4.0 Tritium

This chapter provides information on the sources and biokinetics of tritium and summarizes the technical basis used for the internal dosimetry of tritium (^3H) at Hanford. This chapter is not intended to be an all-encompassing technical basis for any type of tritium exposure, but rather to provide the approach to be used for routinely encountered exposures at Hanford. A detailed review of tritium metabolism and dosimetry was published by Hill and Johnson (1993). There is broad consensus on the internal dosimetry for tritiated water vapor. However, organic forms and stable tritium particulates (notably metal tritides) are currently undergoing substantial technical evaluation within the DOE complex and the dosimetry for such materials is subject to change with emerging knowledge. Therefore, this chapter addresses such special forms of tritium in only a cursory manner at this time. Internal dosimetry staff should be contacted for concerns about these materials.

4.1 Sources and Environmental Levels of Tritium

Tritium exists as part of the natural background of environmental radiation (NCRP 1979a) originating from cosmic ray interactions. It is also a man-made nuclide that has been widely dispersed in the environment from nuclear weapons tests, nuclear power programs, and radioisotope applications.

Tritium work at Hanford has included tritium production, research associated with tritium production, the decontamination and decommissioning (D&D) of former tritium production facilities and laboratories associated with such facilities, radioluminescent lights developed by PNNL, and as a tracer or labeling compound for biological research projects. Tritium waste is also received at Hanford from other sites. Predominant forms of tritium have been tritium oxide (tritiated water), tritium gas, and at least one project involving stable metal tritides (notably, zirconium tritide).

Tritium oxide in the human body can be routinely detected at levels well below those of any dosimetric concern. Therefore, in addition to its use for dosimetry, tritium bioassay can be readily used as a workplace monitoring technique supplemental to air sampling or contamination surveys.

It can be assumed that the tritium concentration of the body water of nonoccupationally exposed persons should be reasonably close to that of their drinking water. The EPA has reported that background tritium concentrations in U.S. drinking water range from 100 to

400 pCi/l (EPA 1985), which corresponds to about 0.2 to 1 dpm/ml. In addition, the EPA has promulgated a limit for tritium in drinking water of 20 nCi/l, based on 4 mrem/yr (EPA 2000), although an upward revision of this limit seems technically justifiable (Moghissi and Cothern 1986).

Tritium has been widely distributed in the public domain as a source of luminosity for various "glow-in-the-dark" applications, such as the faces of watches, clocks, instruments, and exit signs. Breakage or other loss of containment in such devices could result in tritium levels in urine being substantially above background without occupational exposure. Normal diffusion of tritium through watch cases can account for detectable urinary excretion of tritium. Brunner et al. (1996) reported urine concentrations of 197 to 1133 Bq/l (12 to 68 dpm/ml) in 108 persons wearing plastic case watches containing tritium.

4.2 Chemical Forms of Tritium

Tritium occurs in several chemical forms that significantly affect the internal dosimetry associated with it. These forms include tritium gas (which is an external dose hazard posing little internal dosimetry impact, and thus is not addressed here), tritiated water vapor or liquid (HTO), and special tritium compounds including organically bound tritium and stable metal particulates. Tritiated water is the typical form encountered at Hanford, and routine Hanford dosimetry is based on this form. Organically bound tritium may be associated with things such as contaminated oils or experiments using tritium as a tracer. Stable metal particulates are often linked to metal tritides associated with tritium storage devices or tritium rust (tritiated iron oxide). Limited activities involving stable metal tritides have been identified by PNNL. The internal dosimetry for organically bound tritium and stable metal particulates is undergoing substantial review within the DOE complex, and this technical basis document will be augmented as needed to address new guidance. Organically bound tritium and stable metal particulates of tritium can deliver substantially more dose per unit intake than tritiated water.

Internal dosimetry for each of the three tritium forms of greatest concern is discussed in the following sections.

4.3 Internal Dosimetry for Tritiated Water

Determining the dose from tritium exposures involves calculating the dose to soft tissue from tritium that is assumed to be uniformly distributed throughout the body water. The body water concentration can be determined by first sampling the body fluids

(typically urine), then by directly measuring tritium using liquid scintillation techniques. For acute exposure situations, the initial body water concentration can be estimated from the retention function, and a total tritium uptake can be calculated using the Reference Man body water mass from ICRP 23 (1974). From this uptake, the soft tissue dose equivalent can be calculated for any pertinent time period. For chronic exposure situations, an equilibrium body burden of tritium can be estimated from the body water concentration, and a dose equivalent can be calculated for any pertinent time period using a dose rate factor. A summary of selected Hanford internal dosimetry factors for HTO is shown in Table 4.1. Their derivation is described in the following paragraphs.

Table 4.1. Hanford Tritiated Water (HTO) Dosimetry Factors

Radiological Half-Life	12.35 yr
Specific Effective Energy (SEE) Factor	9.0E-08 MeV/g-transformation
Effective Energy per Transformation	5.7 keV (0.0057 MeV)
Quality Factor	1.0
Biological Half-Life	10 days
Effective Half-Life	10 days
Tissue Weighting Factor	1.0
Source Organ	Body water
Source Organ Mass	42,000 g
Target Organ	Soft tissue
Target Organ Mass	63,000 g
Hanford HTO Dose Coefficient	1.8E-11 Sv/Bq, or 0.066 mrem/μCi
Water Absorption Rate through skin	0.065 mg/cm^2 min
Dose Equivalent per Unit Concentration Factor	1.3E-03 mrem per dpm/ml 2.8 mrem per μCi/l
Dose Rate per Unit Body Water Concentration Factor	0.19 mrem/day per μCi/l 8.7E-5 mrem/day per dpm/ml
Derived Air Concentration (10 CFR 835 Appendix A)	2E-05 μCi/m. or 8E+05 Bq/m^3

Historically, the approach to tritium dosimetry used in ICRP 2, ICRP 10, and American National Standards Institute (ANSI) N13.14-1983 was to calculate the dose to body water as the critical organ (ICRP 1959, 1969; ANSI 1983). A body water mass of 42,000 g was assumed for ICRP 23 Reference Man (1974). It was assumed that the dose to body water was essentially the same as the dose to soft tissue. In ICRP 30 (1979), a more realistic approach to tritium dosimetry was defined. The body water mass of ICRP 23 Reference Man (42,000 g) was recognized to be essentially uniformly distributed throughout the body mass of soft tissue (63,000 g). Consequently, tritium is now considered to be uniformly distributed throughout soft tissue, and it is the soft tissue mass that is

irradiated rather than merely the body water. The net effect is to distribute the decay energy over a larger mass of tissue, resulting in a lowered total dose. Although less conservative, this approach is more accurate from a biological and technical point of view. Reported tritium doses for exposures to tritium at Hanford prior to the 1989 implementation of this approach were approximately 33% higher than if they had been calculated using the newer approach.

