

## Appendix A

# Two-Compartment Environmental Transport Model for Tritium

The physical and chemical properties of HTO include its complete miscibility in water, the absence of any known sequestering tendencies (i.e., no preferential uptake of HTO by organisms or other components of the environment), the similarity of its properties (such as diffusion coefficient and vapor pressure) to water, and the observed uniform distribution of HTO among the aqueous phases of all interacting compartments in field studies that have approximated steady-state conditions [Murphy, 1984, 1993]. These properties imply that the fate and transport tendencies of HTO are best predicted by modeling it as having infinite affinity for the water phase of any compartment and relatively negligible affinity for other phases, such as the organic phase of biota or mineral phase of soil.

### A.1 General Issues

We use a two-compartment model to estimate the steady-state distribution of tritiated water between air and soil media that would result from continuous HTO emissions to the atmosphere (air compartment) from the NTLF. Using the principle of mass conservation, the model provides an algorithm for predicting steady-state HTO-specific activities (concentrations) in the soil and air compartments.

#### A.1.1 Tritium in Air

On a local scale, the transfer of HTO from air to the land surface occurs mainly by precipitation with a minor role played by diffusional vapor exchange [NCRP, 1979]. On

a global scale, the tritium concentration in air is relatively uniform and, on average higher than that in soil, so that the reverse of the local-scale case appears to hold.

The deposition of HTO from air to ground does not necessarily represent a definitive loss from the air compartment since deposited HTO can re-emerge back into the air compartment via evapotranspiration or simple evaporation. Only HTO that finds its way deep into the ground (well below the root zone) represents a true air compartment loss.

### **A.1.2 Tritium in Soil**

When HTO enters soil, it follows the same transport processes as H<sub>2</sub>O [Murphy, 1993]. Thus, important transport mechanisms in the terrestrial environment include bulk flow (due to gradient of hydraulic head), and flow due to vapor gradient, temperature gradient, and HTO concentration gradient. The environmental half-life of tritium in soil is generally longer than in other components of the ecological system, and this relatively longer compartment half-life extends the residence time of tritium in vegetation rooted in that soil. High-water-use plants may affect the movement of a tritium pulse in soil. The observed environmental half-life of tritium in soil appears to be made up of two components—a shorter one reflecting the bulk movement of water and a longer one reflecting tritium retained in more stationary water, such as chemically bound water [Koranda and Martin, 1973].

### **A.1.3 Tritium in Surface Waters**

Under steady-state conditions, the concentration of tritium in surface waters would be the same as that in the water-phase of the atmosphere. When the source of tritium is air and the residence-time of the surface water body is long relative to the half-life of tritium—which is the case for the oceans, the Great Lakes, San Francisco Bay, etc.—the HTO concentration in the surface water is lower than that in atmospheric water on average. However, near the top of a surface water column a steady-state concentration is likely to exist. HTO concentrations in aquatic organisms closely follow those in the water [Murphy, 1993].

### **A.1.4 Tritium Uptake in Biota**

Plants take up HTO from water vapor in air through plant respiration and from water in soil through transpiration [Koranda and Martin, 1973]. For plants grown in tritium-free soil, the tritium concentration in plant leaves is on the order of 0.3 to 0.7 times the tritium concentration in atmospheric water [Murphy, 1993]. Some of the tritiated water taken into plant tissues can be converted to organically-bound tritium (OBT), which has a longer residence time in plants than molecular water. Photosynthesis is the primary process by which HTO is converted to OBT in plants. However, a very low fraction of

tritium moving through the plant is transformed to OBT. Thus, Murphy [1993] has noted that OBT in plants can be neglected as a sink for Tritium. Nevertheless, the effective residence time of tritium in plants may be affected by even small amounts of OBT.

### A.1.5 Why Only Two Compartments?

As discussed in Section A.1.4, tritium activity in the terrestrial biota compartment is readily inferred once the soil and air activities are known. Thus, the activity in the biota compartment need not be predicted explicitly. Adding a biota compartment would require the quantification of inputs such as the uptake rate from soil into plants, but there is insufficient information for this quantification.

Because the current application of the model does not include estimating exposure through the food ingestion pathway, the biota concentrations are not required for our purposes. Biota need only be considered inasmuch as it affects the ultimate steady state HTO inventories in air and soil water (soil water affects runoff concentration, which will be subject to dermal contact). In addition, the fraction of land covered by surface water is minimal, allowing the surface water compartment to be neglected for the purposes of the fate and transport modeling (streams are considered in the dose assessment). Thus, a two compartment model is sufficient.

The premises of our modeling approach are that HTO will distribute itself primarily in the aqueous phase of a compartment, that non-aqueous tritium (i.e., OBT) in any compartment can be accounted for by increasing the effective residence time and that under equilibrium conditions water-phase tritium activities in each compartment will be equal.

For convenience, we call the water-phase HTO-specific activity in compartment  $i$ , the "equivalence," which will be denoted  $AQ_i$ . In a closed system that is in equilibrium, the equivalences of all compartments are the same. Similar terminology has been used in modeling the fate and transport of inorganic and organic chemical species [Mackay and Diamond, 1989; Diamond et al., 1992; McKone, 1993].

We propose here a model for a system that has achieved steady state in terms of mass exchange by balancing gains and losses. However, in terms of chemical thermodynamics the system is not assumed to be at equilibrium. The simultaneous balancing of gains and losses for both soil and air compartments allows non-equilibrium equivalences of the two compartments to be calculated. The bulk compartment's specific activity is easily calculated once its equivalence is quantified. Because only the aqueous phase of a compartment is allowed to hold HTO, both the total compartments inventory and water-phase inventory of tritium are the same. The bulk specific activity (i.e., inventory normalized by the aqueous as well as non-aqueous phase volumes) of compartment  $i$ , is calculated as a function of its volumetric water content, denoted  $\varnothing_i$ , and its equivalence ( $AQ_i$ ) as:

$$C_i = \emptyset_i \times A Q_i \quad (\text{A-1})$$

where  $C_i$  denotes compartment  $i$ 's bulk specific activity, and the other terms are as defined above.

Thus, the bulk specific activities of HTO in adjacent compartments may differ even under equilibrium conditions, since the two compartments may differ in their volumetric water contents. Under equilibrium conditions compartment  $i$ 's capacity for holding HTO is effectively dictated by its volumetric water content,  $\emptyset_i$ .

The volumetric fraction of water in air is calculated based on the observed relative humidity (RH—expressed as the fraction of saturation) at LBNL, and the saturation vapor pressure. The saturated vapor pressure ( $VP_{sat}$ ) in Pascals (Pa) is calculated as a function of temperature by using the following Antoine equation [Weast et al., 1986].

$$\log VP_{sat} = 11.28 - 2319.25 / T \quad (\text{A-2})$$

where  $T$  is the ambient absolute air temperature in kelvins. Using  $VP_{sat}$ , we calculate the volume fraction of water in air,  $\emptyset_a$ , as

$$\emptyset_a = RH \times \frac{VP_{sat}}{R \times T} \times \frac{MW_{H_2O}}{\rho_{H_2O}} \quad (\text{A-3})$$

where  $R$  is the universal gas constant,  $8.314 \text{ Pa}\cdot\text{m}^3/\text{mol}\cdot\text{K}$ ;  $MW_{H_2O}$  is the molecular weight of water,  $18 \text{ g/mol}$ ; and  $\rho_{H_2O}$  is the density of water,  $10^6 \text{ g/m}^3$ .

