater than a few days. Because of the low weighting factor for the thyroid ($W = 0.03$), the limiting dose from a regulatory standpoint is the nonstochastic limit of 50 rem/yr.

Table 6.1 gives first-year and 50-year committed effective dose equivalents per nanocurie for acute inhalation intakes of radioiodines (class D, 1- μ m AMAD). The 50-year committed effective dose equivalent will be received within a few weeks for ^{131}I , within a few months for ^{125}I , and within a few years for ^{129}I as shown in Figure 6.2.

Table 6.2 gives expected thyroid activity following an acute intake sufficient to result in a first-year effective dose equivalent of 100 mrem. Conversion from effective dose equivalent to thyroid dose is made by multiplying the effective dose equivalent by 33.3.

TABLE 6.1. First-Year and 50-Year Committed Effective Dose Equivalent Following an Acute Inhalation Intake of Radioiodine^(a)

Nuclide	Half-Life	mrem/nCi Intake		Fraction Received First Year
		First-Yr Eff. Dose Eq. ^(b)	50-Yr Comm. Eff. Dose Eq. ^(b)	
^{125}I	60 days	0.023	0.023	99%
^{129}I	1.6E+7 yr	0.15	0.16	89%
^{131}I	8 days	0.032	0.032	100%

(a) Assuming 1- μ m-AMAD particles.

(b) Thyroid dose equivalent is 33 times the effective dose equivalent.

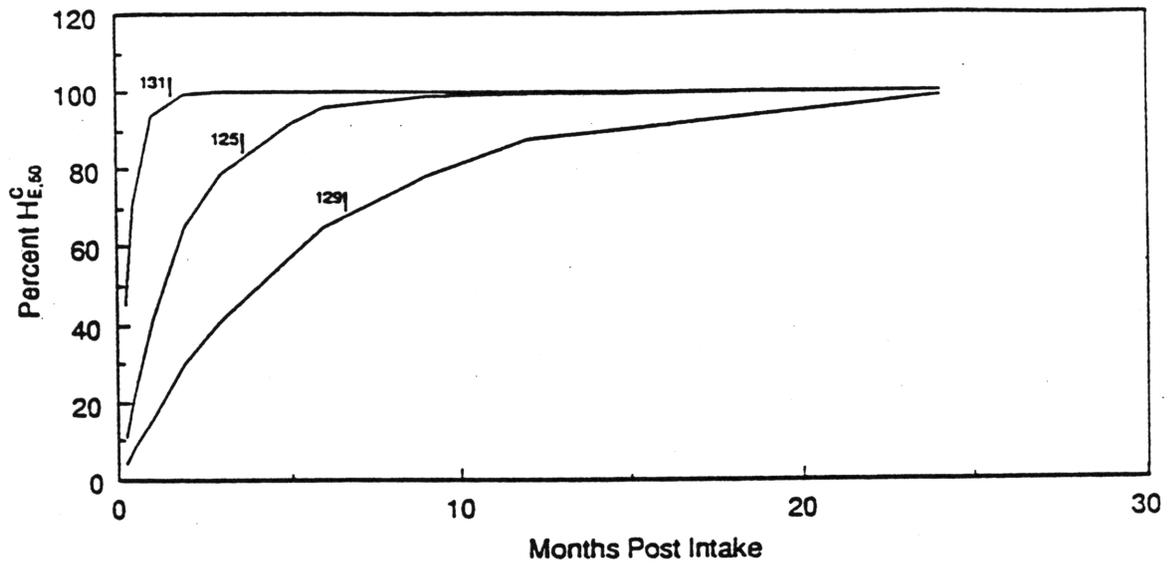


FIGURE 6.2. Percent of 50-Year Committed Effective Dose Equivalent Received at Times After Intake

TABLE 6.2. Expected Radioiodine in Thyroid Following an Acute Inhalation Resulting in a First-Year Effective Dose Equivalent of 100 mrem (Class D, 1- μ m AMAD)

Days Post Intake	Activity, nCi		
	¹²⁵ I	¹²⁹ I	¹³¹ I
1	650	100	430
2	780	120	480
5	790	130	390
7	760	130	320
14	670	120	170
30	500	110	38
60	290	91	2.4
90	170	76	(a)
180	36	45	(a)
365	1.4	15	(a)
730	(a)	1.7	(a)

(a) Much less than 1 nCi.

Table 6.3 gives the relationship between retained activity in the thyroid and effective dose equivalent.

Although the biokinetic models described in this section can be used to provide initial estimates of intake and dose following an exposure, in vivo measurements permit the actual retention in the thyroid to be determined. Thus, successive thyroid counts following an internal exposure yield data from which cumulated thyroid activity (in nCi-days) can be calculated. The dose conversion factors in Table 6.3 are applied to the calculated cumulative activities over time periods of interest to assess thyroid and effective dose equivalent.

The stochastic ALIs for class D ^{125}I , ^{129}I , and ^{131}I are $2\text{E}5$, $3\text{E}4$, and $2\text{E}5$ nCi, respectively; and the nonstochastic ALIs, based on thyroid dose, are $5\text{E}4$, $8\text{E}3$, and $5\text{E}4$ nCi, respectively.

