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Age-Dependent Dose Coefficients for Tritium in Asian Populations

Coefficients de dose selon l'Âge pour le tritium dans la population Asiatique

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par

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RÉSUMÉ

Les Publications 56 (1989) et 67 (1993) de la Commission internationale de protection radiologique (CIPR) ont décrit les modèles biocinétiques et les coefficients de dose selon l'âge pour l'eau tritiée et le tritium lié organiquement. Les coefficients de dose sont calculés à partir des valeurs choisies pour spécifier les caractéristiques anatomiques, morphologiques et physiologiques d'enfants de trois mois, d'un an, de cinq ans, de 10 ans, de 15 ans et d'adultes (homme de référence) de race blanche vivant en Amérique du Nord et en Europe occidentale. Toutefois, les valeurs relatives à l'homme de référence et aux autres groupes d'âge ne sont pas applicables directement aux Asiatiques en raison des différences de race, de coutumes, d'habitudes alimentaires et de conditions climatiques. Un modèle d'homme asiatique, comprenant cinq groupes d'âge, a été proposé par Tanaka et Kawamura (1996, 1998) pour l'utiliser dans la dosimétrie interne. Le concept de base de l'homme de référence de la CIPR et le système qui décrit la composition de l'organisme dans la Publication 23 (1975) de la CIPR ont été utilisés. Les valeurs de référence pour les Asiatiques ont été données en ce qui a trait au poids du corps et à la taille, à la masse du tissu mou, à la masse de l'eau de l'organisme et au bilan hydrique quotidien, et sont utilisées pour compiler les coefficients de dose pour le tritium. Les coefficients de dose dépendant de l'âge pour les Asiatiques en ce qui a trait aux ingestions d'eau tritiée sont inférieures de 20 à 30 % aux valeurs prescrites actuellement (Trivedi, 1998). La réduction des valeurs du coefficient de dose est due au bilan hydrique quotidien parmi les Asiatiques. Le coefficient de dose pour l'eau tritiée est de 1,4 x 10^{-11} Sv Bq^{-1} dans le cas de l'homme asiatique par rapport à 2 x 10^{-11} Sv Bq^{-1} pour l'homme de référence. Les coefficients de dose pour le tritium lié organiquement ne sont que très légèrement différents par rapport à ceux des valeurs du CIPR. Le coefficient de dose pour le tritium lié organiquement dans le cas de l'homme asiatique est de 4 x 10^{-11} Sv Bq^{-1} par rapport à 4,6 x 10^{-11} Sv Bq^{-1} pour l'homme de référence.

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ABSTRACT

The International Commission on Radiological Protection (ICRP) Publications 56 (1989) and 67 (1993) have prescribed the biokinetic models and age-dependent dose coefficients for tritiated water and organically bound tritium. The dose coefficients are computed from values selected to specify the anatomical, morphological and physiological characteristics of a three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult (Reference Man) Caucasian living in North America and Western Europe. However, values for Reference Man and other age groups are not directly applicable to Asians, because of differences in race, custom, dietary habits and climatic conditions. An Asian Man model, including five age groups, has been proposed by Tanaka and Kawamura (1996, 1998) for use in internal dosimetry. The basic concept of the ICRP Reference Man and the system describing body composition in ICRP Publication 23 (1975) were used. Reference values for Asians were given for the body weight and height, the mass of soft tissue, the mass of body water and the daily fluid balance, and are used to compute the dose coefficients for tritium. The age-dependent dose coefficients for Asians for tritiated water intakes are smaller by 20 to 30% of the currently prescribed values (Trivedi, 1998). The reduction in the dose coefficient values is caused by the increased daily fluid balance among Asians. The dose coefficient for tritiated water is 1.4×10^{-11} Sv Bq^{-1} for Asian Man compared to 2.0×10^{-11} Sv Bq^{-1} for Reference Man. The dose coefficients for organically bound tritium are only marginally different from those of the ICRP values. The dose coefficient for organically bound tritium for Asian Man is 4.0×10^{-11} Sv Bq^{-1} compared to 4.6×10^{-11} Sv Bq^{-1} for Reference Man.

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1. INTRODUCTION

The International Commission on Radiological Protection (ICRP) has prescribed dose coefficients for tritium for occupational workers (ICRP 68, 1995) and members of the public (ICRP 72, 1995). Secondary limits, such as the annual limit of intake (ALI) and the derived air concentration (DAC) for tritium, are recommended for operational convenience, and are derived from the dose coefficient values for tritium. The computation of the dose coefficient, and values for ALI and DAC, are based on Reference Man (ICRP 23, 1975). Reference Man is an adult between 20 and 50 years of age who lives in a climate with an average temperature of from 10°C to 20°C (Table 1). Reference Man is Caucasian, and is Western European or North American in habitat and custom. The values selected to specify Reference Man typically define the anatomical, morphological and physiological characteristics of an adult of such a geographical population.