The volumetric water fraction of the soil compartment is determined directly from field data (See Table 6).

## A.2 Steady State Mass Balance Equations

The steady-state equations describing gains and losses in the two compartments are used to solve for the steady-state inventory in each compartment. Equations A-4 and A-5, which are the same as Equations 4-1 and 4-2, express gains and losses for the air and soil compartments, respectively.

$$S + T_{sa} N_s = L_a N_a \quad , \quad (\text{air}) \quad (\text{A-4})$$

and

$$T_{as} N_a = L_s N_s \quad , \quad (\text{surface soil}) \quad (\text{A-5})$$

where  $N$  represents a compartment HTO inventory (a compartment's bulk inventory and its water-phase inventory are equivalent) and the  $T_{ij}$  ( $i, j = a$  or  $s$ ) are transfer rate

constants, with units of  $\text{day}^{-1}$ , that express fraction per unit time of the inventory of compartment  $i$  that is transferred to compartment  $j$ . The compartment abbreviations are  $a$  for air, and  $s$  for surface soil. The product of an  $N$  term and a  $T$  term is the rate of change of inventory in Bq/d.  $L_i N_i$  represents all losses from compartment  $i$ , Bq/d. The term  $S$  in Equation A-4 represents the rate of HTO input (i.e., the NTLF's HTO emission rate) into the air compartment, Bq/d. Transfer-rate constants are functions of landscape characteristics and environmental mass transfer rates.

In terms of equivalence the balance in Bq/d is expressed as a loss from a compartment  $i$  and transfer to a compartment  $j$  in the form

$$\text{loss} = \text{Area} \times v_{ij} \times \emptyset_{ik} \times A Q_i = T_{ij} N_i \quad , \quad (\text{A-6})$$

where  $\text{Area}$  in  $\text{m}^2$  is that across which mass exchange occurs,  $v_{ij}$  is the advection velocity from  $i$  to  $j$  at the exchange boundary, and  $\emptyset_{ik}$  is the volumetric moisture content of the moving phase  $k$  from  $i$  to  $j$ , (in this analysis the moving phase is always water, e.g., recharge or runoff, and therefore  $\emptyset_{ik}$  is generally equal to  $\emptyset_{\text{water}}$  and  $A Q_i$  represents the equivalence of compartment  $i$ . Compartment inventory  $N_i$  is calculated using Equation A-1 and the compartment volume.

$$N_i = \emptyset_i A Q_i V_i \quad (\text{A-7})$$

Combining Equations A-6 and A-7 and rearranging terms yields the following for  $T_{ij}$ ,

$$T_{ij} = \frac{\text{Area} \times v_{ij} \emptyset_{ik}}{V_i \emptyset_i} = \frac{v_{ij} \emptyset_{ik}}{d_i \emptyset_i} \quad , \quad (\text{A-8})$$

where  $V_i$  is the compartment volume,  $d_i$  is the compartment depth or height, and  $\emptyset_i$  is the volumetric fraction of water in compartment,  $i$ . This is the general approach used in the paragraphs that follow to obtain the transfer rate constants.

## A.2.1 Transfer Rate Constants

In the box model used for air, the inventory  $N_a$ , in Bq, is described by solving Equations A-4 and A-5.  $L_a$  is the sum of all loss-rate constants from the air compartment.

$$L_a = T_{as} + T_{a0} + \quad (\text{A-9})$$

$L_a N_a$  is the sum of all losses from the air compartment, in Bq/d. The rate constant  $T_{as}$  accounts for rain-water washout from air to surface soil.

$$T_{as} = \frac{\text{rain} \times \emptyset_{\text{water}}}{\emptyset_a \times d_a} \quad , \quad (\text{A-10})$$

The air compartment mixing depth is analogous to the mixing height parameter used in Gaussian plume modeling. For the NTLF analysis this parameter depends on the box-model volume used in the analysis. For the Zone 1 risk characterization, the mixing depth is roughly 15 m (see Site Characteristics subsection below). In Equation A-10,  $\emptyset_{water}$  describes the scavenging factor for rain drops passing through air.

The factor  $T_{ao}$  on a box model accounts for atmospheric dispersion that is applied to the natural bowl in which the NTLF is located. According to Benarie [1980], the long-term average pollutant concentration in a region bordered by a box model with volume  $V_a$  and pollution source,  $S$  in Bq/d, is given by

$$C_{air} = N_a / V_a = \frac{cS}{Area \times v_w} , \quad (A-11)$$

where  $c$  is a unitless proportionality constant,  $Area$  is the area of the model region, and  $v_w$  is the long-term average wind speed in m/d. This implies that the inverse of the rate constant,  $T_{ao}$ , is the convective residence time and is given by the expression,  $c d_a / v_w$ , where  $d_a$  is the atmospheric mixing height. Based on a model for area sources developed by Turner [1970], the constant  $c$  can be estimated as  $4.3 \sqrt{Area} / d_a$ . Making the appropriate substitutions gives the following expression for the convective loss-rate constant in the air compartment:

$$T_{ao} = \frac{0.23 v_w}{\sqrt{Area}} . \quad (A-12)$$

Equation 5 describes the mass balance for the soil compartment inventory,  $N_s$ , in Bq of HTO.  $L_s$  is the sum of soil compartment transfer-rate constants:

$$L_s = T_{sa} + T_{recharge} + T_{runoff} + \lambda , \quad (A-13)$$

where  $T_{sa}$  is the soil-to-air transfer rate primarily representing evapotranspiration processes,  $T_{recharge}$  and  $T_{runoff}$  are the rate constants for recharge losses to ground water and runoff losses to outside the unit, respectively; and  $\lambda$  is the radioactive decay rate. Rate constants are in units of  $day^{-1}$ . These loss-rate constants are given by

$$T_{sa} = \frac{evapotrans \times \emptyset_{water}}{\emptyset_s \times d_s} , \quad (A-14)$$

$$T_{recharge} = \frac{recharge \times \emptyset_{water}}{\emptyset_s \times d_s} , \quad (A-15)$$

$$T_{runoff} = \frac{runoff \times \emptyset_{water}}{\emptyset_s \times d_s} , \quad (A-16)$$

$$\text{recharge} = \text{rain} - \text{evapotrans} - \text{runoff} \quad . \quad (\text{A-17})$$

The parameter *recharge* is the yearly average ground-water recharge at the site, in m/d; *rain* is the yearly average rainfall, in m/d; *evapotrans* is the yearly average evapotranspiration, in m/d; and *runoff* is the yearly average runoff; in m/d.