6.4 BIOASSAY

In vivo measurements and a routine monitoring program for radioiodine isotopes are the main bioassay considerations.

6.4.1 Bioassay Methods

All radioiodine isotopes can be detected by in vivo measurements. Iodine-131 and the other short-lived iodine radionuclides can be detected readily using the NaI-detector-based preview counter (Palmer et al. 1987). Because of their low-energy photon emissions, ^{125}I and ^{129}I can only be measured using the intrinsic germanium (IG) detector systems in the thyroid-counting configuration.

TABLE 6.3. Dose from a Thyroid Burden of Radioiodine

Nuclide	Dose Conversion Factor, rem/nCi-day		Activity in Thyroid Yielding Eff. Dose Eq. Rate of 100 mrem/yr, μCi
	Thyroid	Eff. Dose Eq.	
^{125}I	7.1E-5	2.1E-6	0.13
^{129}I	1.7E-4	5.2E-6	0.053
^{131}I	5.1E-4	1.5E-5	0.018

In vivo measurement detection capabilities are summarized in Table 6.4.

6.4.2 Routine Bioassay Monitoring Program

It is recommended that routine bioassay measurements be performed at intervals not exceeding four to five effective half-lives of the radionuclide because of uncertainties associated with the assumed retention characteristics. In addition, a minimum annual bioassay frequency is recommended regardless of the effective half-life, so that adequate documentation of the internal exposure status is provided.

Thus, based on the above recommendations, the measurement frequency for the minimum recommended routine monitoring program for workers potentially exposed to ^{131}I , ^{125}I , and ^{129}I , respectively, is monthly, semiannually, and annually. Because of their short physical half-lives, it is generally not practicable to perform routine bioassay monitoring for $^{132-135}\text{I}$. Instead, assessment of exposures to these nuclides is normally accomplished by facility monitoring (e.g., air sampling).

Table 6.5 provides estimates of the annual effective dose equivalent potentially missed for several measurement frequencies. The doses are calculated assuming a worst-case scenario in which the individual receives an intake on the first day of each monitoring period that would be just below the

TABLE 6.4. Sensitivities of In Vivo Measurements for ^{125}I , ^{131}I , and ^{129}I

<u>Type of Measurement</u>	<u>Minimum Detectable Activity, nCi</u> (a)		
	<u>^{125}I</u>	<u>^{131}I</u>	<u>^{129}I</u> (b)
Whole body count			
Preview counter	(c)	4.5 ^(d)	(c)
Thyroid count			
Germanium detectors	0.004	0.03	0.004
3 x 3 NaI detectors	(c)	0.02	(c)

- (a) From Palmer et al. (1987). (See also Appendix C.)
 (b) Sensitivity is about the same as for ^{125}I .
 (c) Not detectable using these systems.
 (d) Using the detectors located over the chest region.

TABLE 6.5. Detectable Annual Effective Dose Equivalent for Various Routine In Vivo Monitoring Frequencies^(a)

Measurement Frequency	Detectable First-Yr and 50-Yr Committed Dose Equivalent, mrem ^(b)			
	Whole Body Count ¹³¹ I	Thyroid Count (using Ge detector)		
		¹²⁵ I	¹²⁹ I	¹³¹ I
Weekly	73	<1	<1	<1
Biweekly	69	<1	<1	<1
Monthly	140	<1	<1	<1
Bimonthly	(c)	<1	<1	(c)
Quarterly	(c)	<1	<1	(c)
Semiannual	(c)	<1	<1	(c)
Annual	(c)	(c)	<1	(c)

- (a) Assumes an acute intake occurs on the first day of each monitoring period during the year. Thus the detectable dose is N times the dose detectable during each monitoring period, where N is the number of monitoring periods per year. Based on detection capabilities for thyroid counts from Table 6.4.
- (b) The 50-year committed effective dose equivalent is essentially equal to the first-year effective dose equivalent for ¹²⁵I and ¹³¹I and is about 1.1 times the first-year effective dose equivalent for ¹²⁹I.
- (c) Surveillance frequency exceeds five times the effective thyroid residence time.

detection level of the next routine measurement. This approach was taken because of the relatively short retention time of ¹³¹I in the body and thus the need to perform routine bioassay measurements frequently during the year. No credit was taken for the long-term buildup of radioiodine in the thyroid that would decrease the doses reported in the table. Although values for ¹²⁹I were similarly calculated, an annual frequency is possible in that case.

From Table 6.5, it is apparent that for ¹³¹I the routine whole body count provided by the preview counter (MDA = 4.5 nCi) could ensure detection of a 100-mrem annual dose if performed biweekly, whereas a monthly germanium thyroid count could detect as low as a 1-mrem dose. The most appropriate

monitoring program for ^{131}I would thus be a whole body count every 2 weeks (or a thyroid count once every month) during the potential exposure period.