Obviously, the characteristics and parameters listed for Reference Man would not be directly applicable to other populations, because of differences in race, custom, dietary habits and climatic conditions. Questions have been raised about applying age-dependent parameters, as provided by the ICRP, for general use in radiation protection (Jain et al., 1995; Gupta et al., 1998). The suitability of the age-dependent dose coefficients for tritium is also questioned for members of an Asian population that differs from the ICRP-formulated values. Different groups in various countries have made efforts to formulate their own Reference Man specification and age-specific parameters. Proposals for Indian Reference Man (Jain et al., 1995), Chinese Reference Man (Jixian and Bengxiao, 1995), and Japanese Reference Man (Tanaka and Kawamura, 1996; 1998) have been made.

Tanaka et al. (1998) have recently proposed an Asian Man model, including males and females of six age groups (three months, one year, five years, 10 years, 15 years and adult) for use in internal dosimetry. This proposal was in relation to activities of the ICRP Task Group on Reference Man Revision and the International Atomic Energy Agency (IAEA) coordinated proposal for a Reference Asian Man (IAEA, 1991). Initially, the basic concept of Reference Man and the system describing body composition in ICRP Publication 23 (1975) were used to formulate Asian Man, and to a limited extent to formulate age-dependent and gender-specific parameters (Tanaka, 1993).

The Asian Man specification and the age-specific parameters are used in the present report to compute the dose coefficients for tritium, and are compared with the currently prescribed values. These age-dependent dose coefficients for tritium should be useful in setting radiation protection standards and in assessing reliable doses for Asian populations.

2. REFERENCE MAN VERSUS ASIAN MAN

The ICRP formulated Reference Man to have well-defined anatomical, morphological and physiological characteristics that can suffice for most requirements of radiation protection. ICRP Publication 23 (1975) provides a comprehensive list of reference values for various anatomical and physiological parameters. These reference values are used to calculate dose per unit intake of radionuclides for the occupational worker and members of the general population. Some reference values have been updated recently: the respiratory tract in ICRP Publication 66 (1994), and the skeleton in ICRP Publication 70 (1995).

The ICRP recognized that the prescribed reference values are not intended to be average values for the worldwide population, but a coherent set of values for Caucasians in North America or Western Europe. Studies carried out in India (Dang et al., 1994; Jain et al., 1995) and in Japan (Tanaka, 1993) have demonstrated that Asians are much different from Caucasians in physique, as well as in customs and in dietary habits. The ICRP advises that adjustments to the recommended parameter values must be made for any known variation in a specific population. ICRP Publication 66 (1994) provides some guidance and relevant reference values for respiratory physiological parameters for the sex, age and ethnic group of interest (Table 9 and Annex B of ICRP 66).

The reference values for physiologic and metabolic parameters are proposed for Indian Reference Man (Jain et al., 1995) and Japanese Reference Man (Tanaka and Kawamura, 1996). An Asian Man with the same basic concept and system as for Reference Man has been developed (Tanaka and Kawamura, 1998). Here, only those physiologic and metabolic parameters that are likely to have an impact on tritium dosimetry are compared.

Table 1 compares the anatomical and morphological characteristics of Reference Man and Asian Man. For example, Reference Man weighs 70 kg and his height is 170 cm, while Asian Man weighs 60 kg and his height is 170 cm. The ratio of body mass index (BMI)[1] for Asian Man (21) to Reference Man (24) is 0.88, indicating that Asian Man is metabolically more active than Reference Man.

Table 2 compares the physiological characteristics of Reference Man and Asian Man. The body composition data shows that the mass of body water is 42 kg (60% of the body mass) for Reference Man and 37 kg (62% of the body mass) for Asian Man; the mass of skeleton is about 14% and 15% of the whole-body mass for Reference Man and Asian Man, respectively.

Table 3 compares the water balance data for Asian Man with those for Reference Man. The amount and rate of fluid intake, and loss from the body, are governed by atmospheric conditions, being highest in summer and lowest in winter. An average adult in Asia consumes 4.5 L d^{-1} of water through different sources (Dang et al., 1994); that is 50% more than the amount reported for Reference Man (3 L d^{-1}). The elevated water balance in Asians relates to the hot-humid tropical climate conditions in which they live, and has direct influence on the turnover rate of tritium.

