

TABLE 6.2. Anatomical and Health Physics Values for Reference Persons

Item	Male	Female	Reference
Total Mass	70 kg	58 kg	ICRP (1975, p. 13)
Body Water Content	42 L	29 L	
	0.6 L/kg	0.5 L/kg	ICRP (1975, p. 29)
Soft Tissue Mass	63 kg	54 kg <sup>(a)</sup>	ICRP (1979a)
Skeletal Mass	7 kg	4.2 kg	ICRP (1975, p. 74)
SEE SI units	9.0E-8 MeV/(g-trans)	1.1E-7 MeV/(g-trans)	(b)
trad units	1.9E-1 rad/(Ci-h)	2.2E-1 rad/(Ci-h)	

(a) Female value calculated by subtracting skeleton mass (ICRP 1975, p. 74) less the bone marrow mass (ICRP 1975, p. 90) from the total mass.  
 (b) Computed by dividing <sup>3</sup>H beta transition energy (5.68E-3 MeV) (ICRP 1983).

man, described in ICRP 23 (ICRP 1975). The dose equivalent to a reference man from tritiated water is given by:

$${}^3\text{H} = Q \frac{\text{rem}}{51.22 \text{ SEE A}_{\text{day}}} \quad (6.6)$$

where the values are as previously described. In the following discussions the SEE and the constant 51.22 are combined.

In the calculation of the SEE, the quality factor has already been included by the ICRP, thereby making the Q in Equation (6.6) redundant and technically incorrect. The Q is explicitly stated because certain regulatory agencies (e.g., the NRC) call for a quality factor different than one, and the purpose of the explicitly stated Q is to remind the reader to modify the equation by the appropriate value.

PROSPECTIVE DOSE CALCULATIONS

In this section the equations are derived that may be used to calculate prospective doses. Throughout this section we show Q explicitly in the equations. In some cases, the addition of Q to the

equation is not correct because the formalism employed by the ICRP includes a quality factor of one. The Q is included in the equations to remind the reader that some regulatory agencies may require a Q greater than one (see Brodsky 1983).

Prospective dose calculations are often used to estimate the radiation dose to an individual who may be exposed to the radioactive material. Because the dose estimations are hypothetical, they are computed for an individual who has the characteristics of the ICRP reference man (ICRP 1975).

The prospective dose calculations described here are for ingestion of tritiated water, submersion in tritiated water vapor (along with subsequent inhalation), inhalation of tritium gas, and submersion of an individual in tritiated water.

Ingestion of Tritiated Water

The committed dose equivalent to reference man from ingestion of tritiated water is from Equation (6.6) and substitution for assumed values for M (63 kg) and T<sub>e</sub> (10 days) as follows:

$$\frac{H}{T_{50}} = Q 66.6E-6 q(0) \text{ rem} \quad (6.7)$$

where  $H_{T,50}$  = the committed effective dose equivalent, rem  
 $Q$  = the quality factor, dimensionless  
 $66.6E-6 =$  conversion factor  $\{419.7E-6 * 10/63 = >66.6E-6\}$ , rad/ $\mu$ Ci  
 $q(0)$  = the quantity of tritiated water ingested,  $\mu$ Ci.

#### Submersion in Tritiated Water Vapor

When an individual is submerged in tritiated water vapor, there are two primary sources of radiation dose: 1) from inhaled tritiated water vapor and 2) from tritiated water absorbed through the skin.

Inhaled Water Vapor. All inhaled water is taken up by the body (see discussion on intake mechanisms). Thus, the previous equation may be used by computing the intake,  $q(0)$ , from the equation:

$$q(0) = 20.0E3 C T \mu\text{Ci} \quad (6.8)$$

where  $C$  is the air concentration of tritiated water, in  $\mu\text{Ci/mL}$ ;  $T$  is the exposure time in minutes; and  $20.0E3$  is the 'light work' breathing rate in mL/min. Substitution into Equation (6.8) yields

$$H_{T,50} = Q \frac{1.26 C T \text{ rem}}{1.33} \quad (6.9)$$

where  $H_{T,50}$  = the committed dose equivalent, rem  
 $Q$  = the quality factor, dimensionless  
 $1.33 =$  conversion factor  $\{66.62E-6 * 20.E3 = > 1.33\}$ , mL-rad/ $\mu$ Ci-min  
 $C$  = the air concentration of tritiated water,  $\mu\text{Ci/mL}$   
 $T$  = the exposure time, min.