Tritiated water is readily absorbed through intact skin. Pinson and Laugham (1980) reported a skin absorption rate for water of 0.065mg/cm^2 min.

Tritium as HTO is assumed to be instantaneously and uniformly mixed with body water immediately following intake. The f_1 factor is assumed to be 1 for all ages. This makes HTO a special case where total intake and systemic uptake are identical. Although the NCRP (1976) suggests that 2 or more hours may be required for this distribution and mixing to occur, from a practical standpoint the process is quite rapid and an approximate equilibrium condition will probably be reached by the time a sample can be collected. The collection of overnight urine samples provides good assurance that an equilibrium condition in the body has been achieved, however adequate dosimetry can be done using single void samples.

The metabolic model used for tritium is described in ICRP 30 (1979). Tritiated water is assumed to be uniformly distributed among all soft tissues at any time following intake. Its retention, R(t), is described as a single exponential with an effective clearance half-time of 10 days. Thus, the fraction of tritium taken into the body as tritiated water, which is retained in the body at time t days later, is given by:

$$R(t) = e^{\frac{-0.693}{10} \times t} = e^{-0.0693\,t} \qquad (4.1)$$

Radioactive decay is insignificant in this determination because the biological clearance half-time of 10 days far surpasses the physical decay half-time of 12 years as a mode of clearance from the body. This retention function has been well established and is considered appropriate for exposures to tritiated water (HPS 1994). It can be expected that the retention of tritiated water in individuals will vary from this, and if sufficient data are available to establish an alternate model for an individual worker's exposure, they should be used. In addition to body water, ICRP 30 acknowledged the existence of two organically bound tritium components. However, the ICRP concluded that these could be ignored for radiation protection purposes, and Johnson (1982) estimated that these components

would add approximately 10% to the committed dose equivalent. Unless worker data specifically indicate the existence of significantly longer-term components, the HIDP will follow the ICRP recommendation of single compartment retention. The number of transformations (U_s) resulting from an intake of 1 Bq can be calculated by integrating the retention function over the appropriate time interval. This calculation is shown below for the 50-year committed dose period:

$$\begin{aligned} U_s &= \int_0^{18,250} e^{-0.0693\,t}\,dt \\ &= 14.43\text{Bqd} \times 24\text{hd}^{-1} \times 3,600\text{sh}^{-1} \\ &= 1.25 \times 10^6 \text{ transformations} \end{aligned} \tag{4.2}$$

4.3.1 Dose Calculation for an Acute Exposure to HTO

The uniform concentration of tritium in body water and its single component clearance rate allow for the estimation of uptake based on concentration rather than total daily excretion. The retention function (Equation [4.1]) can be used to directly estimate the body water concentration as follows:

$$C_t = C_0 \times e^{-0.0693\ t} \tag{4.3}$$

where C_t is body water concentration on day t, C_0 is initial body water concentration, and t is elapsed time (days) post intake. C_0 can be determined from C_t and t by simple algebraic manipulation of this equation.

$$C_0 = \frac{C_t}{e^{-0.0693\ t}} \tag{4.4}$$

Once C_0 has been determined, the intake I_0 (same as uptake for tritiated water) for an acute exposure can be estimated by multiplying C_0 by the source organ (body water) mass as shown in Equation (4.5):

$$I_0 = C_0 \times \text{Body Water Mass or Volume} \tag{4.5}$$

where concentration and body water mass or volume units are consistent. The ICRP Reference Man body water mass of 42 kg or volume of 42,000 ml is used for normal internal dose calculations.

Using the ICRP 30 fundamental dose calculation described in Chapter 2.0 (Equation [2.2]), the transformations per unit intake

factor derived above, and the tritium SEE factor, the committed effective dose equivalent for an intake of 1 Bq of tritiated water is calculated to be

$$\begin{aligned} H_{E,50}\ (\text{Sv}) &= (1.6\times10^{-10})\times(1.25\times10^{6})\times(9.0\times10^{-8}) \\ &= 1.80\times10^{-11}\ \text{Sv} \end{aligned} \tag{4.6}$$

giving a dose coefficient ($h_{E,50}$) of 1.80E-11 Sv Bq^{-1}. This dose coefficient and its conventional unit's conversion (0.0666 mrem/μCi) are the factors used for tritiated water for Hanford internal dosimetry.