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[1] The BMI equals M/H^2, where M is body mass in kg, and H is height in metres of an individual (Geigy Scientific Tables, 1984). The BMI is an index of the metabolic and physiologic status of an individual.

3. ICRP BIOKINETIC MODELS FOR TRITIUM INTAKES

As in ICRP Publications 56 (1989) and 67 (1993), a single reference subject is used to represent each age group. Generally, parameter values for males have been adopted, because of the availability of biokinetic data. There are no known differences in the biokinetics of tritium among sexes, ages and races. ICRP Publication 56 (1989) has retention functions and age-dependent biokinetic data for tritiated water (HTO) and organically bound tritium (OBT) intakes, which are used to compute the dose coefficients. ICRP retention functions are also used to calculate the dose coefficients for the Asian populations. The age-specific biokinetic data for tritium in Asians are calculated (see Section 4). Six age groups are considered:

Group	Representative of Ages
Three months	from 0 to 12 months of age
One year	from one year to two years
Five years	from two years to seven years
Ten years	from seven years to twelve years
Fifteen years	from twelve years to seventeen years
Adult	more than seventeen years

3.1 Tritiated Water

Ingested tritiated water mixes rapidly and completely with total body water after its entry into the blood. A fraction of tritium in tritiated water then becomes organically bound, and thus its retention depends on the metabolic activities of various tissues. To calculate the dose from tritium that has entered the body as tritiated water, the *Guidelines for Tritium Bioassay in Canada* (FPWG, 1982) and ICRP Publication 56 (1989) have a simplified two-component exponential function:

$$R(t) = Ae^{-0.693t/T_1} + Be^{-0.693t/T_2} \quad (1)$$

where T_1 can be calculated from the daily water intake and the mass of total body water:

$$T_1 = (\ln 2)\,(\text{mass of body water})\,(\text{daily water balance})^{-1}$$

and T_2 can be calculated from the daily carbon balance and the mass of total body carbon:

$$T_2 = (\ln 2)\,(\text{carbon body content})\,(\text{daily carbon balance})^{-1}$$

The whole-body retention of tritium taken as tritiated water is described by the retention function:

$$R(t) = 0.97e^{-0.693t/T_1} + 0.03Be^{-0.693t/T_2} \quad (2)$$

A schematic representation of the retention function for tritiated water is shown in Figure 1. The first component (~97%) is for tritium in the body water as HTO. The second component is assigned with ~3% of the tritium from an HTO intake, and originates from the tritium in an organic fraction of the soft tissue. The second component, representing metabolized OBT, contributes about 10% to the committed dose.

3.2 Organically Bound Tritium

ICRP Publication 56 (1989) has a simplified two-component exponential function for OBT ingestion. In a biokinetic model, 50% of the OBT that enters the blood is assumed to show the same metabolic behavior as the main component of retained HTO. The remaining 50% is assumed to bond with carbon and follow the general metabolic behavior of carbon. A schematic representation of the biokinetic model is shown in Figure 2. The whole-body retention of tritium taken as organically bound tritium is represented by the retention function:

$$R(t) = 0.5e^{-0.693t/T_1} + 0.5Be^{-0.693t/T_2} \quad (3)$$

There is no prescribed biokinetic model for OBT intake in Canadian guidelines (FPWG, 1982).

4. AGE-DEPENDENT BIOKINETIC DATA

4.1 Tritium in Body Water

The age-dependent biological half-times for tritium in the body water (T_1) are estimated from the daily water balance and the mass of total body water for each age group, and are listed in Table 4.

ICRP derives values for the daily water balance (fluid intake plus water of metabolism) for children on the physiological premise that 1 mL of water is required for each 4.2 kJ of energy expended (ICRP 23, 1975). In contrast to the allowances of individual nutrients, the energy allowance is established at a level thought to be constant with good health in average individuals in each age group and within a given category. The energy requirement is made up of the basal (resting) metabolic rate, the specific dynamic effect of the food consumed (14 to 16% of the caloric value of the protein, 5 to 6% of that of the carbohydrate, and 2 to 3% of that of the fat), and the energy expended in bodily activity. From ICRP Publication 23 (1975) (p. 340, Table 115), the values of energy expenditure can be derived as 4 870 kJ/d, 7 140 kJ/d, 9 790 kJ/d and 12 180 kJ/d for the one-year-old, five-year-old, 10-year-old, and 15-year-old, respectively. For a three-month-old child, a water balance of 1 L/d is assumed (ICRP 23, 1975). To calculate the mass of total body water, values of 70% for the three-month-old, and 60% for all other age groups are adopted based on ICRP Publication 23 (1975). These data yield the following biological half-times for tritium in body water: 3 d, 3.5 d, 4.6 d, 5.7 d, 7.9 d and 10 d for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult, respectively.

