대한방사선방어학회지
제 9 권 제 2 호 1984

Comparative Study on the Committed Dose Equivalent for Adults and Infants

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=Abstract=

Weighted committed dose equivalents(W_T H_{50}) per intake of unit activity of four nuclides-I-131, I-133, Cs-134 and Cs-137-, which was based on the concepts of ICRP Pub. 30, are calculated for adult who is 70 kg and 25 years old and, for infant who is 10 kg and 1 year old.

Metabolism of iodine taken through oral or inhalation pathway is described by using the three-compartment model which consists of inorganic, thyroid and organic compartment. After intake, the amount of iodine in every compartment is calculated by solving the transfer equations among the these compartments.

As soon as caesium is taken into the body, it is distributed uniformly in the body through the transfer compartment. In this case, the amount of caesium in total body is calculated by using the total body compartment model which is divided into two tissue compartments because of their different biological half-lifes of caesium in body.

As a result of calculations, whether oral or inhalation pathway, the values of (W_TH_{50}) per intake of unit activity of I-131 for infants are about ten times as much as those of adults.

On the other hand, for Cs-134 and Cs-137, the values of W_TH_{50} per intake of unit activity show that, whether adults of infants, they have almost the same values.

1. Introduction

In 1959, the International Commission on Radiological Protection (ICRP) issued ICRP Pub. 2[1)] which had guided for the control of intakes of radionuclides into the body with the critical organ concept.

Afterward, ICRP Pub. 22(1973)[2)] and Pub. 26(1977)[3)] made great changes in the basic concept of the control of internal dose. ICRP Pub. 22 recommended that the resulting doses are as low as reasonably achievable (ALARA), economic and social considerations being taken into account, In ICRP Pub. 26, the total risk concept-several organs and tissues, not only critical organ, would be irradiated following the entry of a radionuclide into body-was recommended.

With new informations on the uptake and retention of radioactive materials in body and on radioactive decay scheme, ICRP Pub. 30 (1979)[4)] describes how to calculate the internal dose by means of these new concepts and give a new quantity, committed dose equivalent (H_{50}).

In Korea, some radionuclides in gaseous and liquid effluents released from many nuclear power plants are detected in usual operational circumstances and around power plants site[5]. Of all radioactive effluents, H_{50} for I-131, I-133 Cs-133 and Cs-137 were calculated in this paper. The purpose of this paper is to obtain the H_{50} per intake of unit activity for adult who is 70 kg and 25 year sold and for infant who is 10 kg and 1 year old[6,7].

Johnson[8] calculated the amount of iodine in a thyroid and in other tissues which are divided into organic and inorganic compartment by using the three-compartment model, By this model, the values of H_{50} for I-131 and I-133 can be calculated. Miller and Richmond[9,10], et al., experimented on the metabolism of caesium in body and got the empirical equation which describes the metabolism of caesium. But, in this paper, the representing values, which are taken from AECL-6540, for biological half-life of caesium in body are used in calculating H_{50}.

Accurate decay schemes of four radionuclides and data for the mass of organs are required to calculate the H_{50}. Dillman[11] gives the decay schemes of I-131 and Cs-137, which inform the energies of secondary radiations originated from γ-rays, appropriate to the internal radiation dosimetry. But the proper decay schemes of I-133 and Cs-134 are not published yet and simple decay schemes of them are used[12].

2. Basic Concepts for the Control of Internal Dose

2.1. Dose Equivalent Limits

For the purpose of radiation protection, two broad categories of radiation induced effects are considered.

1) Stochastic effects: malignant and hereditary disease for which the probability of a somatic effect occurring rather than its severity is regarded as a function of dose without threshold.

2) Non-stochastic effects: effects such as opacity of the lens and cosmetically unacceptable changes in the skin for which a threshold of dose must be exceeded before the effect is induced.

For stochastic effects Commission's recommended dose Limits is based on the principle that the limit on risk should be equal whether the whole body is irradiated uniformly or non-uniform irradiation.

This condition will be met if

$$\sum{}_T W_T H_T \leq H_{wb\cdot L}$$

where H_T : annual dose equivalent in tissue (T).

$H_{wb\cdot L}$: the recommended annual dose equivalent limit for uniform irradiation of the whole body.

W_T : a weighting factor representing the proportion of the stochastic risk resulting from tissue (T) to the total risk (Table 2.1).

In order to meet the Commission's basic limits for the occupational exposure, the intake of radioactive materials in any year must be limited to satisfy the following conditions.