Using conventional units of mrem for $H_{E,50}$ and μCi for I_0, as is customary for the HIDP, the committed effective dose equivalent from an intake of tritium is calculated as

$$H_{E,50}\ (\text{mrem}) = 0.0666\times I_0\ (\mu\text{Ci}) \tag{4.7}$$

Substituting concentration C_0 (in μCi/l) times the Reference Man body water volume of 42 l for I_0, gives the following relationship, as described in American National Standard HPS N13.14 (1983):

$$H_{E,50}\ (\text{mrem}) = 2.79\times C_0\ (\mu\text{Ci}/\text{l}) \tag{4.8}$$

which, when converted to the Hanford reporting units for concentration of dpm/ml, becomes

$$H_{E,50}\ (\text{mrem}) = 0.00126\times C_0\ (\text{dpm}/\text{ml}) \tag{4.9}$$

A comparison of HTO dose coefficients from several published sources is shown in Table 4.2. The reason for the discrepancy between the Hanford dose coefficient derived by Equation (4.6), the ICRP 30 value, and the EPA value is differences in rounding conventions between the calculations. The reason for discrepancies between the Hanford value and the ICRP 56 and ICRP 78 (1989; 1997) values is more complex. According to discussions between Hanford internal dosimetry staff and the internal dosimetry modeling group at Oak Ridge National Laboratory (ORNL) that originated the values, the ICRP 56 ingestion value was in error and was updated in ICRP 67 (1993) without notice of an erratum. As opposed to the ICRP 30 soft tissue mass of 63 kg, the ICRP 67 model used a body mass of 68.831 kg representing the total body mass minus the contents of the GI tract and urinary and gall bladders. Thus the resulting ICRP 67 SEE factor was 8.25E-08 Mev/g-trans (compared with the ICRP 30 value of 9E-08 Mev/g-trans). This adjustment offset the 10% increase in the number of transformations resulting

from using the ICRP 56 two-component biokinetic model (97% of the tritium clearing with a 10-d half-time and 3% clearing with a 40-d half-time, representing a small organically bound component).

Table 4.2. Comparison of Tritium Dose Factors

Tritiated Water (HTO)	**Reference**
Dose Coefficients	
1.8E-11 Sv/Bq (0.0666 mrem/μCi)	Hanford (this manual)
1.7E-11 Sv/Bq	ICRP 30 (1979)
1.73E-11 Sv/Bq	EPA (1988)
1.6E-11 Sv/Bq	ICRP 56 (1989)
1.8E-11 Sv/Bq	ICRP 67 (1993), 68 (1994), 71 (1995) and 78 (1997)
Derived Air Concentration (DAC)	
2E-05 μCi/ml (8E+05 Bq/m^3)	10 CFR 835 Appendix A
2E-05 μCi/ml (8E+05 Bq/m^3)	EPA (1988)
8E+05 Bq/m^3	ICRP 30 (1979)
Organically Bound Tritium (OBT)	
Dose Coefficients	
4.0E-11 Sv/Bq	Ingestion ICRP 56 (1989)
4.2E-11 Sv/Bq	Ingestion ICRP 67 (1993), 68 [1994]), 78 (1997)
4.1E-11 Sv/Bq	Inhalation ICRP 71 (1995), 78 (1997)
Air Concentration Value (ACV)	
Insoluble=1E-06 μCi/ml. (6E+04 Bq/m^3)	DOE (2001)
Soluble=9E-06 μCi/ml (3E + 05 Bq/m$^{3)}$	DOE (2001)
Stable Tritiated Particulates (STP)	
Dose Coefficients	all from ICRP 71 (1995)
6.2E-12 Sv/Bq	Inhalation of 1-μm AMAD particles, type F, f_1=1
4.5E-11 Sv/Bq	Inhalation of 1-μm AMAD particles, type M, f_1=0.2
2.6E-10 Sv/Bq	Inhalation of 1-μm AMAD particles, type S, f_1=0.02
Air Concentration Value (ACV)	all from DOE (2001)
Type F: 2E-05 μCi/ml (8E + 05 Bq/m^3)	
Type M: 1E-06 μCi/ml (4E + 04 Bq/m^3)	
Type S: 1E-06 μCi/ml (4E + 04 Bq/m^3)	

Thus, there is not a significant difference in the ICRP 30 dose coefficient calculated by the HIDP using first principles and the ICRP 67, 68, and 78 dose coefficients calculated by ICRP using a reduced SEE factor (ICRP 1979; 1993; 1994; 1997). As of this writing, it has not been resolved to the satisfaction of the HIDP staff that the later ICRP method is a significantly improved approach.

Consequently, the Hanford dose coefficient as derived from basic principles using ICRP 30 methods in this chapter is used for dosimetry.

4.3.2 Dose Calculation for a Chronic Exposure to HTO

For chronic exposure, or a series of continuing acute exposures, an equilibrium concentration in body water is assumed. The dose equivalent rate during the period when the concentration is maintained can be calculated by substituting the equilibrium body water concentration (C_{eq} (μCi/l) × 42) for A_s in Equation (2.1) and addressing units conversion, which gives

$$\dot{H}_{E,eq}\ (\text{mrem/d}) = 0.19 \times C_{eq}\ (\mu\text{Ci/l}) \tag{4.10}$$

and in units typically reported by the Hanford radiochemistry bioassay laboratory:

$$\dot{H}_{E,eq}\ (\text{mrem/d}) = 8.7 \times 10^{-5} \times C_{eq}\ (\text{dpm/ml}) \tag{4.11}$$

The dose equivalent for the time period during which the equilibrium body water concentration is maintained can then be calculated by

$$H_E\ (\text{mrem}) = \dot{H}_{E,eq} \times t \tag{4.12}$$

where t = duration of exposure in days.

The total committed dose resulting from a chronic exposure interval consists of the dose incurred during the interval (as calculated by Equation (4.12) and the dose incurred following the termination of intake. This latter component can be calculated using the equation for an acute exposure (e.g., Equation [4.8]) where C_0 is equal to C_{eq}) in μCi/l as follows:

$$H_{E,total}\ (\text{mrem}) = (\dot{H}_{E,eq} \times t) + (2.8 \times C_0) \tag{4.13}$$

4.3.3 HTO Dosimetry Based on Multiple Sample Results

When data from routine monitoring indicate that multiple acute intakes or combinations of acute and chronic exposure conditions may exist, dosimetry may be performed by integrating the body water concentration over time and multiplying by the dose rate per unit concentration factor listed in Table 4.2 (as shown in Equation

[4.14]). This method is particularly useful if samples are obtained frequently enough to provide an accurate estimate of the integral value.

$$H_E = 0.19 \int C_t \, dt \tag{4.14}$$

where H_E = mrem and C_t is in μCi/l.