## A.2.2 Solutions for the Compartment Inventories

Equations A-4 and A-5 represent a system of two equations, with two unknowns, and can be solved to determine the steady-state inventories,  $N_i$ , of contaminant in the soil and air compartments. This solution yields the following relationships,

$$N_s = \frac{S}{\frac{L_s}{T_{as}} \times L_a - T_{sa}} \quad (\text{A-18})$$

$$N_a = \frac{S}{L_a - T_{sa} \times \frac{T_{as}}{L_s}} \quad (\text{A-19})$$

These solutions are used to determine the inventory of tritium in the air, soil, and runoff from the site.



## **Appendix B**

# **Human Anatomical and Intake Factors Used in the Exposure Assessment Calculations**

In constructing dose models one needs to define the characteristics of individuals in various age/gender categories and the characteristics of the microenvironments in which they live or from which they obtain water and food. Appendix B defines the types of anatomical and activity data needed to carry out the exposure/dose assessment and explains how these data are obtained. For all factors used in this assessment, we define both an arithmetic mean value and a coefficient of variation (CV), which is the arithmetic standard deviation divided by the arithmetic mean.

### **B.1 Body Weight**

We calculate the arithmetic-mean body weight and CV of body weight for three age groups—infant, child, and adult. The body weight for infants is needed for estimating exposures to contaminants in breast milk. Body weight for adults and children are needed to calculate lifetime-average contact rates per unit body weight and contact rates for an exposure duration of less than a full lifetime. The child age category applies to ages 0 to 15 years, but excludes breast-fed babies. General data on body-weight distributions by age and gender are available from the ICRP [1975], the U.S. EPA [1985, 1989a] and Najjar and Roland [1987]. Because it provides more details on age-specific variations, we used the Najjar and Roland [1987] data set to develop the mean value and CV of body weight for ages 0 to 1, 0 to 15, 15 to 70, and for lifetime. These values are listed in Table B-1.

**Table B-1**  
**Values of Human Anatomical and Intake Properties Used in the Exposure Calculations(a)**

Parameter, symbol	Child(b)		Adult(b)		Combined(b)		Units
Body weight of infants age 0 to 1 y, BW	7.2	(0.3)	--		--	--	kg
Body weight, BW	29	(0.24)	71	(0.2)	62	(0.2)	kg
Surface area, SA <sub>b</sub>	0.032	(0.09)	0.024	(0.06)	0.026	(0.07)	m <sup>2</sup> /kg
Working breathing rate, BR <sub>w</sub>	--	--	0.030	(0.3)	--	--	m <sup>3</sup> /kg-h
Active breathing rate, BR <sub>a</sub>	0.023	(0.3)	0.018	(0.3)	0.019	(0.3)	m <sup>3</sup> /kg-h
Resting breathing rate, BR <sub>r</sub>	0.008	(0.3)	0.006	(0.2)	0.0064	(0.2)	m <sup>3</sup> /kg-h
Fluid intake, I <sub>f</sub>	0.029	(0.2)	0.020	(0.2)	0.022	(0.2)	L/kg-d
Breast milk intake(c), I <sub>bm</sub>	0.11	(1)	--		--		kg/kg-d
Water intake during recreation, I <sub>f r</sub>	0.0007	(1)	0.0007	(1)	0.0007	(1)	L/kg-h
Ingestion of homegrown exposed produce, I <sub>ep</sub>	0.0016	(0.7)	0.00078	(0.7)	0.00096	(0.7)	kg/kg-d
Ingestion of homegrown unexposed produce, I <sub>up</sub>	0.00095	(0.7)	0.00053	(0.7)	0.00062	(0.7)	kg/kg-d

**Notes to Table B-1:**

- (a) Listed are the arithmetic-mean value and (in parentheses) the estimated coefficient of variation (CV), equal to the standard deviation divided by the mean. Body weights are from Najjar and Roland [1987], breathing rates are from ICRP [1975], tap water intakes are from Yang and Nelson [1986] and Ershow and Cantor [1989] and food intakes are from Yang and Nelson [1986].
- (b) The child category covers ages 0 to 15, the adult category covers ages 16 to 70, the combined category is used to represent lifetime equivalent exposure and is obtained by multiplying the child category by 15/70, the adult category by 55/70, and then summing these products.
- (c) Breast-milk intakes are from Butte et al. [1984] and Whitehead and Paul [1981].

## B.2 Body Surface Area

Information on the relation between human body weight and surface area has been published by the ICRP [1975] and the U.S. EPA [1989b]. The EPA [1989b] reports that surface area (SA) in m<sup>2</sup> can be estimated as 0.1 times body weight (BW) in kg raised to the 2/3 power. Using this formula, along with methods described in Bevington [1969], we estimate the mean value and standard deviation of surface area per unit body weight, SA<sub>b</sub>, in m<sup>2</sup>/kg for children and adults using the formula

$$SA_b = \frac{SA}{BW} = 0.1 \times BW^{-1/3} \pm 0.1 \frac{BW}{3} BW^{-4/3}, \quad (\text{B-1})$$

where the second term is the standard deviation of the surface area-body weight ratio. The resulting surface-area values and CVs are given in Table B-1.

### B.3 Breathing Rate

General data on breathing rates by age and gender are available from the EPA [1985, 1989a] and the ICRP [1975]. Values in Table B-1 are taken primarily from the ICRP [1975] with variances estimated by McKone and Daniels [1991]. The working breathing rate is for 8 hours of work and, when combined with 8 hours of breathing at the active rate and 8 hours at the resting rate, gives a daily equivalent intake of 30 m<sup>3</sup> for an adult [EPA, 1989b]. Layton [1992] has derived breathing rates that are consistent with the quantities of oxygen needed to metabolize reported dietary intakes of fats, carbohydrates, and proteins. He has shown that the values in Table B-1 could be high by a factor of from 20% to 30%, but this is within the CV reported here.

### B.4 Water Ingestion

Tap-water intake includes all household tap water that is consumed as a beverage or used to prepare foods and beverages. Yang and Nelson [1986] have published tap-water and total-fluid intakes in mL/d for the U.S. population by age, sex, and region of the country. Ershow and Cantor [1989] have published population-based estimates of sex-, region-, and season-averaged tap-water intakes per unit body weight by the U.S. population in mL/kg-d. From these two papers, we have derived intakes of tap water in L/kg-d for children, adults, and lifetime equivalent. We also need to determine the amount of incidental ingestion that occurs during water recreation. Based on EPA [1989b] data, we use 0.0007 L/kg-h (CV equal to 1) as the ingestion rate of any surface water during recreational use. The mean values and CVs of tap-water intake and surface water intake are listed in Table B-1.

### B.5 Breast-Milk Ingestion

Data on ingestion of breast milk by infants are available in Butte et al. [1984] and Whitehead and Paul [1981]. We calculate the breast-milk ingestion per unit body weight for infants ages 0 to 12 months as 0.11 kg/kg-d with a CV of 0.2. This CV is based on other ingestion factors.