There was no credible database for the values of energy expenditure by Asians. The energy expenditure for each age group is assumed to be the same as for the ICRP age groups. Since about a 50% increase in daily fluid balance is observed for Asian adults (Table 3), the fluid balance for ICRP age groups is adjusted by a factor of 1.5. For the three-month-old child, a water balance of 1 L d^{-1} is assumed. To calculate the mass of total body water, values of 70% for the three-month-old child and 60% for all other groups are based on the published data for Asians (Tanaka, 1993; Dang et al., 1994). These data yield the following biological half-times for tritium in the body water: 3.2 d, 2.5 d, 3.0 d, 3.6 d, 5.1 d and 5.5 d for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult, respectively. The reduced biological half-times for HTO, as compared to 10 d for Reference Man, are well known for Asian adults (Sandarangani et al., 1971).

4.2 Tritium in Organic Compounds

The age-dependent biological half-times for tritium in the organic compounds (T_2) are computed from the daily carbon balance and the mass of total body carbon for each age group; they are listed in Table 5.

ICRP Publication 23 (1975) assigns a value of 16 kg for the total body content of carbon in an adult, which corresponds to 57% of the fractional carbon content of dry body mass. Assuming that this ratio is applied to all ages, the carbon content for the three-month-old, one-year-old, five-year-old, 10-year-old and 15-year-old is 1.0 kg, 2.2 kg, 3.3 kg, 7.3 kg and 12.5 kg, respectively, when the corresponding fractional content of body water to total body mass is taken into account. ICRP Publication 23 (1975) also provides values for a carbon balance of 100 g/d, 200 g/d and 300 g/d for the one-year-old, 10-year-old and adult. Age-dependence on carbon dioxide production and carbon losses into urine and feces suggests that the daily carbon balance does not differ by more than 10% from that of the one-year-old. Thus, values for carbon balance are extrapolated and/or interpolated for the three-month-old, five-year-old and 15-year-old, and are assumed to be 90 g/d, 160 g/d and 270 g/d, respectively. These data yield the following biological half-times for tritium in the organic compound: 8 d, 15 d, 19 d, 26 d, 32 d and 40 d for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult, respectively.

There is no specific information on the total body content of carbon and the daily carbon intake in the Asian population. As with Reference Man, the ICRP Publication 23 (1975) suggested value of 57% of the fractional carbon content of dry body mass for all ages was applied. The carbon content for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult Asian is 1.1 kg, 2.4 kg, 4.2 kg, 6.9 kg, 12.2 kg, and 13.7 kg, respectively. The ICRP Publication 23 (1975) assigned values for the daily carbon balance for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult were used. The biological half-times for tritium in the organic compound were estimated to be 8.6 d, 16.8 d, 18.2 d, 24 d, 31.4 d and 31.6 d for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult Asian, respectively. The carbon turnover rate for the Asian Man was reduced by 20% compared to Reference Man.

5. DOSE COEFFICIENTS FOR TRITIUM INTAKES

Dosimetry for tritiated water is normally based on the soft tissue dose (ICRP-30, 1979; FPWG, 1982; ANSI, 1994). However, ICRP Publication 67 (1993), applying the biokinetic models for tritium intakes, has prescribed dose coefficient values for the distribution of tritium over the mass of whole body less the contents of certain internal organs (the gastrointestinal tract, urinary bladder and gall bladder). On page 2 para 13 of ICRP Publication 67, calculations for tritium assumed to be uniformly distributed over the total body are based on a mass of 68.8 kg rather than 63 kg (the mass of soft tissue). Apparently, since ICRP Publication 30 (1979) was published, a decision was made to calculate dose to the whole body rather than to the soft tissue, and recent ICRP publications refer to "Distribution (%) Total Body". The dose coefficients for an adult are 1.8×10^{-11} Sv Bq^{-1} for HTO intakes and 4.2×10^{-11} Sv Bq^{-1} for OBT intakes, respectively. Subsequent ICRP publications prescribe the same values as prescribed in ICRP Publication 67 for occupational workers (ICRP 68, 1995) and members of the public (ICRP 72, 1995).

Since 1982, the *Guidelines for Tritium Bioassay in Canada* (FPWG 1982) has used a dose coefficient of 2.0×10^{-11} Sv Bq^{-1} for HTO intake. There is no prescribed dose coefficient value for intakes of OBT.