4.3.4 Bioassay for Intakes of Tritiated Water

Bioassay monitoring for intakes of tritiated water is relatively simple and involves sampling a representative body fluid. Any body fluid can be used, but from a practical standpoint urine is the medium of choice. Because dosimetry can be readily performed using concentration data and because the models are quite simple, a single voiding (spot) urine sample is sufficient to obtain an adequate volume for analysis. Only a few milliliters are actually used in the liquid scintillation analysis procedure. Sufficient time should pass following exposure to allow for uniform distribution throughout body fluids. The NCRP suggests that 2 or more hours may be required for this (NCRP 1976). For this reason, it is usually recommended that tritium samples be collected at home using a multiple voiding sampling protocol to obtain an average concentration.

The Hanford bioassay laboratory's liquid scintillation procedure involves direct mixing of a small quantity (1ml) of the urine sample with the scintillation cocktail solution. The sample is then counted in a liquid scintillation analyzer.

4.3.5 Derived Reference Levels for HTO Bioassay

Derived screening levels, investigation levels, and compliance levels, based on committed effective dose equivalents of 10-mrem, 100-mrem, and 5,000 mrem, respectively, are shown in Table 4.3 for a single acute intake, and Table 4.4 for multiple intakes.

4.3.6 Bioassay Measurements Capability for Acute HTO Exposures

The detection capability of a routine tritium bioassay monitoring program for acute exposures has been considered in terms of minimum detectable dose (committed effective dose equivalent) per intake and year, using an analytical procedure sensitivity of 20 dpm/ml. In making these calculations, it was assumed that an acute intake occurred on the day immediately following a sample; thus, the time post intake was considered equal to the length of the sample interval. It was also assumed that the pattern of one intake at

the start of each interval might be maintained for a year. The results of these calculations are listed in Table 4.5 and plotted as the acute intake curve in Figure 4.1.

Table 4.3. Single Acute Intake Derived Reference Levels for Tritium Urine Excretion

Days Post Intake	Body Water IRF 100% - 10 day ICRP 30 HTO	10-mrem $H_{E,50}$ Derived Screening Level[(a)] (dpm/ml)	100-mrem $H_{E,50}$ Derived Investigation Level[(b)] (dpm/ml)	5-rem $H_{E,50}$ Derived Compliance Level[(c)] (dpm/ml)
0	1.0E+00	7.9E+03	7.9E+04	4.0E+06
1	9.3E-01	7.4E+03	7.4E+04	3.7E+06
2	8.7E-01	6.9E+03	6.9E+04	3.5E+06
3	8.1E-01	6.4E+03	6.4E+04	3.2E+06
7	6.2E-01	4.9E+03	4.9E+04	2.4E+06
14	3.8E-01	3.0E+03	3.0E+04	1.5E+06
30	1.3E-01	9.9E+02	9.9E+03	5.0E+05
60	1.6E-02	1.2E+02	1.2E+03	6.2E+04
90	2.0E-03	1.6E+01	1.6E+02	7.8E+03
180	3.8E-06	3.0E-02	3.0E-01	1.5E+01
365	1.0E-11	8.2E-08	8.2E-07	4.1E-05

(a) Based on 150 μCi intake.
(b) Based on 1,500 μCi intake.
(c) Based on 75,000 μCi intake.

Table 4.4. Multiple Acute Intake Derived Reference Levels for Tritium Urine Excretion

Days Post Intake	Body Water IRF 100% - 10 day ICRP 30 HTO	Monitoring Intervals per Year	10-mrem $H_{E,50}$ Derived Screening Level[(a)] (dpm/ml)	100-mrem $H_{E,50}$ Derived Investigation Level[(b)] (dpm/ml)
1	9.3E-01	3.7E+02	2.0E+01	2.0E+02
2	8.7E-01	1.8E+02	3.8E+01	3.8E+02
3	8.1E-01	1.2E+02	5.3E+01	5.3E+02
7	6.2E-01	5.2E+01	9.4E+01	9.4E+02
14	3.8E-01	2.6E+01	1.2E+02	1.2E+03
30	1.3E-01	1.2E+01	8.3E+01	8.3E+02
60	1.6E-02	6.0E+00	2.1E+01	2.1E+02
90	2.0E-03	4.0E+00	3.9E+00	3.9E+01
180	3.8E-06	2.0E+00	1.5E-02	1.5E-01
365	1.0E-11	1.0E+00	8.2E-08	8.2E-07

(a) Assumes one intake per monitoring interval and ignores residual from previous intakes.
(b) Based on 10-mrem screening level intake of 150 μCi cumulative for 1 year.
(c) Based on 100-mrem investigation level intake of 1500 μCi cumulative for 1 year.

Table 4.5. Minimum Detectable Intakes (MDIs) and Doses (MDDs)[a] for Acute Tritium Intake Based on the ICRP 30 Retention Model and Analytical Sensitivity of 20 dpm/ml in Body Water

Days Post Intake	ICRP 30[b] Retention Fraction	MDI for Interval (µCi)	Interval MDD (mrem)	Monitoring Intervals per Year	Maximum Annual MDD[c] (mrem)	Chronic Exposure (mrem)
1	9.3E-01	4.1E-01	2.7E-02	NA	NA	0.64
2	8.7E-01	4.3E-01	2.9E-02	NA	NA	0.64
3	8.1E-01	4.7E-01	3.1E-02	NA	NA	0.64
7	6.2E-01	6.1E-01	4.1E-02	52	2.1E+00	0.64
14	3.8E-01	1.0E+00	6.6E-02	26	1.7E+00	0.64
30	1.3E-01	3.0E+00	2.0E-01	12	2.4E+00	0.64
60	1.6E-02	2.4E+01	1.6E+00	6	9.7E+00	0.64
90	2.0E-03	1.0E+02	1.3E+01	4	5.2E+01	0.64
120	2.4E-04	1.5E+03	1.0E+02	4	4.1E+04	0.64
180	3.8E-06	9.9E+04	6.6E+03	2	1.3E+04	0.64
365	1.0E-11	3.7E+10	2.4E+09	1	2.4E+09	0.64

(a) Committed effective dose equivalent.
(b) ICRP 30 model is 100% retained with a 10-day biological half-time.
(c) Assumes one intake per interval and no buildup from intakes.