#### Percutaneous Absorption of Tritiated Water Vapor.

The quantity of tritiated water that may be absorbed through intact skin can be estimated using the information given in the section that described intake mechanisms. However, for estimating prospective dose, it is convenient to employ the ICRP assumption (ICRP 1977) that total percutaneous absorption will equal about one-half the intake due

to inhalation at the 'light work' breathing rate. NRC licensees, however, should be aware that a footnote to 10 CFR 20.103(a)(1) indicates that the assumption employed to prepare the tables of maximum permissible concentrations was that intakes by the two routes were assumed to be equal. The committed dose equivalent from percutaneous absorption of tritium is then:

$$H_{T,50} = Q 0.63 C T \text{ rem} \quad (6.10)$$

where  $H_{T,50}$  = the committed dose equivalent, rem  
 $Q$  = the quality factor, dimensionless  
 $0.63 =$  conversion factor  $\{ 1.33 / 2\}$ , mL-rad/ $\mu$ Ci-min  
 $C$  = the air concentration of tritiated water,  $\mu\text{Ci/mL}$   
 $T$  = the exposure time, min.

Thus, the total committed dose equivalent due to submersion in tritiated water vapor is the sum of that due to inhalation and percutaneous absorption.

$$H_{T,50} = Q 2.0 C T \text{ rem} \quad (6.11)$$

where the variables are as previously described.

#### Inhalation of Tritium Gas

Following inhalation of tritium gas, radiation dose may be accrued from three sources: dose to the lung from tritium in the lung, dose to the whole body from elemental tritium absorbed in the blood, and dose to the whole body from tritiated water formed from the inhaled tritiated gas.

Dose to Lung from Inhalation of  $^3\text{H}$  Gas. The ICRP (ICRP 1979, supplement to part 1) lists the dose equivalent rate to the lung due to tritium gas in the air as  $611.2E-6$  (rem-mL)/(min- $\mu$ Ci) [ $9.9E-15$  (Sv- $\text{m}^3$ )/(Bq-h)]. The dose to the lung from exposure to elemental tritium at an air concentration of  $C \mu\text{Ci/mL}$  for time  $T$  minutes is then

$$H = Q 611.2E-6 C T \text{ rem} \quad (6.12)$$

where H = the dose equivalent to the lungs, in rem  
 C = the air concentration of tritium gas,  $\mu\text{Ci/mL}$   
 Q = the quality factor, dimensionless  
 T = the exposure time, min.

Because the dose to the lung will cease when the source is removed, the above dose also represents the committed dose equivalent to the lung from elemental tritium in the lung. The effective dose equivalent from the lung dose is computed by multiplying Equation (6.12) by the lung weighting factor of 0.12 (ICRP 1977). The equation for the effective dose equivalent in the lung is then:

$$H_{E,50} = Q 73.33E-6 C T \text{ rem} \quad (6.13)$$

where  $H_{E,50}$  is the committed effective dose equivalent, in rem, due to irradiation of the lung by elemental tritium in the inhaled air.

Elemental Tritium Dissolved in the Blood. To compute the dose to the whole body from gaseous tritium dissolved in the blood, the following assumptions are made. First, elemental tritium in blood will uniformly irradiate the whole body. Second, the solubility of tritium in blood is equal to that of hydrogen in water at the same temperature. Third, the dose to the whole body from  $^3\text{H}$  dissolved in body fluids is equal to the dose to that from tritiated water. Based on this last assumption, the dose equivalent rate conversion factor is  $1.9E-7 \text{ rad}/(\mu\text{Ci-day})$ .

The dose equivalent to the body from tritium dissolved in the blood is then given by the equation:

$$H = \frac{3.2 \times 10^{-9} 1.713E9 C}{2.37E6} \quad (6.14)$$

where  $3.2 \times 10^{-9}$  = a conversion factor,  $\text{rad}/\mu\text{Ci}$   
 $1.713E9$  = the quantity of  $\text{T}_2$  dissolved in blood at saturation,  $\mu\text{Ci}$   
 $2.37E6 \mu\text{Ci/mL}$  = the maximal air concentration of tritium gas (see section 2.4.2)  
 T = the exposure time, min  
 C = air concentration of  $\text{T}_2$  gas,  $\mu\text{Ci/mL}$

which is

$$H = Q 2.32E-6 C T \text{ rem} \quad (6.15)$$

where the units are as defined above. The dose to the whole body from dissolved tritium gas is a small fraction of the effective dose equivalent received due to gas in the lung.