Trivedi (1998) has investigated the basis for the discrepancy in the dose coefficient values for tritiated water by the ICRP and Canadian publications, and has concluded that the Canadian value is appropriate for dosimetry. The dose to soft tissue is equivalent to a microdosimetric dose calculation of dose to a cell with water content equal to 0.67 of the cell mass (ANSI, 1994). Trivedi (1998) recommended the use of the soft tissue mass of 61.9 kg in computing the dose coefficients for tritium intakes, rather than 68.8 kg as suggested by the ICRP. The mass of soft tissue excludes the skeleton mass and the contents of the gall bladder, gastrointestinal tract and urinary bladder. Accordingly, the mass of soft tissue for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult is updated on the basis of published data for the mass of whole body, soft tissue, skeleton and the content of certain organs for the Reference and Asian populations, respectively.

Table 6 lists the revised mass of whole body and soft tissues for ICRP age groups. The mass of soft tissue for the one-year-old, five-year-old, 10-year-old, 15-year-old and adult is 8.5 kg, 17.5 kg, 29.4 kg, 50.4 kg and 62 kg, respectively. Table 7 lists the revised mass of whole body and soft tissues for Asian age groups. The mass of soft tissue for the three-month-old, one-year-old, five-year-old, 10-year-old, 15-year-old and adult is 5.8 kg, 9.6 kg, 15.7 kg, 26.2 kg, 47.5 kg and 52.8 kg, respectively.

The revised age-dependent mass of soft tissue in Tables 6 and 7, and the prescribed biokinetic models with the age-dependent biokinetic data for tritium in Tables 4 and 5, are used to calculate the age-specific dose coefficients for ICRP and Asian populations. The ICRP-published and revised age-dependent dose coefficients are listed in Table 8 for HTO and in Table 9 for OBT.

Revised calculations for an adult in the ICRP group gave values of 2.0 x 10^{-11} Sv Bq^{-1} for HTO and 4.6 x 10^{-11} Sv Bq^{-1} for OBT intakes, and are larger by 10 to 11% from the prescribed values in ICRP Publication 72 (Trivedi, 1998) (see Tables 8 and 9). The updated age-dependent dose coefficients for the ICRP population are larger by 6 to 11% for HTO and 3 to 9% for OBT intakes for the one-year-old, five-year-old, 10-year-old, 15-year-old and adult.

Since there are no detailed physiological and anatomical databases for the three-month-old in ICRP publications, the conservative dose coefficient values are calculated from the available infant data (Table 6). The ICRP dose coefficients for the three-month-old are revised upwardly by 74% and 62%, respectively. The physiological and anatomical data for the three-month-old Asian were available (Table 7), and used to derive the dose coefficients.

The dose coefficient values for HTO in Asian populations are smaller by about 25% compared with the ICRP-prescribed values (ICRP 72, 1995). The dose coefficient values for OBT intakes are almost similar to the ICRP-prescribed values. The increased daily fluid balance in the Asian population is considered to be the reason for the difference, even though the nominal mass of the soft tissue is reduced by 22% in Asians. The rapid clearance of tritium results in a lower body burden of tritium in body water, and subsequently a smaller dose per unit intake of tritium. The dose coefficient is 1.4 x 10^{-11} Sv Bq^{-1} for tritiated water and 4.0 x 10^{-11} Sv Bq^{-1} for organically bound tritium in an Asian adult (Table 10).

Table 10 compares the age-dependent dose coefficients for HTO and OBT intakes between the Reference and Asian population. The ratio of dose coefficients indicates that, for HTO intakes, the dose coefficient values for Asian populations are 0.6- to 0.8-times smaller than for the Reference population. However, except for three-month-old, the dose coefficient values for OBT intakes are not much different between the two populations. This comparison shows that the doses will be overestimated, but cannot be underestimated, if the dose coefficients for the Reference population (Table 10) are used for tritium intakes. However, it is recommended that for reliable dose assessment, the appropriate dose coefficients for tritium intakes listed in Table 10 be used for members of the Reference and Asian population, respectively.

The dose coefficients for tritium gas and tritiated methane, as listed in ICRP Publication 72 (1995), are also adjusted, as their values were derived from the biokinetic data and dose coefficient value of HTO (ICRP 67, 1993). Table 11 lists values for the dose coefficient and the annual limit on intake (ALI) for tritiated water, organically bound tritium, tritium gas and tritiated methane. The ALI values for an Asian adult worker are 40% higher than the values for tritiated water, tritium gas and tritiated methane that are recommended for Reference Man.