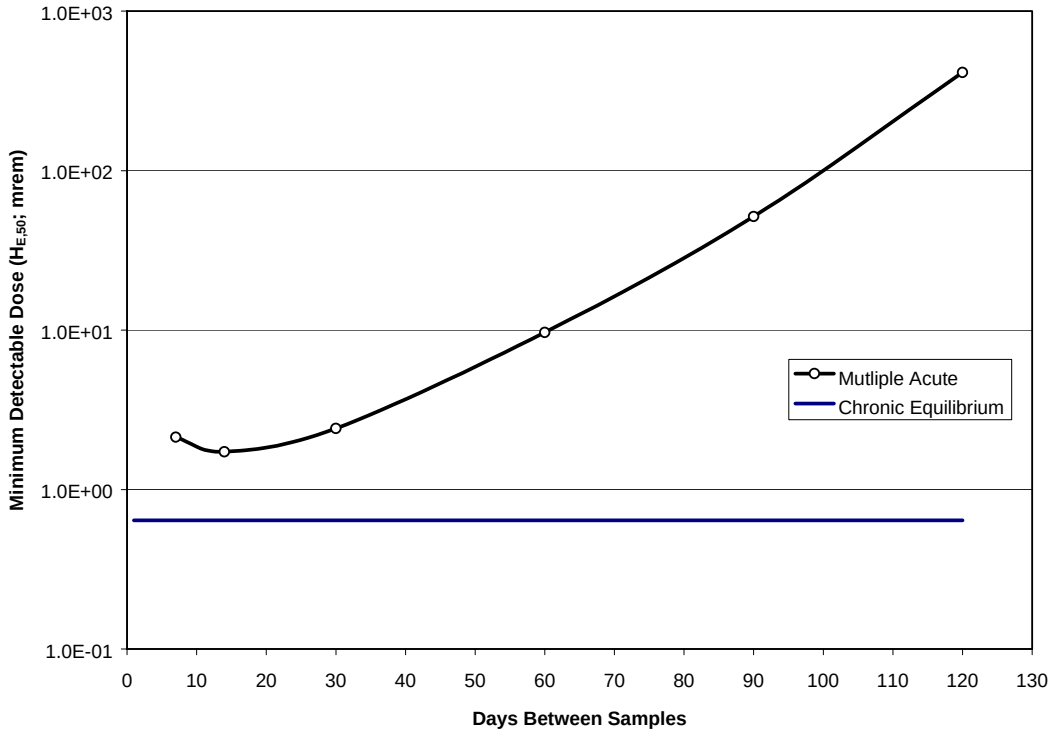

Figure 4.1. Tritium Bioassay Monitoring Program Detection Capability for Analytical Sensitivity of 20 dpm/ml using the ICRP 30 Retention Model

As previously noted, there is evidence for an organically bound component of a tritium oxide intake that can affect bioassay data interpretation at long times (e.g., >90 days) post intake. Table 4.6 shows the bioassay program capability for a program factoring in the 3% organically bound component. Because of the uncertainties associated with this component and the significant impact on minimum detectable dose of extending bioassay intervals to periods in excess of 90 days (compare with Table 4.5), this component is not being incorporated into routine program design and interpretation. If post-intake monitoring of an individual worker shows evidence of this organically bound component, it will be factored into the calculations.

Table 4.6. Minimum Detectable Intakes (MDIs) and Doses (MDDs)[(a)] for Acute Tritium Intakes, Assuming the ICRP 56 Two-Component Body Water Retention Model and an Analytical Sensitivity of 20 dpm/ml in Body Water

Days Post Intake	ICRP 56[(b)] Retention Fraction	MDI for Interval (μCi)	Interval MDD (mrem)	Monitoring Intervals per Year	Maximum Annual MDD[(c)] (mrem)
1	9.3E-01	4.0E-01	2.9E-02	NA	NA
2	8.7E-01	4.3E-01	3.1E-02	NA	NA
3	8.2E-01	4.6E-01	3.4E-02	NA	NA
7	6.2E-01	6.1E-01	4.4E-02	52	2.3E+00
14	3.9E-01	9.7E-01	7.0E-02	26	1.8E+00
30	1.4E-01	2.7E+00	2.0E-01	12	2.4E+00
60	2.6E-02	1.5E+01	1.1E+00	6	6.4E+00
90	8.2E-03	4.6E+01	3.3E+00	4	1.3E+01
120	4.0E-03	9.5E+01	6.9E+00	4	2.8E+01
180	1.3E-03	2.8E+02	2.1E+01	2	4.1E+01
365	5.4E-05	7.03E+03	5.1E+02	1	5.1E+02

(a) Committed effective dose equivalent.
(b) ICRP 56 retention model is 97% retained with a 10-day half-life and 3% retained with a 40-day half-life.
(c) Assumes 1 intake per interval and no buildup from multiple intakes.

4.3.7 Bioassay Measurement Capability for Chronic HTO Exposures

If the exposure condition is chronic and an equilibrium body water concentration of 20 dpm/ml is assumed (equal to the sensitivity of the analytical procedure and implying a daily intake rate of 26 nCi), then the resulting committed effective dose equivalent from 365 days of intake would be 0.64 mrem. Because of the assumption of chronic equilibrium conditions, this estimate is independent of sample frequency, and is thus shown as a flat line in Figure 4.1.

4.3.8 Optimum Bioassay Sampling Intervals for HTO Exposures

From Figure 4.1, it is apparent that the optimum routine bioassay sampling frequency for tritium is once every 2 weeks (biweekly) for periodic acute intakes of tritium. Where exposure conditions are well established and anticipated tritium doses are low (e.g., <100 mrem for the year), less frequent intervals (e.g., monthly to quarterly) are adequate. However, the uncertainties with dose estimates associated with longer sampling intervals become much higher. Because of the 10-day effective half-life and the uncertainties associated with a possible organically bound tritium component, sampling intervals for HTO greater than 90 days are specifically not recommended. If the potential exposure to tritium is anticipated only for a very limited interval, starting and ending bioassay samples might be more suitable than participation in a continuing monitoring program.