## B.6 Ingestion of Homegrown Fruits, Vegetables, and Grains

Ingestion of homegrown foods obtained from gardens in the vicinity of the NTLF are included in the risk assessment. For the food intakes included in the exposure assessment, we calculate here the arithmetic mean and standard deviation of homegrown food intakes per unit body weight for children, adults, and lifetime equivalent exposure, all on body-weight basis. We consider *homegrown* foods to be those produced on the land associated with a household and consumed within that household. The following food groups are considered in the exposure assessment:

- Leafy vegetables, which include exposed produce such as cabbage, cauliflower, broccoli, celery, lettuce, and spinach;
- Other exposed produce, such as apples, pears, berries, cucumber, squash, grapes, peaches, tomatoes, string beans, etc.;
- Protected produce or root crops, such as carrots, beets, turnips, potatoes, legumes, melons, citrus fruits, etc.; and
- Grains such as wheat, corn, rice, barley, millet, etc.

Total intake of foods in each of these groups is obtained from data compiled by the Nationwide Food Consumption Survey (NFCS) [USDA, 1983]. In this survey, the U.S. Department of Agriculture (USDA) used a stratified probability sample of households in the 48 conterminous states and the District of Columbia in each of four seasons from April 1977 through March 1978. The samples were designed to be representative of the United States and were classified according to geographic regions of the country, geographic divisions within each of the regions, and central city, suburban, and non-metropolitan populations. We calculate total annual average food intakes using results compiled by Yang and Nelson [1986], who analyzed the data from the USDA survey. The variance of intake-per-body-weight ratio used to determine the CV is calculated under the assumption that food intake correlates with body weight to the two-thirds power. The mean and variance of body weight used in this estimate are taken from Table B-1. Listed first in Table B-1 is our estimated total annual average population intake of fruits and vegetables and of grains expressed on a body-weight and age-specific basis.

Limited data are available on the amount of home-grown food that is produced and consumed in California or in the U.S. The U.S. EPA [1989a] has compiled for U.S. households data on the fractions of consumed produce that come from home gardens. For all categories of fruits and vegetables reported in this study, the fraction that is homegrown is in the range 0.04 to 0.75, and for the one grain listed (corn), the average fraction that is homegrown is 0.45 for the 25% of the individuals surveyed who consumed homegrown corn. From these data we estimated that the fraction of consumed fruits and vegetables that are homegrown is 0.24 with a CV of 0.7, and that

the fraction of consumed grains (mostly corn) that are homegrown is 0.11 also with a CV of 0.7. These values represent households with home gardens and not necessarily the average of total homegrown consumption in either the U.S. or California.

According to Yang and Nelson (1986), 47% of all consumed produce (fruits and vegetables) consists of leafy vegetables and other exposed produce, which intercept contaminants from the atmosphere. The remaining 53% of fruits and vegetables consists of protected produce or root crops, in which contaminant transfer to the edible portion is primarily by root uptake. All grain crops are assumed to be exposed primarily to air contaminants.

Based on the information provided in the previous paragraphs, we estimated the mean and CV of the ingestion of exposed (above-ground) and unexposed homegrown produce in households near the NTLF. Table B-1 lists our estimates of the mean average annual ingestion of both exposed and unexposed homegrown foods on a body-weight basis for children, for adults, and for a lifetime of exposure. As is the case for other contact rates, both the mean value and the CV are provided.



## Appendix C

# Landscape, Climate and Hydrology Parameters

The purpose of this appendix is to describe how values and ranges of inputs for the landscape, climate, and hydrology parameters used in the risk assessment model are obtained. Table C-1 lists the landscape properties for the NTLF environment derived in this appendix.

Table C-1  
Landscape Properties for the NTLF Environment.

Parameter description	Symbol	Mean value	CV	Reference(s)
Yearly average wind speed, m/s	$v_w$	2	0.3	Thorson [1995]
Yearly average temperature, °C	$T$	12.5	0.2	Merry [1991] NOAA [1974]
Yearly average relative humidity, %	$RH$	79	0.04	Merry [1991] NOAA [1974]
Soil compartment depth, m	$d_s$	2.5	0.5	Thibodeaux, [1994] Murphy [1993]
Volumetric moisture content of soil, L(water)/L(soil)	$\emptyset_s$	0.3	0.1	van der Leeden et al. [1991]
Annual average precipitation, m/y	$rain$	0.64	1.0	Merry [1991] NOAA [1974]
Annual average evapotranspiration, m/y	$evapotrans$	0.45	0.14	van der Leeden et al. [1991]
Annual average runoff, m/y	$runoff$	0.13	0.26	van der Leeden et al. [1991]
Infiltration to ground water, m/y	$recharge$	0.06	0.26	This report
Scavenging efficiency	$AQ_{rain}$	0.4	0.2	Murphy [1993]

## C.1 Wind Speed

Winds are generally light and blow from the southeast or west-northwest (Figure 2-10 in the 1995 Site Environmental Report, [Thorson, 1996]). During 1995, wind speeds were less than 1.5 meters per second (3.5 miles per hour) about 40% of the time. Over 95% of the time, winds were less than 5 meters per second (11 miles per hour) [Thorson, 1996]. Predominant wind patterns have winds blowing from the southeast during nighttime hours and from a westerly direction during the daytime. Based on this data and a compilation of hourly wind data, we used a mean annual wind speed of 2 m/s with a CV of 0.3.

## C.2 Temperature

The mean monthly temperature for San Francisco is 14 °C and has a coefficient of variation (CV) of 0.21 [NOAA, 1974]. The average annual temperature employed in the 1994 NESHAPS study for LBNL (derived from Oakland airport data) was 10 °C (283 K) while Merry [1991] reports average summer and winter temperatures for the LBNL site of 17 °C and 9 °C, respectively (implying an approximate average of 12.5 °C, or 285 K). The latter average annual temperature compares well with that observed at LLNL [Sims et al., 1989]. We use 12.5 °C with a CV of 0.21 to represent the LBNL site.

## C.3 Humidity

Merry [1991] reports average relative humidity ranges of 85-90% and 65-75% in the early morning and afternoon, respectively, for the LBNL site. The mean humidity obtained from these values is 79%. Mean monthly relative humidity for San Francisco over a 12-year period has a mean annual value (and CV in parentheses) of 84% (0.03) at 7 am, 70% (0.08) at 1 PM and 77% (0.04) overall [NOAA, 1974]. We use a mean annual humidity of 77% and a CV of 0.04 to represent the LBNL site.

## C.4 Depth of Soil Compartment

For the purposes of modeling, the soil compartment represents only the vertical extent of soil interacting with the air compartment. Theoretically, when HTO reaches a critical depth in soil it has such a small likelihood of re-emerging to air that it can effectively be treated as sequestered in the soil compartment. In our model, this critical depth is used to delimit the vertical extent of the soil compartment. The Damkoehler Number [Thibodeaux, L.J., personal communication] is used to define a “maximum depth of penetration.” When the Damkoehler Number is one, radioactive decay and diffusion/advection are balanced. The depth which corresponds to a unit Damkoehler number is the maximum depth of penetration for that chemical. We estimate the depth

corresponding to the unit Damkohler number for tritium as roughly 2.5 meters. This depth is adopted as the vertical extent of the soil compartment. Murphy has noted that the vertical extent of soil interacting with the air compartment depends to a great extent on the depth of roots of the native vegetation since transpiration plays an important role in the interaction of the soil and air compartments [Murphy, 1993]. A typical depth of root penetration for the U.S. is 1 m, which is compatible with the 2.5 meter depth adopted for this study. However, site-specific field measurements of soil penetration could help identify a better choice of depth for defining the soil compartment.