If a radioiodine isotope is detected in a routine measurement, follow-up measurements to confirm the intake should be performed. The measurements can usually be conveniently performed immediately following the initial measurement while the subject is at the whole body counting facility. The use of the high resolution germanium detectors for follow-up measurements is preferred in order to accurately quantify the thyroid deposition.

6.4.3 Bioassay Measurements Following an Acute Intake

Thyroid counts should be performed to assess the significance of an acute intake of radioiodine. The deposition of iodine in the thyroid following an acute intake is not instantaneous; rather, buildup of iodine in the thyroid will occur over a period of about 3 days following the intake. Results of thyroid counts obtained within a day or so of an intake may thus underestimate the maximum retained quantity that will be achieved following the exposure. Measurements made 2 to 3 days post intake will likely provide the best indication of the maximum retained quantity in the thyroid from the intake.

If significant quantities of short-lived iodine isotopes are possibly associated with an exposure, then in vivo measurements should be performed within a day of the intake. The measurements should be made using a germanium detector to achieve optimum resolution. Follow-up counts, if needed, should be performed. Data from facility monitoring may be used to identify the relative activities of the various radioiodines present at the time of intake. Caution should be exercised when analyzing in vivo data for short-lived iodine isotopes, to ensure that activity within the thyroid and not external contamination is being measured.

6.5 ASSESSMENT OF INTERNAL DOSE EQUIVALENT

Radioiodines can be detected and quantified in the thyroid using in vivo techniques. Thyroid counts are sufficiently sensitive to enable detection of activity in the thyroid at levels well below that of any dosimetric

consequence (see Table 6.5). Measurement of ^{125}I and ^{129}I requires the use of the low-energy germanium counting system.

Several methods exist to evaluate in vivo results in order to assess the internal dose equivalent. The simplest method, and one that is recommended for initial evaluation of in vivo results as well as for final evaluations when doses are very low, involves fitting the in vivo measurement data to the expected internal activity using the biokinetic model prescribed in this section. This model is implemented using GENMOD, and values of thyroid activity at various times following a given intake are provided in Table 6.2.

Assumptions that are used for this evaluation are that the material is inhaled in class D form, that the intake date, if unknown, is assumed to be the midpoint of the period during which the intake could have occurred, and that the intake consisted of the inhalation of an aerosol with an AMAD of $1\ \mu\text{m}$. The resulting retention function, calculated using GENMOD, is fit to the observed in vivo measurement data using techniques described in Appendix C.

A simplified dose assessment procedure for use in cases when annual effective dose equivalents are below 100 mrem is as follows:

1. Determine the time of intake. Assume the midpoint of the period during which the exposure could have occurred if a specific intake date is not known. For example, evaluation of measured activity in an annual count might assume that the intake occurred at the midpoint of the measurement period provided the worker could have incurred an intake at any time during the prior year.
2. Evaluate the bioassay measurement result using the biokinetic model described above.
3. If the calculated dose exceeds a 100-mrem first-year effective dose equivalent, then consider taking additional in vivo measurements to confirm the retention characteristics of the material and re-establish baseline internal activity levels.

If the intake could potentially result in an annual effective dose equivalent exceeding 100 mrem, then an investigation should be performed to determine whether other radionuclides were involved to review the validity of the above assumptions and to develop a case-specific retention function.

Observed in vivo retention should be used in place of the ICRP biokinetic model for evaluations of internal doses that potentially exceed 100 mrem/yr when sufficient in vivo data are available for such an analysis. This can be most easily accomplished by graphically analyzing the in vivo data to identify retention components. The retention curves are then integrated to obtain cumulative activity for calendar years following intake, and the cumulative activity is multiplied times the organ and effective dose equivalent conversion factors in Table 6.3 to obtain annual dose equivalents.

6.6 MANAGEMENT OF INTERNAL CONTAMINATION CASES

In an accident exposure situation, iodine will likely be taken in by inhalation, ingestion, and absorption through the skin. If the iodine is very soluble, it will reach the thyroid relatively quickly; however, maximum thyroid activity may not occur until 2 or 3 days post intake. Thus, thyroid counts performed shortly after intake may underestimate the deposition. Also of concern for in vivo measurements made shortly after intake are contributions to the count from radioiodine located outside the body or in other regions of the body. However, if thyroid measurements are made with a collimated germanium detector, these interferences can most likely be reduced to negligible levels.

The adult thyroid gland is considered to be a relatively radioresistant organ (weighting factor = 0.03) with respect to the risk of fatal malignancies. However, thyroid nodules, cancer, and hypothyroidism are all associated with radiation exposure to the thyroid. NCRP 65 (1980) recommends immediate administration of 300 mg KI or NaI tablets, regardless of the route of exposure, and daily administrations for 7 to 14 days (to prevent recycling back into the thyroid as a mitigative action following a large intake). For individuals receiving greater than a 100-rem dose equivalent to the thyroid, an estimate of residual thyroid function should be made within 2 or 3 months after exposure (NCRP 1980). Occupational Medicine (at HEHF) should be immediately notified of a potentially severe intake of radioiodine.