For stochastic effects

Table 2.1. Dose Equivalent (D) to a Tissue giving same Risk as 0.05 Sv (5rem) to Whole Body and Weighting Factor (W_T)

Organ or Tissue	D Sv	 rem	W_T
Gonads	0.2	20	0.25
Breast	0.33	33	0.15
Red bone marrow	0.42	42	0.12
Lung	0.42	42	0.12
Thyroid	1.67	167	0.03
Bone surface	1.67	167	0.03
Remainder	0.83	83	0.3

$$\sum_T W_T H_{50.T} \leq 0.05(Sv) \cdots\cdots\cdots\cdots (2.1)$$

For non-stochastic effects

$$H_{50.T} \leq 0.5(Sv) \cdots\cdots\cdots\cdots\cdots\cdots\cdots (2.2)$$

where $H_{50.T}$ (in Sv) is the total committed dose equivalent in tissue (T) resulting from intake of radioactive materials from all sources during the year.

In case of non-occupational exposure the value of annual dose equivalent is recommended as one tenth of that of occupational exposure$^{3)}$.

2.2. Committed Dose Equivalent (H_{50})

For purposes of planning in radiological protection it is assumed that risk of a given biological effect is linearly related to dose equivalent. In this circumstances, risk of an effect is determinded by the total dose equivalent averaged throughout the organ or tissue at risk, independent of the time over which that dose equivalent is delivered. The total dose equivalent averaged throughout any tissue over the 50 years after intake of a radionuclide into the body is termed the committed dose equivalent (H_{50}).

$$H_{50}=\sum_i \frac{\int^M D_{50,i}\, Q_i\, N_i\, dm}{\int^M dm} \cdots (2.3)$$

where i : the type of radiation.

M : the mass of the specific organ or tissue.

$D_{50.i}$: total absorbed dose during a period of 50 years for each type of radiation i.

Q_i : the quality factor.

N_i : the product of all other modifying factor.

The expression for H_{50} shown in eqt (2.3) can be simplified to

$$H_{50}=\sum_i Q_i\, \overline{D_{50.i}}$$

where $\overline{D_{50.i}}$ is averaged value of $D_{50.i}$

In this paper, estimates are made of the committed dose equivalent (H_{50}) in a number of target organ (T) from the activity in a given source organ (S).

Therefore,

$$\begin{aligned} H_{50}(T\leftarrow S)_i &= Q_i\, \overline{D_{50}}(T\leftarrow S)_i \\ &= Us\times SEE(T\leftarrow S)_i \times 1.6\times \\ &\quad 10^{-10}(Sv) \cdots\cdots\cdots\cdots\cdots (2.4) \end{aligned}$$

where Us : the number of transformation in source over the 50 years following intake of the radionuclide.

$SEE(T\leftarrow S)_i$: the specific effective energy for radiation type i, suitably modified by quality factor, absorbed in target from each transformation in source. (MeV/g per trans.)

1.6×10^{-10} : the conversion iactor.

The masses of target and source organs used in this paper are taken from ICRP Pub. 23 and AECL-6540.

3. Calculations of H_{50} for I-131 and I-133

3.1. Metabolism of Iodine

The metabolism of iodine in man has been described by a three-compartment model. These compartments are

1) Inorganic compartment; consisting of all extrathyroidal iodine that is not bound to thyroid-produced organic molecules and which may be excreted or taken by the thyroid for conversion into organic iodine.

2) Thyroid compartment; consisting of all iodine in the thyroid.

3) Organic compartment: consisting of all extra-thyroidal iodine bound to thyroid-produced organic moleules and capable of being excreted or being converted back to inorganic iodine.

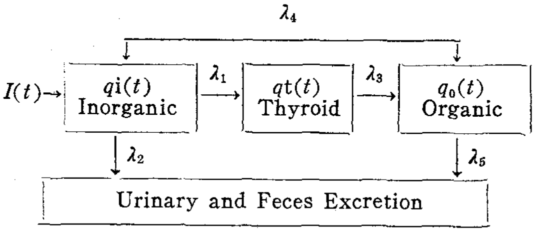


Fig. 3.1. The Compartment Model of Iodine
$I(t)$: The rate of entry of the radionuclide at time t.
$q_n(t)$: The amount of radionuclide in the compartment n at t after intake.
λ_i : Rate constant ($i=1,2,3,4,5$).