Vadose zone monitoring well observations of HTO levels at various depths in the soil are compatible with a 2.5 meter penetration depth. The measurements show a leveling-off of HTO levels beyond the 7 ft (2.2 m) depth ["Tritium Results for Soil Samples", BSVM-TS-1]. However, the observations originating from just one monitoring well are not necessarily representative of the entire soil body within the study area.

## C.5 Moisture Content of Soil

The average mass percent of water measured in soil samples taken from boreholes made in the vicinity of the Grizzly Area is 17 percent (including only those samples taken between 0 ft and 8 ft deep, i.e., to get a water fraction representative of the soil compartment). The equivalent mass fraction can be converted to a volumetric fraction assuming the ratio of aggregate soil (i.e., including soil water and air fractions) to that of water to be 1.6. Using this factor, a nominal volumetric water fraction for the soil compartment is calculated as, 0.30. We estimate the CV in this value to be 0.10.

## C.6 Precipitation

The annual average precipitation reported for the LBNL site is 0.64 m/y [Merry, 1991]. Monthly distributions of average precipitation for San Francisco give a mean annual rainfall of 0.47 m and a coefficient of variation (CV) of 1.0 [NOAA, 1974]. Based on these values, we use an average annual rainfall of 0.64 m/y and a CV of 1.0 to model the LBNL site.

## C.7 Evapotranspiration

No site-specific data for evapotranspiration are available. According to the Water Encyclopedia [van der Leeden et al., 1991], evapotranspiration is roughly 60 % of rainfall in North America and is 65% worldwide with a CV of 0.14. For dryer climates, such as Australia and Africa, it is as much as 90%. Assuming the Berkeley climate is dryer than the average North American climate, we set the nominal evapotranspiration at 70% of the local precipitation rate or 0.45 m/y, with a CV of 0.14.

## C.8 Runoff

No estimates of runoff are available for the LBNL site. Merry [1991] noted that rainfall intensities at LBNL are rarely greater than 1.3 cm/hr. With this relatively low intensity, one would expect a lower than average runoff, since runoff basically results when the rainfall rate exceeds the infiltration rate. However, the presence of parking lots around the facility should increase the rate of runoff above average. The Water Encyclopedia [van der Leeden et al., 1991] reports that runoff generally represents between 10 and 30% of the precipitation rate with a global average of 25% and global CV of 0.26, and North American average of 30%. We adopt 20% as the representative value for LBNL, which corresponds to a yearly average runoff of 0.13 m/y with a CV of 0.26.

## C.9 Infiltration to Ground Water

Because no infiltration data are available for the LBNL site, the infiltration rate is taken as the difference between the precipitation rate and the sum of the runoff and evapotranspiration rates.

## C.10 Rain Scavenging Efficiency

The scavenging efficiency is the fraction of HTO in air that is transferred to rain. Transfer occurs by one of two processes:

- Incorporation during the formation of raindrops in the atmosphere
- Rain-out of HTO as falling rain drops adsorb some fraction of HTO vapor.

A scavenging efficiency can be inferred from observed ratios of  $A_{Q_{rain}}$  to  $A_{Q_{air}}$ . Murphy [1993] notes that this ratio is generally less than unity, implying lower HTO equivalence in rain than in airborne vapor. He reports that the minimum, average, and maximum ratios are 0.20, 0.40, 0.55, respectively. In the present analysis this range is assumed equivalent to a scavenging efficiency with a mean value of 0.40 and CV of 0.2.

## Appendix D

# Evaluating the Potential Legacy of Past Elevated HTO Emissions

In the past the NTLF emitted HTO at a greater rate. Prior to 1989 the emissions were three times the current release rates. Depending on the effective residence time of HTO in the soil compartment, the pre-1989 releases may have left a legacy of non-negligible soil levels over and above those predicted under the premise of the current release rates. Here we investigate the potential significance of such a legacy. This analysis requires a dynamic treatment of the compartmental inventories because the HTO source is transient. From literature review and based on our experience with multi-media fate and transport modeling of other contaminants, the effective residence time of tritium in the soil can be far greater than that in air. Thus only the soil compartment must be treated as a dynamic compartment. Based on Equations 1 and 2, the following revised system of equations can be defined:

$$S + T_{sa} N_s = L_a N_a \quad (\text{air}) \quad (\text{D-1})$$

and,

$$\frac{dN_s}{dt} = T_{as} \times N_a - L_s \times N_s \quad (\text{surface soil}) \quad (\text{D-2})$$

The above system of equations can be solved to determine the time-dependent inventory of the soil compartment,  $N_s(t)$ , as:

$$N_s(t) = N_s(0) - \frac{T_{as} \times S}{L_a \times Y} \times \exp(-Yt) + \frac{T_{as} \times S}{L_a \times Y} \quad (\text{D-3})$$

where,

$$Y = L_s - \frac{T_{sa} \times T_{as}}{L_a} \quad (D-4)$$

$N_s(0)$  is the HTO inventory ( in Bq) in the soil compartment at  $t = 0$ , and all other terms are as previously defined. Assuming that emissions prior to 1989 were continuous at three times the current level, a steady state inventory in soil due to the pre-1990 emissions can be expressed as:

$$N_{s(1989)} = \frac{3 \times S \times T_{as}}{L_a \times Y} \quad (D-5)$$

Equation D-5 can be found by allowing  $t \rightarrow$  infinity in Equation D-3. Equation D-5 can be substituted into Equation D-3, as the initial concentration, i.e., for  $N_s(0)$ , to calculate a time-dependent inventory in soil reflecting the cumulative result of both the initial conditions established by the legacy of the early elevated emission rate and the subsequent post-1989 continuous release of tritium at the rate of  $S$ . The resultant inventory at 1994 due to both legacy and continuous release will be denoted  $N_{s(t=1994)}$ . The ratio of the latter to  $N_s$ , as calculated using Equation D-5 (i.e., under steady state conditions and neglecting the legacy of former operations) can be expressed as:

$$\frac{N_{s(t=1994)}}{N_s} = \frac{3 \times S - S}{S} \times \exp(-Yt) + 1 \quad (D-6)$$

or,

$$\frac{N_{s(t=1994)}}{N_s} = 2 \times \exp(-Yt) + 1 \quad (D-7)$$

The above ratio is used to evaluate the relative significance of the legacy from past elevated release in terms of affecting the current HTO inventory in soil. This analysis does not take into account the enhanced residence time in soil, which would be affected by OBT. However, Murphy [1993] asserts that the amount of HTO that would be converted to and reside in the organically bound form is negligible in terms of quantity.

## Conclusion

The analysis presented here indicates that risk levels associated with releases larger than 100 Ci/y can be found by multiplying this report's risk levels by the ratio of the larger release rate (averaged over the same time period) to the 100 Ci/y release rate. For example, if past releases over a ten-year period averaged 200 Ci/y and then came down to 100 Ci/y and we want to assess the impact of this on the 40-year estimated risk, we would effectively increase the estimated risk associated with the continuous release of 100 Ci/y by a factor of 1.25, that is 10 years at 200 Ci/y plus 30 years at 100 Ci/y divided by 40 years at 100 Ci/y.