Based on Table 4.5, a worker monitoring program using screening levels of 110 dpm/ml for biweekly samples or 80 dpm/ml for monthly samples is capable of detecting a 10-mrem dose equivalent in a year based on a series of acute or chronic HTO intakes. These screening levels are conservative because they ignore the buildup of excretion of tritium in urine as the number of periodic intakes increases during the year, as shown in Figure 4.2. At these screening levels, sampling schedules should be reviewed to ensure that workers are on an adequate routine monitoring program consistent with their work. If indications are that annual doses may exceed 100 mrem from ongoing work, then a biweekly sampling program is recommended.

4.3.9 Special Monitoring for HTO

Special monitoring may be required after unplanned or unusual exposures. When an unusual exposure has been suspected or reported, arrangements should be made to collect a urine specimen within a reasonably short period of time following the exposure, allowing for the achievement of body water equilibrium. For potentially high exposures, this sample might be a single voiding sample collected at the workplace. For less serious exposures, an overnight (simulated 12-hour) or simulated 24-hour sample provides confidence that body equilibrium has been achieved and may be more convenient.

Follow-up sampling should be performed to confirm the initial sample results if implied doses might exceed 100 mrem. Additional

follow-up samples may be warranted to verify the applicability of the 10-day retention half-time in the individual, or to assess a more

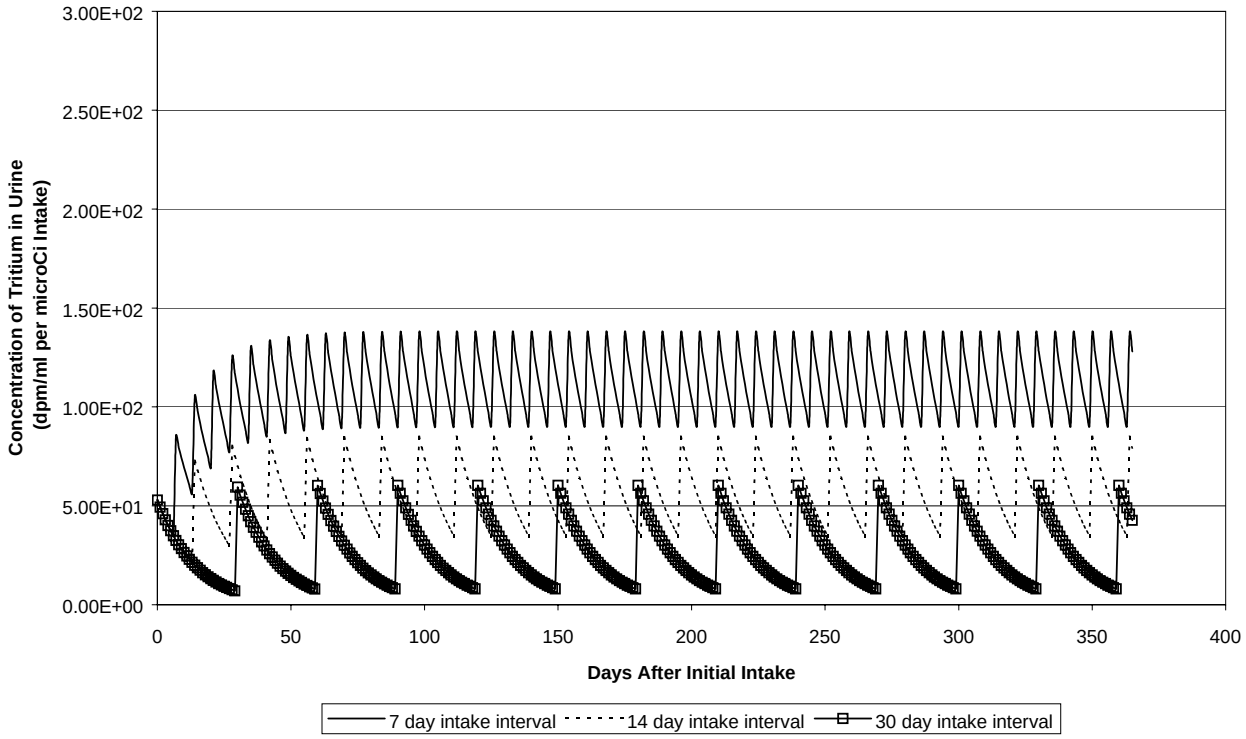

Figure 4.2. Excretion of Tritium Following Multiple Intakes Based on the ICRP 30 Model and Assuming 1-µCi Intake per Interval

suitable half-time. To adequately determine the degree of agreement between observed and anticipated retention may require only two or three samples over a period of about 3 weeks, or it may involve a more extended sampling program. The evaluator must exercise judgment in determining the number of samples warranted. If the exposed worker is already on a routine (e.g., bi-weekly) monitoring frequency, additional special sampling for follow-up may not be required.

Once an exposure has been evaluated, elevated urine samples might be expected for some time (several months). If the worker returns to work that involves potential tritium exposure, a more frequent sampling program may be required until normal baselines are re-established. During this time period, consideration may need to be given to the possibility that additional low-level uptakes of tritium might occur, which could be undetectable due to variability in the excretion pattern of tritium retained from the earlier intake.

4.4 Internal Dose Assessment Protocols for HTO

This section provides summary protocols for the assessment of occupational internal dose for HTO. As such, it applies the concepts described in the foregoing Section 4.3.

4.4.1 Dose Assessment for a Single Acute Exposure

To calculate the committed effective dose equivalent from an acute intake of tritium based on a single urine sample result, proceed as follows:

1. Calculate the sample concentration, C_t, in dpm/ml.

$$C_t = \frac{\text{reported result, dpm}}{\text{sample volume, ml}} \tag{4.15}$$

2. Calculate the initial body water concentration, C_0, in dpm/ml.

$$C_0 = \frac{C_t}{e^{-0.0693 \times t}} \tag{4.16}$$

where t is the time in days between the intake and the collection of the urine sample.