Metabolic diagram of iodine and clearance rate constants are shown in Fig. 3.1 and Table 3.1.

According to the daily intake and to the content of iodine in the thyroid and the body of adults, the rate constant can be obtainded.

The differential equations for this model are

$$\frac{dq_i(t)}{dt}=-(\lambda_1+\lambda_2)q_i(t)+\lambda_4 q_0(t)+I(t)\cdots\cdots(3.1)$$

$$\frac{dq_t(t)}{dt}=\lambda_1 q_i(t)-\lambda_3 q_t(t)\quad\cdots\cdots(3.2)$$

$$\frac{dq_0(t)}{dt}=\lambda_3 q_t(t)-(\lambda_5+\lambda_4)q_0(t)\cdots(3.3)$$

The physical decay of radioiodine dose not include in the eqt. 3.1 to eqt. 3.3. It can be included simply by multiplying all solutions by $exp(-\lambda rt)$.

Table 3.1. Rate Constant

Route	Constant λ_i of Adult (days^{-1})
1	0.93
2	1.92
3	0.0087
4	0.053
5	0.005

These equations can be solved by using boundary conditions appropriate to a single instaneous input of radioactive iodine into the inorganic compartment ($\therefore I(t)=0$).

The analytical solutions to these equations using the constant from Table 3.1 are

$$q_i(t)=I_0[1.000e^{-2.85t}-9.9\times10^{-4}\ e^{-0.0609t}+9.5\times10^{-4}\ e^{-0.0058t}]\cdots\cdots(3.4)$$

$$q_t(t)=I_0[-0.327\ e^{-2.85t}+0.0175\ e^{-0.0609t}+0.310\ e^{-0.00586t}]\cdots\cdots(3.5)$$

$$q_0(t)=I_0[0.001\ e^{-2.85t}-0.0517\ e^{-0.0609t}+0.0507\ e^{-0.00586t}]\cdots\cdots(3.6)$$

Judging from Fig. 3.2, the retention in other compartments excepts the thyroid can be neglected because of their extremely small iodine deposition in body.

In the case of infants, the half-life for removal of iodine from the infant inorganic

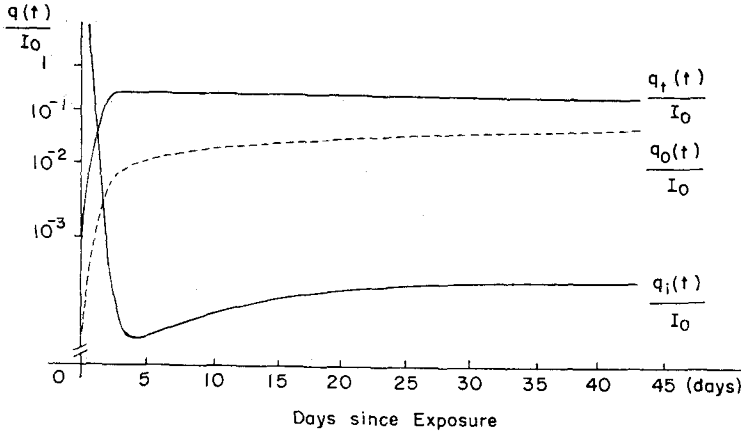


Fig. 3-2. Relative Amount of I-131 and I-133 Deposition in Case of Adult Body.

compartment and the ratio of thyroid uptake to whole body intake are assumed to the same as that for the adults. This assumption fixes the values of λ_1 and λ_2 at the adult values.

The mass of iodine in the infant's thyroid was calculated to be 3.0×10^{-7} kg from data in ICRP Pub. 23. The daily iodine output of the thyroid (as organically bound iodine) is 6×10^{-8} kg for a 70 kg man and is assumed to be 8.57×10^{-9} kg for a 10 kg infant. Assuming that all the iodine in an infant's thyroid has equal opportunity of leaving the thyroid as organically bound iodine, then λ_3 for infant is $8.57\times10^{-9}/3.0\times10^{-7}=0.0286\ d^{-1}$. If the concentration of organically bound iodine in infant's soft tissue is to be equal to that used for adults and the production of thyroid hormones is assumed to be directly proportional to body weight, it seems reasonable to assume that λ_4 and λ_5 are equal for infants and adults[7].