## **Appendix E**

# **Results of the Risk Assessment Carried Out for NTLF Releases, Using the EPA CAP88 Computer Model**

CAP88-PC is a microcomputer radionuclide dispersion and dose-assessment code supplied and approved by US/EPA. This model was used to calculate doses to individuals at various distances from the NTLF. For the point of maximum off-site exposure, the dose represents the cumulative exposure from all significant exposure pathways (inhalation, ingestion, air immersion, and surface exposure). The methods and parameters used to calculate the dose are very conservative. For example, the model assumes that some portion of the food consumed by the hypothetical individual was grown within the assessed area. The individual was assumed to reside at this location continuously throughout the year. In addition, all of the tritium released was assumed to be the most hazardous form, tritium oxide. Consequently, this dose is not a dose actually received by anyone, but an upper-bound estimate.



## Appendix F

# Validation of the Input Data for Risk Assessment

This appendix compares the input tritium concentrations used in the risk assessment with site-specific data from special studies and with information that is provided in the 1995 LBNL Site Environmental Report [Thorson, 1996]. It includes a summary comparison for air, rain water, surface water, soil and sediment, vegetation and other biota, and urine measurements. Table F-1 provides a summary comparison of the estimates and measurements.

### F.1 Comparison of Risk Assessment Estimates to Measured Air Quality Data

To assess the environmental impact of tritium releases, a network of eight sampling locations collected samples for atmospheric tritium analysis in 1995 [Thorson, 1996]. Of particular interest in these results is the rapid drop-off in tritium levels from Zone 1 sample location (ENV-69A) toward Zone 2 locations and other sites as the distance from the main source on site increases. ENV-69A is located near the base of the NTLF's tritium stack and measured a 1995 average tritium concentration of 24 Bq/m<sup>3</sup>. All other sample locations correspond to Zone 2 and measured yearly average tritium concentrations in the range 3.3 to 6.8 Bq/m<sup>3</sup>, with a mean value of 4.5 Bq/m<sup>3</sup>. One of the samplers is located at the Lawrence Hall of Science and measured a 1995 average tritium level of 5.3 Bq/m<sup>3</sup>. No air sample measurements are available for Zone 3. The air sample measurements for 1995 are compared to the risk assessment estimates in Table F-1.

**Table F-1  
Estimated and Measured Tritium Levels**

	Zone 1	Zone 2	Zone 3
Emission rate, GBq/d			
assumed	10		
measured	5.4		
assumed/measured	1.8		
Air concentrations, Bq/m <sup>3</sup>			
estimated	96	5.2	0.35
measured	24	4.5	n/a
estimated/measured	4.0	1.2	—
Rain water, Bq/L			
estimated	1600	130	7
measured	290	20	<detection
estimated/measured	5.5	6.5	—
Surface water, Bq/L			
estimated	580	48	11
measured	100	15	10
estimated/measured	5.8	3.2	1.1
Soil and sediments, Bq/kg			
estimated	175	9	n/a
measured	44	3	n/a
estimated/measured	4.0	3.0	—
Ground water, Bq/L			
estimated	580	48	n/a
measured	280	10	n/a
estimated/measured	2.1	4.8	—
Vegetation (free water) Bq/L			
estimated	1350	110	7
measured	1600	100	n/a
estimated/measured	0.84	1.1	—
Body water levels (urine), Bq/L			
estimated	468	28	4
measured	48	20	n/a
estimated/measured	9.8	1.4	—

## **F.2 Comparison of Risk Assessment Estimates to Measured Rain Water Data**

Rain water yields a useful measure of tritium levels in atmospheric water. During the rainfall season, generally October through April, rainwater is collected monthly or during periods of significant rainfall [Thorson, 1996]. During 1995, rainwater was collected at six locations on site and analyzed for tritium. In Zone 1 rain water was collected at a rain gauge at Building 75 and analyzed for tritium. At this site, tritium was always detected in varying amounts, ranging from a low of 77 Bq/L to a maximum of 496 Bq/L, with an average of 290 Bq/L, which we consider representative of Zone 1.

In Zone 2 most rain water samples are below the detection limit. At Building 4 (200 m southwest of Building 75), one sample was as high as 24 Bq/L and at location ENV-B13D on the hill below Lawrence Hall of Science one sample was 52 Bq/L. We estimate from the samples reported in the 1995 Site Environmental Report that the average tritium concentration in Zone 2 rainwater is about 20 Bq/L.

There was one rain water sample location in Zone 3 (ENV13B), and in 1995 it did not have a sample above the detection limit.

See Table F-1 for comparison of rain water sample measurements for 1995 with the risk assessment estimates.

## **F.3 Comparison of Risk Assessment Estimates to Measured Surface Water Data**

The 1995 Site Environmental Report lists 11 creeks in the LBNL vicinity that were sampled for tritium. Of these, five had no detectable levels of tritium and six had tritium levels above the detection level. These findings are discussed below according to the zone with which the runoff from that creek is associated.

Chicken Creek, which is associated with Zone 1 and drains from the area near Building 75, had average tritium levels of 44 Bq/L and a maximum reported level of 180 Bq/L. Creeks associated with Zone 2 include Botanical Garden Creek, Claremont Creek, North Fork of Strawberry Creek, No-Name Creek, Ravine Creek, Ten-Inch Creek, and Wildcat Creek. Samplings from these creeks averaged no greater than 15 Bq/L. Lower Strawberry Creek, which flows into Zone 3, had average tritium levels no greater than 10 Bq/L in 1995.

Routine storm-water samples are also analyzed for the presence of tritium. Tritium values range from none detected at the North Fork of Strawberry Creek to 103 Bq/L at 69-Storm Drain Manhole, an influent site near the NTLF. Other samples of storm-water runoff in the vicinity of NTLF were in the range of 32 Bq/L to 74 Bq/L.

See Table F-1 for comparison of surface water sample measurements for 1995 with the risk assessment estimates.

## **F.4 Comparison of Risk Assessment Estimates to Measured Soil and Sediment Data**

During 1995, soil samples were taken from two onsite sampling locations and one off-site environmental monitoring station and analyzed for tritium. The soil samples correspond to Zone 2. These samples averaged 3 Bq/kg. Sediments collected in Chicken Creek, which are assumed to be associated with runoff from Zone 1, had observed tritium levels of 44 Bq/kg. Sediment levels in the North Fork of Strawberry Creek, which are assumed to be associated with Zone 2, had tritium levels of 2.6 Bq/kg.

See Table F-1 for comparison of soil and sediment sample measurements for 1995 with the risk assessment estimates.

## **F.5 Comparison of Risk Assessment Estimates to Measured Ground Water Data**

The 1995 Site Environmental Report indicates a tritium plume in the vicinity of Buildings 75, 76, 77, and 78. The source of the tritium is emissions from the NTLF stack. The maximum reported concentration of tritium detected in monitoring wells in 1995 was 277 Bq/L. Thus the average concentration of tritium in ground water in Zone 1 is assumed to be 280 Bq/L. Tritium has not been detected in groundwater samples from monitoring wells near the site boundary. Since most of the monitoring wells in Zone 2 show no detectable level of tritium, the average concentration of tritium in Zone 2 is assumed to be about 10 Bq/L. (See Table F-1 for the comparison.)