Tritiated Water Converted from Inhaled Tritium Gas. About 0.003% to 0.004% of the inhaled tritium gas oxidizes to tritiated water in the body (Brodsky 1983). The dose to the whole body from this route of intake is then:

$$H = Q C 20,000 T 4E-5 62.9E-6 \quad (6.16)$$

where  $4E-5$  = 0.004% (percentage of  $^3\text{H}$  gas oxidized to tritiated water),  
 20,000 = the "light work" breathing rate in mL/min, and  
 $62.9E-6$  = a conversion factor in  $\text{rad}/\mu\text{Ci}$  [see Equation (6.7)], which is

$$H = Q 50.32E-6 C T \text{ rem} \quad (6.17)$$

where H = the committed dose equivalent, rem  
 Q = the quality factor, dimensionless  
 C = the air concentration,  $\mu\text{Ci/mL}$   
 T = the exposure time, min.

In summary, the committed effective dose equivalent due to the conversion of tritium gas to tritiated water is nearly equal to that due to irradiation of the lung by tritium gas. In this report the committed effective dose equivalent due to inhalation of tritium gas includes all three components of dose; it is the sum of the three preceding equations and is given by the equation

$$H = Q 126.0E-6 C T \quad (6.18)$$

where H = the committed dose equivalent, rem  
 Q = the quality factor, dimensionless  
 C = the activity concentration of tritium in air,  $\mu\text{Ci/mL}$   
 T = the exposure time, min.

Note: Approximately 5 to 10% differences can be obtained for the constants in the above equations, depending on whether one uses the integrated values listed in ICRP 30 (1977) or uses the dose rate values and then integrates. These differences are rounding errors.

#### Discussion of Prospective Dose Calculation

Summation of the committed dose equivalents for tritium gas yields a value that, according to the calculations presented above, is exactly 15,000 times less than that for tritiated water. If the tritiated water content of a postulated release is greater than about 0.01% of the total release, then the dose due to the tritiated water will predominate. Unless the gas has been dried just before a release, tritiated water will almost always predominate because the available tritium gas normally has a water content of about 0.01% (see Table 2.4). While tritium gas remains encapsulated in light fixtures, some tritiated water forms, with the result that about 1% of the activity is THO (see Table 2.5).

In the above equations we have shown the (air) activity concentration and the time of exposure. These two components together can be called the integral air concentration, in terms of  $\mu\text{Ci-min/mL}$ .

When performing calculations based on air concentration of TH or  $T_2$ , assumptions must be made with care. Humans require a partial pressure of oxygen ( $P_{O_2}$ ) of at least 50 mm Hg for survival; depression of the respiratory center occurs at a  $P_{O_2}$  of about 64 mm Hg (Jensen 1976), but the exact values will depend on the individual's physical condition. The  $P_{O_2}$  at sea level is about 159 mm Hg (Jensen 1976); thus dilution of the air by hydrogen to about 40% of normal levels will result in asphyxiation. This will occur when the  $T_2$  concentration is about  $1.4E6 \mu\text{Ci/mL}$ . Assumptions of air concentrations exceeding 100 or 200 mCi  $T_2/\text{mL}$  air should be carefully checked to ensure that they are reasonable.

Hydrogen in air at concentrations of 4 to 75% by volume are flammable/ explosive (Olishifski and McElroy 1971). These concentrations equate to  $0.0948$  to  $1.778 \text{ Ci/cm}^3$  air for  $T_2$  and  $0.0474$  to  $0.889 \text{ Ci/cm}^3$  for TH. Flammability and/or explosive conditions are another reason to carefully check for reasonableness of any assumptions about air concentrations of tritiated gas.

#### RETROSPECTIVE DOSE CALCULATIONS

Retrospective dose calculations are made for an individual who has been exposed to radioactive materials. Such calculations should use as much information about the individual as possible. That is, the health physicist should determine the individual's unique biological half-time, soft tissue mass, and water volume. If dose must be estimated without knowledge of the specific individual's data, the data for reference man (or woman) should be used.

#### Dose Equivalent Rate

The equations to use are those in Section 4.3.2 with one modification. These equations assumed that all the tritium remains in the body water; this assumption is not entirely correct. Tritium exchanges with the hydrogen in the organic constituents of the body. Hence the specific concentration in the body water is lower than it should be for