The factors derived here result from an assumed daily iodine intake of 0.2 mg for adults and 29 μg for infants. Using λ_3 for infants, $q_t^{inf}(t)$ can be calculated as follows:

$$q_t^{inf}(t)=I_0[-0.3317\ e^{-2.8479t}+0.1813\ e^{0.0211t}+0.1522\ e^{-0.1217t}] \cdots\cdots (3.7)$$

3.2. Calculations of Us and SEE

(1) *Us*

The value of Us means the total number of transformation in source over the 50 years following intake of radionuclide. This is given as follows:

$$Us(T)=\int_0^{50y} e(-\lambda_r t)\ q_j\ (t)dt \cdots\cdots (3.8)$$

where λ_r : radioactive decay constant of the radionuclide.

$q_j(t)$: the amount of radionuclide in the compartment j. Here, two routes of entry of radioactive materials into body namely the gastrointestinal (GI) tract (Oral) and the respiratory system (Inhalation) are considered.

In the case of oral intake for adults, substituting eqt. 3.5 into 3.8, the values of I-131 and I-133 can be calculated.

then, Us^{131}(oral)

$$=I_0\int_0^{50\times365} e^{-0.086t}(-0.327\ e^{-2.85t}+0.0175\ e^{-0.0609t}+0.310e^{-0.00586t})dt$$

$$=2.91\times10^5\ I_0(\text{trans.}) \cdots\cdots\cdots\cdots\cdots (3.9)$$

and Us^{133}(oral)

$$=I_0\int_0^{50\times365} e^{-0.8t}(-0.327e^{-2.85t}+0.0175e^{-0.0609t}+0.310e^{-0.00586t})dt$$

$$=2.60\times10^4 I_0(\text{trans.}) \cdots\cdots\cdots\cdots\cdots (3.10)$$

In the same way, from eqt. (3.7) and eqt. (3.8) the values of *Us* for infants can be obtained as follows:

Us^{131}(oral)

$$=2.95\times10^5\ I_0(\text{trans.}) \cdots\cdots\cdots\cdots (3.11)$$

Us^{133}(oral)

$$=2.65\times10^4\ I_0(\text{trans.}) \cdots\cdots\cdots\cdots (3.12)$$

The quantities of *Us* in the inorganic and organic compartment are so small and are not so important compared to that of the thyroid that they can be negligible.

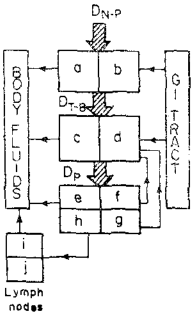
For inhalation intake, it is recognized that after the inhalation of radioactive aerosols the doses receives by various regions in the respiratory system will differ widely, depending on the size distribution of the inhaled material.

In this study, calculations of committed dose equivalents are for aerosol with an AMAD (Activity Median Aerodynamic Diameter) of 1 μm. The fraction of deposition in respiratory system is given as 0.63 from Fig. 3.3 (a).

For adults,

Region	Compart-ment	T day	F
N-P	a	0.01	0.5
($D_{N-P}=0.30$)	b	0.01	0.5
T-B	c	0.01	0.95
($D_{T-B}=0.08$)	d	0.2	0.05
	e	0.5	0.8
P	f	n.a.	n.a.
($D_P=0.25$)	g	n.a.	n.a.
	h	0.5	0.2
L	i	0.5	1.0
	j	n.a.	n.a.

(a)



(b)

Fig. 3.3. Mathematical Model used to describe Clearance from the Respiratory System with an AMAD of 1 μm.

T : removal half-times.

F : the fraction leaving the region.

N-P : nasopharynx region.

T-B : trachea and bronchial tree region.

P : pulmonary region.

L : lymphatic system.

$D_{N\text{-}P}$, $D_{T\text{-}B}$, D_P : the fraction of inhaled meterial initially deposited in the N-P, T-B, and P regions.

$n\cdot a$: not applicable in this calculation.

$$Us^{131}(\text{inhalation})=0.63\ Us^{131}(\text{oral})$$
$$=1.83\times10^5\ I_0(\text{trans.})\ \cdots\cdots\cdots\cdots(3.13)$$

The radioactive half-life of I-133 (20.8h) is not long compared with the removal half-time at pulmonary in respiratory system. Therefore, the radioactive decay of I-133 in pulmonary should be considered.

The removal half-time at region e and h in pulmonary is given as 12 hours from Fig. 3.3 (a) and after that time, the rest of the initially deposited activity can be obtained by the following formula:

$$Dp\ e(-\lambda r\,Tp)=Dp\ e(-0.693\times12/20.8)$$
$$=0.67\,Dp$$

where

Dp : the deposition fraction in pulmonary (=0.25)

λ_r : the physical decay constant of I-133.