6. CONCLUSIONS

The physiological and anatomical characteristics, and metabolic parameters, formulated for the ICRP Reference Man and different age groups are not directly applicable to members of the Asian population. The higher daily fluid balance in the Asian population results in a lower dose per unit intake of tritium than in the ICRP Reference population. The age-dependent dose coefficients for HTO intakes are smaller by 20 to 30% of the prescribed values for Reference Man and other age groups. The dose coefficient for tritiated water is 1.4 x 10^{-11} Sv Bq^{-1}, and for organically bound tritium it is 4.0 x 10^{-11} Sv Bq^{-1} for an adult Asian Man.

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Table 1. Anatomical and morphological characteristics of Asian Man and Reference Man.

Characteristics	Asian Man*	Reference Man**
Age (y)	35 (20-50)	35 (20-50)
Body Height (cm)	170	170
Body Weight (kg)	60	70
Habitat and dietary habit	Asia	Western Europe, North America
Race	Mongoloid and South Caucasoid	Caucasoid

*Tanaka and Kawamura (1996)

**ICRP Publication 23 (1975) and Publication 70 (1995)

Table 2. Physiological characteristics of Asian Man and Reference Man.

Characteristics	Reference Man*		Asian Man**	
	Weight (g)	Relative weight (%)	Weight (kg)	Relative weight (%)
Body Weight	70 000	100	60 000	100
Fat	13 500	19.3	10 000	16.7
Essential	1 500		1 200	
Non-essential	12 000		8 800	
Skeleton	10 500	15.0	8 400	14.0
Lean body mass	56 500	80.7	50 000	83.3
Water	42 000	60.0	37 000	61.7
Extracellular	18 000		16 000	
Intracellular	24 000		21 000	
Body surface	18 000	25.7	16 300	27.2

*ICRP Publication 23 (1975) and Publication 70 (1995)

**Tanaka and Kawamura (1996)

Table 3. Water balance for Asian Man and Reference Man.

Daily Intake (L)			Daily Excretion (L)		
Source of intake	Asian Man*	Reference Man•	Elimination route	Asian Man*	Reference Man•
Drinking water	1.8	0.15	Urine	2.0	1.4
Milk	0.1	0.3	Feces	0.3	0.1
Hot and cold beverages	0.7	1.5	Sweat	1.1	0.65
Meal preparation	1.6	0.7	Insensible loss (exhaled water vapor in breath, etc.)	1.1	0.85
Water of food oxidation	0.3	0.35			
Total intake	***4.5***	***3.0***	***Total loss***	***4.5***	***3.0***

*Dang et al. (1994)

•ICRP Publication 23 (1975)

Table 4. Biokinetic data for tritiated water*.

Age	Distribution (%) total body		Biological half-time (days)			
			ICRP*		Asian**	
	Comp. A	Comp. B	Comp. A	Comp. B	Comp. A	Comp. B
Three months	97	3	3.0	8	3.2	8.6
One year	97	3	3.5	15	2.5	16.8
Five years	97	3	4.6	19	3.0	18.2
10 years	97	3	5.7	26	3.6	24.0
15 years	97	3	7.9	32	5.1	31.4
Adult	97	3	10	40	5.5	31.6

*Table C-1.1 in ICRP Publication 67 (1993)

**Calculated from the water balance and carbon balance data for Asians.

Table 5. Biokinetic data for organically bound tritium*.

Age	Distribution (%) total body		Biological half-time (days)			
			ICRP*		Asian**	
	Comp. A	Comp. B	Comp. A	Comp. B	Comp. A	Comp. B
Three months	50	50	3.0	8.0	3.2	8.6
One year	50	50	3.5	15	2.5	16.8
Five years	50	50	4.6	19	3.0	18.2
10 years	50	50	5.7	26	3.6	24.0
15 years	50	50	7.9	32	5.1	31.4
Adult	50	50	10	40	5.5	31.6

*Table C-2.1 in ICRP Publication 67 (1993).

**Calculated from the water balance and carbon balance data for Asians.

Table 6. Mass (g) of whole body, soft tissue, skeleton and certain internal organs for the ICRP Reference population.

Organ	Newborn[%]	One year	Five years	10 years	15 years	Adult
Revised whole body mass[#]	3 536	9 543	19 458	32 620	55,825	68,831
Revised soft tissue mass[*]	3 216	8 543	17 528	29 380	50,435	61,981
Skeleton mass[**]	370	1 170	2 430	4 500	7,950	10,500
Bone	170	590	1 260	2 300	4,050	5,500
Active Marrow	50	150	340	630	1,080	1,170
Inactive Marrow	0	20	160	630	1,480	2,480
Cartilage	130	360	600	820	1,140	1,100
Miscellaneous[***]	20	50	70	120	200	250

[%] Value for three months is unavailable.