3. Calculate the committed effective dose equivalent, H_E, in mrem.

$$H_E = 0.0013 \times C_0 \tag{4.17}$$

4.4.2 Dose Assessment for Chronic Exposure

To calculate the committed effective dose equivalent from a chronic exposure to tritium (assuming the equilibrium condition), proceed as follows:

1. Calculate the body water equilibrium concentration, C_{eq}, in dpm/ml.

$$C_{eq} = \frac{\text{reported result (dpm)}}{\text{sample volume (ml)}} \tag{4.18}$$

2. Calculate the committed effective dose equivalent, H_E, in mrem, for the interval of the exposure (t, in days).

$$H_E = \left[\left(8.7 \times 10^{-5} \times t\right) + 0.0013\right] \times C_{eq} \tag{4.19}$$

4.4.3 Dose Assessment for Periodic Samples

In situations where periodic samples are obtained, not associated with specifically identified intakes but rather with ongoing work practices, an average concentration and dose associated with a sampling interval can be calculated. The choice of an arithmetic mean versus a logarithmic mean has little impact on the dose estimates for intervals of 1 month or less (La Bone 1992). The dose for each sampling interval can be calculated using Equations (4.11) and (4.12), and the total dose for multiple intervals (e.g., for a year) can be calculated by summing the interval doses for the total period. This approach lends itself well to a simple computer spreadsheet application software, which the HIDP typically uses for these cases.

4.5 Management of Internal Contamination Cases

The primary treatment for reducing internal dose from a tritium uptake is to accelerate the turnover of body water. This can be done by substantially increasing the fluid intake rate of an individual through oral or intravenous means, and/or using diuretics (Bhattacharyya et al. 1992; NCRP 1980; IAEA 1978). A case study by Lloyd et al. (1986) of therapy for two HTO intakes indicated that diuresis therapy while hospitalized resulted in a 2.7-day clearance half-time, compared with a 10-day normal clearance half-time, and a sustained drinking regime gave a clearance half-time of about 6 days. Dose-mitigating actions should be recommended by the Occupational Medicine Department of the Hanford Environmental Health Foundation (HEHF) in consultation with Internal Dosimetry.

4.6 Tritium Monitoring Program for the 400 Area

The 400 Area of the Hanford Site, which includes the Fast Flux Test Facility (FFTF), obtains its drinking water from groundwater wells. Some of these wells contain low levels of tritium (below the EPA drinking water standards) originating from aquifer contamination by the past operation of 200 Area fuel processing and waste management facilities (Jaquish and Bryce 1989). Planned operations supporting fusion materials research were expected to produce large quantities of tritium, resulting in the need for a routine tritium bioassay program. In FFTF workers, the existence of potentially detectable tritium, which could be attributable to environmental sources rather than occupational exposure, warranted establishing a screening level to use as a basis for initiating investigations and dose assessments of potential occupational exposure.

A baseline bioassay monitoring program was undertaken for FFTF workers prior to the commencement of the tritium operations (Carbaugh, Sula, and McFadden 1990). Forty-seven urine samples were collected from FFTF operations personnel over a 5-month period in early 1989. The sample data are plotted in Figure 4.3.