## **F.6 Comparison of Risk Assessment Estimates to Measured Vegetation Data**

Menchaca [1996a] has made measurements of tritium levels in foliage samples in trees from eight locations within LBNL. In trees from Zone 1 she found tritium levels ranging from 350 to 2900 Bq/L (assumed average of 1600 Bq/L). The highest level corresponds to a tree just two meters from the NTLF stack. In Zone 2, Menchaca reported tritium levels at distances of 100 to 300 meters from the stack ranging from 23 to 180 Bq/L, with an average of 92 Bq/L. Menchaca [1996b] has also reported on measured tritium activity in excreta, milk, and pasture for goats grazing at LBNL. These tritium activities range from none detected to as high as 55 Bq/L, with an average on the order of 20 Bq/L. In the Site Environmental Report [Thorson, 1996] vegetation

samples from the area surrounding the Building 85 site were reported to have tritium levels in the range of 12 to 670 Bq/L, with an average of about 200 Bq/L. We combined these data to estimate the tritium level in Zone 2 to be of the order of 100 Bq/L. See Table F-1 for comparison of vegetation sample measurements for 1995 and 1996 with the risk assessment estimates.

## **F.7 Analysis of Urine Data**

LBNL monitors the level of tritium exposure for employees by taking and analyzing urine samples from employees working near the NTLF and at other locations. During the period of March-June 1995 samples of urine were collected weekly from workers in Buildings 75, 75B, 69, 26, 76, and 90. Tap water samples from the East Bay Municipal Utility District (EBMUD) water supply were analyzed concurrently. Figures F-1 and F-2 show the weekly distribution of tritium activity (reported in Bq/L) in Zone 1 and Zone 2, respectively.

Tritium concentrations in urine samples collected in Zone 1 (Buildings 69, 75 and 75B) during the above period ranged between 189 Bq/L and 4.4 Bq/L with an average of 48 Bq/L. The tritium concentrations collected in Zone 2 (Buildings 26, 76, and 90) during the above period ranged between 90 Bq/L and 1.5 Bq/L with an average of 20 Bq/L. The estimated values of these concentrations for the risk assessment were 468 Bq/L and 28 Bq/L, respectively, as shown in Table 4-15.