[#] The mass of the whole body minus contents of the gastrointestinal tract, the urinary bladder and the gall bladder (Page 28; ICRP 71, 1995).

[*] According to ICRP Publication 23 (1975), but adjusted with the revised masses of the skeleton and marrows in ICRP Publication 70 (1995).

[**] The skeleton does not include periarticular tissue or blood (ICRP 70, 1995).

[***] Including teeth, periosteum and blood vessels.

Table 7. Mass (g) of whole body, soft tissue, skeleton and certain internal organs for the Asian population.

Organ	Three months	One year	Five years	10 years	15 years	Adult
Revised total body mass [#]	6 338	10 792	17 641	29 409	52 957	58,898
Revised soft tissue mass[*]	5 808	9 642	15 711	26 149	47 517	52,798
Total body mass	6 500	11 000	18 000	30 000	54 000	60,000
Skeleton mass[**]	750	1 480	2 540	4 560	7 440	8,400
Bone	300	850	1 400	2 400	4 000	4,500
Active Marrow	110	190	310	700	900	1,000
Inactive Marrow	110	140	300	600	1 100	1,300
Cartilage	130	170	290	480	840	900
Miscellaneous[#]	100	130	240	380	600	700
Mass of contents in:						
Gastrointestinal tract	140	180	310	510	900	950
Gall bladder	7	9	16	27	47	50
Urinary bladder	15	19	33	54	96	102

[#] The mass of the whole body minus contents of the gastrointestinal tract, the urinary bladder and the gall bladder.
[*] From Table 23 in Tanaka (1993) minus masses of the bone, cartilage and miscellaneous (teeth, periosteum, and blood vessels).
[**] The skeleton does not include periarticular tissue or blood (ICRP 70, 1995).

Table 8. Age-dependent dose coefficients for tritiated water intake.

Population Type	Mass of Total Body (kg)	Mass of Soft Tissue (kg)	Compartment A (Bq)	Biological Half-time (T_1) (d)	Compartment B (Bq)	Biological Half-time (T_2) (d)	Revised Dose Coefficient (Sv Bq^{-1})	ICRP Dose Coefficient (Sv Bq^{-1})	Ratio (Revised to ICRP)
Reference Population									
Three months	3.54	3.22	0.97	3	0.03	8	1.1E-10	6.4E-11	1.74
One year	9.54	8.54	0.97	3.5	0.03	15	5.1E-11	4.8E-11	1.07
Five years	19.46	17.53	0.97	4.6	0.03	19	3.3E-11	3.1E-11	1.06
10 years	32.62	29.38	0.97	5.7	0.03	26	2.4E-11	2.3E-11	1.06
15 years	55.83	50.44	0.97	7.9	0.03	32	1.9E-11	1.8E-11	1.08
Adult	68.83	61.98	0.97	10	0.03	40	2.0E-11	1.8E-11	1.11
Asian Population									
Three months	6.34	5.81	0.97	3.2	0.03	8.6	6.5E-11	6.4E-11	1.02
One year	10.79	9.64	0.97	2.5	0.03	16.8	3.5E-11	4.8E-11	0.73
Five years	17.64	15.71	0.97	3.0	0.03	18.2	2.5E-11	3.1E-11	0.81
10 years	29.41	26.15	0.97	3.6	0.03	24.0	1.8E-11	2.3E-11	0.80
15 years	52.96	47.52	0.97	5.1	0.03	31.4	1.4E-11	1.8E-11	0.79
Adult	58.90	52.80	0.97	5.5	0.03	31.6	1.4E-11	1.8E-11	0.76

Table 9. Age-dependent dose coefficients for organically bound tritium intake.

Population Type	Mass of Total Body (kg)	Mass of Soft Tissue (kg)	Compartment A (Bq)	Biological Half-time (T_1) (d)	Compartment B (Bq)	Biological Half-time (T_2) (d)	Revised Dose Coefficient (Sv Bq^{-1})	ICRP Dose Coefficient (Sv Bq^{-1})	Ratio (Revised to ICRP)
Reference Population									
Three months	3.54	3.22	0.5	3	0.5	8	1.9E-10	1.2E-10	1.62
One year	9.54	8.54	0.5	3.5	0.5	15	1.2E-10	1.2E-10	1.03
Five years	19.46	17.53	0.5	4.6	0.5	19	7.7E-11	7.3E-11	1.05
10 years	32.62	29.38	0.5	5.7	0.5	26	6.1E-11	5.7E-11	1.08
15 years	55.83	50.44	0.5	7.9	0.5	32	4.5E-11	4.2R-11	1.07
Adult	68.83	61.98	0.5	10	0.5	40	4.6E-11	4.2E-11	1.09
Asian Population									
Three months	6.34	5.81	0.5	3.2	0.5	8.6	1.1E-10	1.2E-10	0.96
One year	10.79	9.64	0.5	2.5	0.5	16.8	1.1E-10	1.2E-10	0.96
Five years	17.64	15.71	0.5	3.0	0.5	18.2	7.7E-11	7.3E-11	1.06
10 years	29.41	26.15	0.5	3.6	0.5	24.0	6.0E-11	5.7E-11	1.05
15 years	52.96	47.52	0.5	5.1	0.5	31.4	4.4E-11	4.2E-11	1.04
Adult	58.90	52.80	0.5	5.5	0.5	31.6	4.0E-11	4.2E-11	0.95