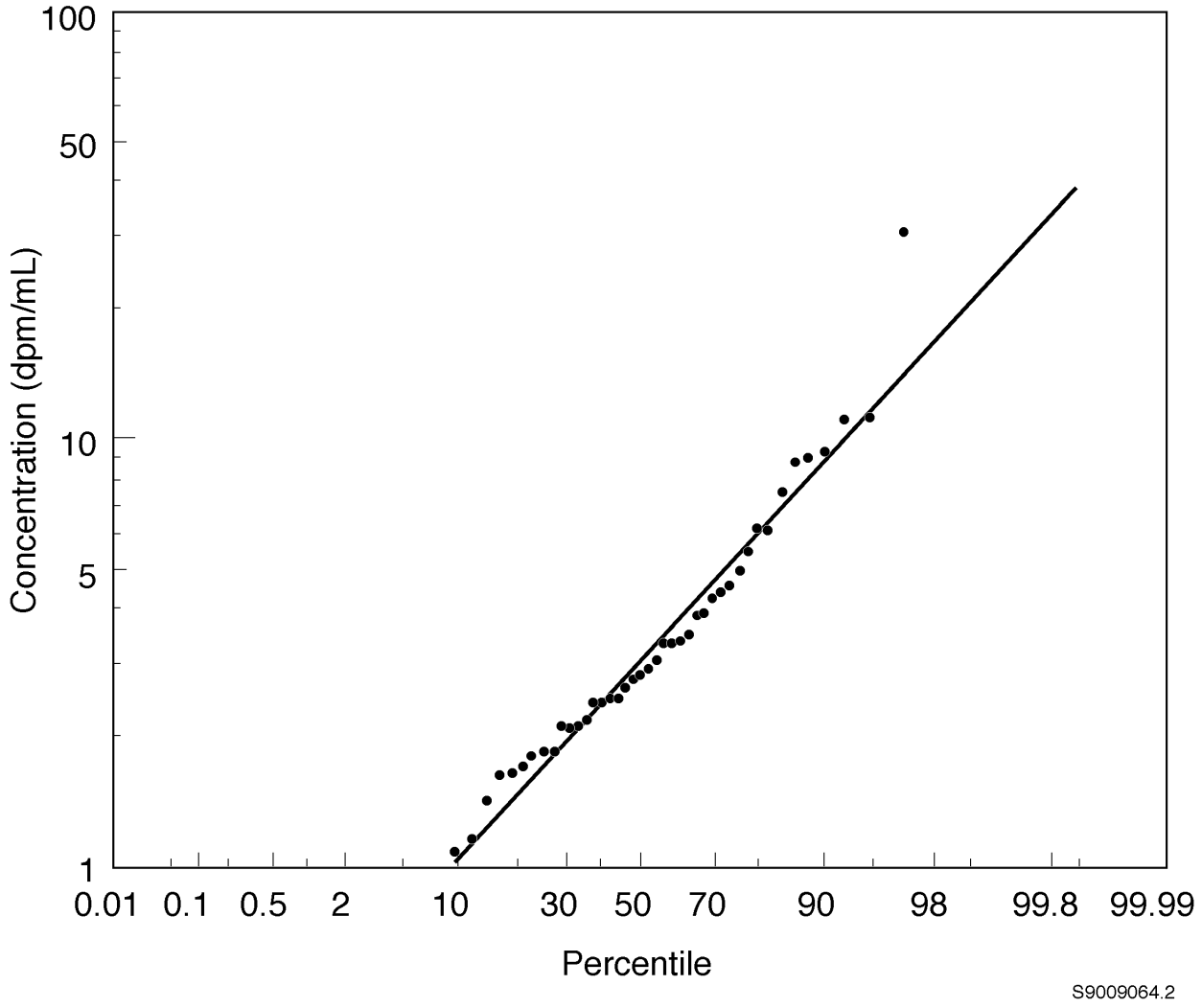

Figure 4.3. Tritium Urine Concentration in Occupationally Unexposed FFTF Workers

Based on the curve fit, it was estimated that the geometric mean was 3 dpm/ml and the tritium concentration corresponding to the 99.9 percentile for environmental exposure at FFTF was 40 dpm/ml. This concentration is similar to the 20,000 pCi/l (44 dpm/ml) EPA Drinking Water Standard for tritium (EPA 2000).

The minimum detectable committed effective dose equivalent associated with a 40-dpm/ml tritium screening level was estimated to be 1.2 mrem for chronic equilibrium exposure conditions, 5 mrem for acute intakes with weekly to monthly sample intervals (the

anticipated range of sampling intervals), and 100 mrem for quarterly intervals.

Because of the low dose potentially associated with chronic exposure or anticipated sampling intervals, use of the 99.9 percentile is justifiable on a cost-benefit basis. Thus, 40 dpm/ml was selected as a baseline level for tritium in 400 Area workers. Results below 40 dpm/ml are considered normal for persons working in the 400 Area. Results in excess of 40 dpm/ml indicate potential occupational exposure.

4.7 Organically Bound Tritium

While this chapter was being written a DOE work group was studying the issue of special tritium compounds (STCs), including organically bound tritium (OBT). The HIDP should be contacted for the status of this work and any recommendations associated with monitoring or dosimetry for OBT. Hanford facilities have not specifically identified sources of OBT. It is anticipated that OBT can be found in ingested foods, machinery oil used in tritium facilities, in laboratory compounds labeled for research purposes, or in wastes received from other DOE facilities. The NCRP has also addressed the issue of dosimetry for tritium-labeled organic compounds incorporated into genetic material in NCRP 63 (NCRP 1979b). The following paragraphs provide a current summary of work in progress.

In its publication 56 (1989), the ICRP recommended a f_1 factor of 1.0 for GI tract absorption to blood for OBT, and proposed a two-component retention model for OBT. The OBT model suggested that 50% of the OBT would be associated with body water and demonstrate the tritiated water half-time of 10 days. The remaining 50% would be associated with carbon-hydrogen bonding in tissues and would demonstrate a metabolic turnover rate similar to carbon (biological half-time of 40 days). The formulation of the retention function is as follows:

$$R(t) = 0.5e^{\frac{-0.693\,t}{10}} + 0.5e^{\frac{-0.693\,t}{40}} \tag{4.20}$$

with t in days.

Equilibrium between body water (e.g., urine) and OBT is not an appropriate assumption because of the substantial fraction bound to organic molecules. Thus, daily urinary excretion of OBT must be considered for bioassay interpretation.

The effective dose coefficients, e(50), for OBT, as tabulated by ICRP in publications 67 (1993), 68 (1994), 71 (1995), and 78 (1997) are as follows:

Inhalation e(50)	4.1E-11 Sv/Bq
Ingestion e(50)	4.2E-11 Sv/Bq

The DOE (2001) has established a radiological control technical position for OBT. In that position it was stated that the latest biokinetic models are permissible for dosimetry. The technical position also tabulated Air Concentration Values (ACVs) for use in a manner similar to DACs. The dose coefficient of ICRP 71 and the DOE ACVs are shown in Table 4.2.

4.8 Tritiated Particulate Aerosols

While this chapter was being written, a DOE working group was studying the issue of STCs, including tritiated particulate aerosols. The HIDP should be contacted for the status of this work and any recommendations associated with monitoring or dosimetry for tritiated particulates. The following paragraphs provide a current summary of work in progress.

Tritiated particulate aerosols result from tritium being absorbed and retained on metal surfaces such as getters for tritium collection and storage devices (typically these are in the form of metal tritides) and as a residual contaminant in tritium production facilities. An additional possibility for tritiated particulates is tritiated metal oxides (e.g., rust and dust). At Hanford, a limited source of zirconium tritide metal filings has been identified in the 325 Building.

Data available to the DOE STC Working Group suggest that solubility in lung fluid could vary over 5 orders of magnitude, making urine bioassay for the more insoluble forms highly ineffective. The ICRP has noted in publication 71 that titanium tritide powder demonstrated absorption type M characteristics and provided f_1 values and effective dose coefficients for absorption types F, M, and S. The desirability of a fecal analysis procedure for tritiated particulates has been identified but such a procedure does not presently exist. The DOE Mound Laboratory is using air sampling (including lapel samplers) to measure worker exposure to air concentrations and calculating internal dose from air concentration and exposure time data.

The DOE has issued a technical position (2001) that addresses tritiated particulate aerosols. Air Concentration Values (similar in concept to DACs) have been compiled in that technical position,

along with permission to use the latest biokinetic models based on known physio-chemical properties of special tritium compounds. Accordingly, the ICRP 71 adult effective dose coefficients are considered appropriate for calculation of committed effective dose equivalent. Table 4.2 lists the effective dose coefficients and the air concentration values.

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