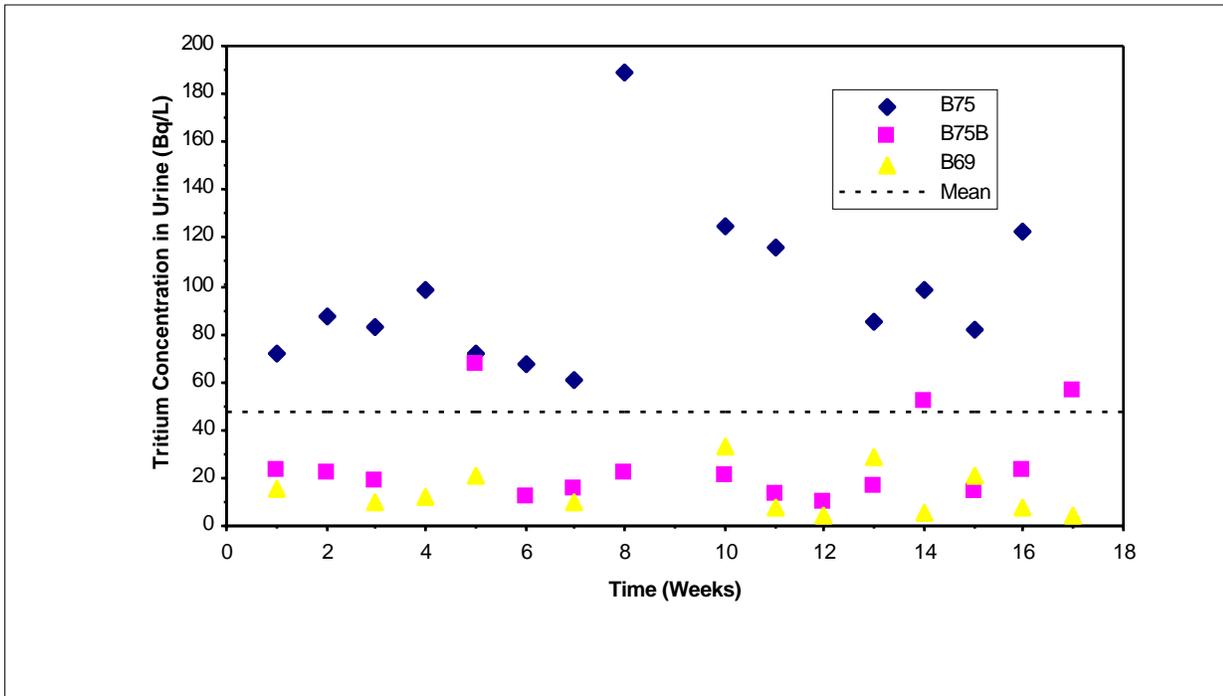


Figure F-1 Distributions of tritium concentration in urine samples in Zone 1

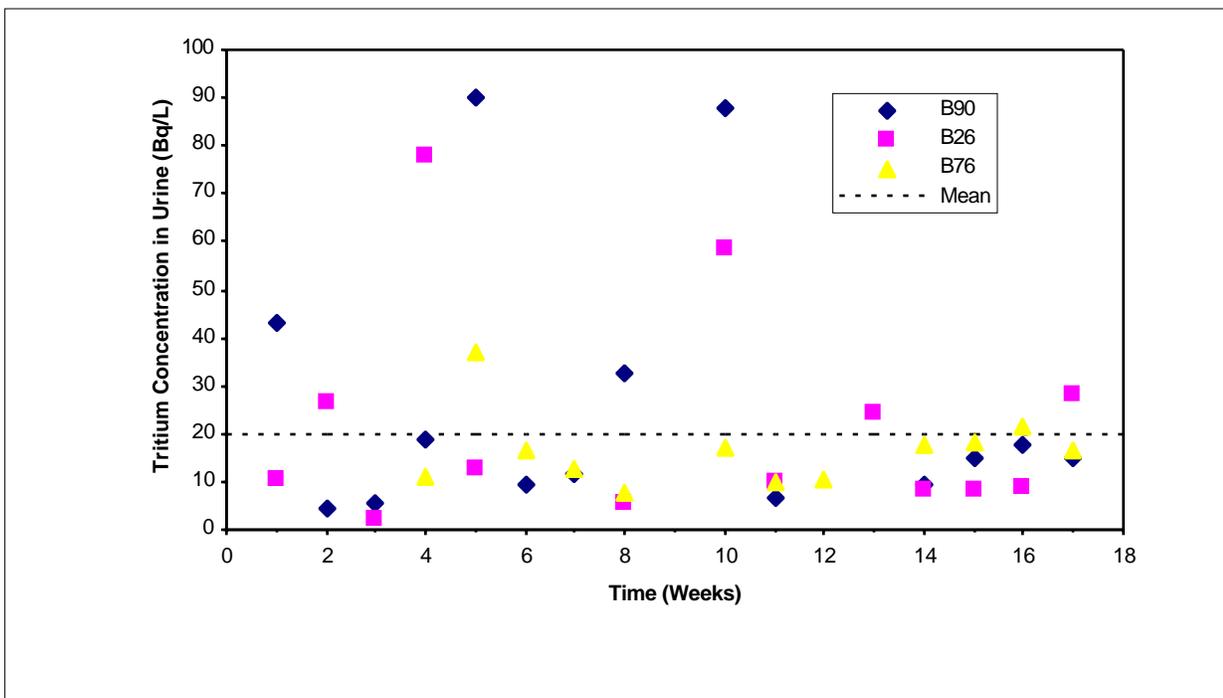


Figure F-2 Distributions of tritium concentration in urine samples in Zone 2

## Appendix G

# Conversion Table for Radiation Units

Unit Classification	US Unit	SI Unit	Conversion
Radioactivity	Ci	Bq	1 Ci = $3.7 \times 10^{10}$ Bq
Radiation Dose	rad	Gy	1 rad = 0.01 Gy
Dose Equivalent*	rem	Sv	1 rem = 0.01 Sv

\*: Equivalent Dose = Radiation Dose  $\times$  RBE  
where RBE is the *Relative Biological Effectiveness of the radiation*



## **Appendix H**

# **Review Comments**



# **Appendix I**

## **Questions and Answers About Tritium**

## **Appendix J**

### **Reviewers' Letters**

# Glossary of Technical Terms

<b>absorbed dose</b>	Energy imparted to a body by radiation, measured per unit mass (kg) of tissue.
<b>activity</b>	The number of transformations that take place each second in a given amount of radioactive material.
<b>alpha particle</b>	A positively charged particle, indistinguishable from a helium atom nucleus and consisting of two protons and two neutrons.
<b>alpha radiation</b>	Same as alpha particle.
<b>becquerel</b>	The special name for the unit that expresses a measure of activity. One becquerel corresponds to one disintegration per second of any radionuclide.
<b>beta particle</b>	A high-speed electron or positron, emitted in radioactive decay.
<b>curie</b>	A unit of radioactivity, equal to the amount of a radioactive isotope that decays at the rate of $3.7 \times 10^{10}$ disintegrations per second.
<b>dermal uptake</b>	The transfer of a contaminant from air, water, or soil into or through the outer skin layer; considered an exposure route in an exposure assessment.
<b>developmental and reproductive effects</b>	Effects caused by some physical, chemical, or biological agent, such as radiation, to the formation and development of a fetus, that results in one or more observed defects, which are not passed on to succeeding generations.

<b>displacement</b>	A chemical reaction in which one kind of atom or molecule is removed from combination and replaced by another.
<b>dissociation</b>	A chemical process by means of which a change in physical condition causes a molecule to split into simple groups of atoms, single atoms, or ions.
<b>dose</b>	The quantity of energy or chemical agent delivered to a specific living tissue following exposure.
<b>dose assessment</b>	The process by which uptake and dose of a toxic substance are identified and quantified.
<b>dose equivalent</b>	An absorbed dose that is adjusted or weighted to account for the potential of different radiations with the same damage.
<b>excitation</b>	The addition of energy to a system, transferring it from a ground state to an excited state.
<b>exposure</b>	The condition of having contact with a physical or chemical agent of harm.
<b>exposure assessment</b>	The process by which contact with a toxic substance is identified and quantified.
<b>gamma radiation</b>	Electromagnetic radiation emitted by radioactive decay and having energies in a range from ten thousand ( $10^4$ ) to ten million ( $10^7$ ) electron volts.
<b>gray</b>	The special name for the unit that expresses a measure of absorbed dose. One gray corresponds to an energy deposition of one joule per kg of living tissue.
<b>half life</b>	<ol style="list-style-type: none"> <li>1. For a quantity of radiation—the time required for half of the nuclei in a sample of a specific isotopic species to undergo radioactive decay.</li> <li>2. For ingested quantities—the time required for the radioactivity of material taken in by a living organism to be reduced to half its initial value by a combination of biological elimination processes and radioactive decay. Known as the <b>biological half-life</b>.</li> </ol>
<b>heritable genetic effects</b>	Genetic damage caused by an external agent such as radiation, which manifests itself in the gene carrier and is capable of being passed on to succeeding generations.

<b>ingestion</b>	To take into the body by the mouth for digestion or absorption; considered an exposure route in an exposure assessment.
<b>inhalation</b>	To draw air into the lungs by breathing; considered an exposure route in an exposure assessment.
<b>ionizing radiation</b>	Radiation that converts the target totally or partially into ions on impact.
<b>isotope</b>	One of two or more atoms having the same atomic number but different numbers of neutrons in their nuclei.
<b>model</b>	A schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics
<b>monitor</b>	To test or sample on a regular or ongoing basis the air or an object's surface for radiation level.
<b>neutron</b>	An electrically neutral subatomic particle, which is stable when bound in an atomic nucleus. Neutrons and protons form nearly the entire mass of atomic nuclei.
<b>nuclide</b>	A type of atom specified by its atomic number, atomic mass, and energy state, such as carbon 14.
<b>probability</b>	A number expressing the likelihood that a specific event will occur, expressed as the ratio of the number of actual occurrences to the number of possible occurrences.
<b>proton</b>	A stable, positively charged subatomic particle. Neutrons and protons form nearly the entire mass of atomic nuclei.
<b>radiation</b>	Energy emitted in the form of rays, waves, or particles by the atoms and molecules of a radioactive substance as a result of nuclear decay.
<b>radioactivity</b>	Spontaneous emission of radiation, either directly from unstable atomic nuclei or as a consequence of a nuclear reaction. This radiation includes alpha particles, nucleons, electrons, and gamma rays, emitted by a radioactive substance.
<b>relative biological effectiveness (RBE)</b>	An adjustment factor used to adjust an absorbed dose to account for its relative potential to do damage in biological tissue.

<b>risk</b>	The estimated probability of injury, loss, or detriment. A measure of the deleterious effects that may be expected as the result of an action or inaction.
<b>risk assessment</b>	The process by which the risks associated with an action or inaction are identified and quantified.
<b>sampling</b>	The act, process, or technique of selecting an appropriate environmental sample.
<b>sievert (Sv)</b>	A unit for expressing the equivalent magnitude of an absorbed dose which has been adjusted by a factor that expresses the relative tissue damage potential of absorbed doses of radiation; equivalent to one joule of x-ray energy deposited per kg of target.
<b>transport</b>	To move or be conveyed from one place to another. In the context of environmental contamination, a contaminant is transported from one location to another by advection (e.g., wind) or diffusion (e.g., dilution in air) processes.
<b>transformation</b>	Alteration of a chemical substance from one chemical form to another through a chemical or physical reaction. Radioactive decay is a nuclear transformation whereby an atom changes from one nuclide to another.

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