Table 10. Comparison of age-dependent dose coefficients for members of the different populations.

Age	Dose Coefficient ($Sv\ Bq^{-1}$) HTO Intake: Reference*	Dose Coefficient ($Sv\ Bq^{-1}$) HTO Intake: Asian*	Ratio Asian to Reference	Dose Coefficient ($Sv\ Bq^{-1}$) OBT Intake: Reference**	Dose Coefficient ($Sv\ Bq^{-1}$) OBT Intake: Asian**	Ratio Asian to Reference
Three months	1.1×10^{-10}	6.5×10^{-11}	0.6	1.9×10^{-10}	1.1×10^{-10}	0.6
One year	5.1×10^{-11}	3.5×10^{-11}	0.7	1.2×10^{-11}	1.1×10^{-11}	0.9
Five years	3.3×10^{-11}	2.4×10^{-11}	0.7	7.7×10^{-11}	7.7×10^{-11}	1.0
10 years	2.4×10^{-11}	1.8×10^{-11}	0.8	6.1×10^{-11}	6.0×10^{-11}	0.9
15 years	1.9×10^{-11}	1.4×10^{-11}	0.7	4.5×10^{-11}	4.4×10^{-11}	1.0
Adult	2.0×10^{-11}	1.4×10^{-11}	0.7	4.6×10^{-11}	4.0×10^{-11}	0.8

*From Table 8.

**From Table 9.

Table 11. Dose coefficient and Annual Limit on Intake for tritium intakes by an adult occupational worker.

Chemical Form/Origin	Biokinetic Model	Dose Coefficient ($Sv\ Bq^{-1}$) Reference Man*	Dose Coefficient ($Sv\ Bq^{-1}$) Asian Man	Annual Limit on Intake♣ (Bq) Reference Man*	Annual Limit on Intake♣ (Bq) Asian Man
Tritiated water	HTO	2.0×10^{-11}	1.4×10^{-11}	1.0×10^{9}	1.4×10^{9}
Tritium gas♦	HTO	2.0×10^{-15}	1.4×10^{-15}	1.0×10^{13}	1.4×10^{13}
Tritiated methane♥	HTO	2.0×10^{-13}	1.4×10^{-13}	1.0×10^{11}	1.4×10^{11}
Organically bound tritium	OBT	4.6×10^{-11}	4.0×10^{-11}	4.3×10^{8}	5.0×10^{8}

*Trivedi (1998)

♦About 0.01% of inhaled tritium gas is absorbed and converted to HTO (ICRP 71, 1995).

♥Assuming 1% of inhaled tritiated methane is metabolized to form HTO (ICRP 71, 1995).

♣Based on annual dose of 0.02 Sv (ICRP-60, 1991)

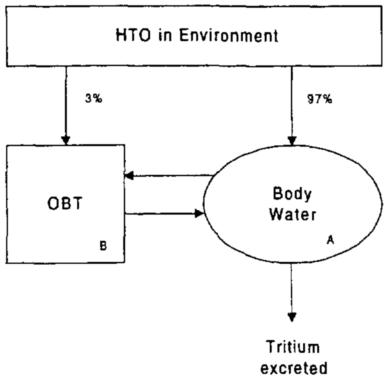

Figure 1: A schematic representation of the ICRP biokinetic model for tritiated water.

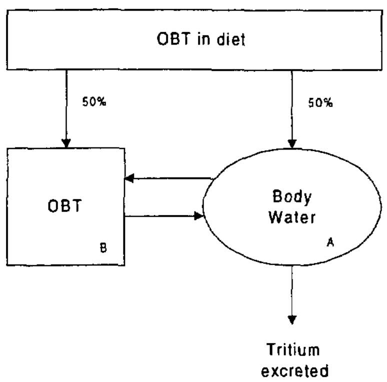

Figure 2: A schematic representation of the ICRP biokinetic model for organically bound tritium.

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