Tp : the removal half-time at region e and h in pulmonary (0.5dy=12hr).

So total deposition fraction for I-133 in respiratory system becomes

$$D_{N-P}+D_{T^-B}+0.67\,Dp\times(0.8+0.2)=0.55$$

Therefore, for adults,

$$Us^{133}(\text{inhalation})=0.55\,Us^{133}(\text{oral})$$
$$=1.43\times10^4\ I_0(\text{trans.})\ \cdots\cdots\cdots\cdots(3.14)$$

and the values for infants are

$$Us^{131}(\text{inha.})=0.63\ Us^{131}(\text{oral})$$
$$=1.86\times10^5\ I_0(\text{trans.})\ \cdots\cdots\cdots\cdots(3.15)$$
$$Us^{133}(\text{inha.})=0.55\ Us^{133}(\text{oral})$$
$$=1.46\times10^4\ I_0(\text{trans.})\ \cdots\cdots\cdots\cdots(3.16)$$

(2) SEE

SEE$(T\leftarrow S)_j$ can be definded as follows:

$$\mathrm{SEE}(T\leftarrow S)_j=\sum_i\frac{Y_i\bar{E}_i\ AF(T\leftarrow S)_iQ_i}{M_T}$$
$$(\text{MeV g}^{-1}\text{ per trans.})\ \cdots\cdots\cdots\cdots(3.17)$$

where the summation means overall radiations produced per transformation of radionuclide j in source organ S and

Y_i : the yield of radiations of type i per transformation of rarionuclide j.

E_i : the average or unique energy of radiation i (MeV)

$AF(T\leftarrow S)_i$: the fraction of energy absorbed in target organ T per emission of radiation i in S.

Q_i : the quality factor appropriate for radiation of type i.

M_T : the mass of the target organ.

For α,β particles, fission fragments and recoil atoms, value of $AF\ (T\leftarrow S)_i$ will usually be either zero, when the target is beyond the range of radiations from the source, or unit when target and source organs are the same tissue.

The values of AF for photons can be estimated by the use of data on Specific Absorbed Fraction (SAF) (absorbed fraction per target mass).

I-131 and I-133 emit β^- particles and γ-rays. β^- particles are directly absorbed in source organs because of its short penetration range. But γ-rays make complicated reactions with target tissues. When γ-rays are emitted into targets, significant γ-ray internal conversions or electron capture processes which give rise to X-rays and Auger eletrons occur.

These radiations should be included in the calculation of SEE.

Therefore,

$$\mathrm{SEE}(T\leftarrow S)=\mathrm{SEE}(S\leftarrow S)_\beta+\mathrm{SEE}(S\leftarrow S)_{\beta'}+\mathrm{SEE}(S\leftarrow S)_\gamma+\mathrm{SEE}(S\leftarrow S)_x+\mathrm{SEE}(T\leftarrow S)_\gamma+\mathrm{SEE}(T\leftarrow S)_x \quad \cdots\cdots(3.18)$$

where

β' : β-like particles caused by γ or X-rays.

X : x-rays.

Here the values of SEE for photons can be neglected because SAF_γ is extremely insignificant compared with the values SAF_β or $\mathrm{SAF}_{\beta'}$.

As a result,

$$\mathrm{SEE}(T\leftarrow S)=\frac{Y_\beta \bar{E}_\beta AF(S\leftarrow S)_\beta Q_\beta}{M_T}+\frac{Y_{\beta'}\bar{E}_{\beta'}AF(S\leftarrow S)_{\beta'}Q_{\beta'}}{M_T} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(3.19)$$

where $Q, AF=1$ for β or β-like particles.

M_T : the mass of thyroid.

From the decay scheme, $(Y_\beta\bar{E}_\beta+Y_{\beta'}\bar{E}_{\beta'})$ for I-131 is 0.2 (MeV/trans) and the values of M_T for adults and infants are 20 g and 2 g, respectively.

So

$$\mathrm{SEE}(T\leftarrow S)\ \text{adult}=\frac{0.2}{20}=0.01$$

$$(\mathrm{MeV\ g^{-1}\ trans^{-2}})\cdots\cdots\cdots\cdots\cdots\cdots(3.20)$$

$$\mathrm{SEE}(T\leftarrow S)\ \text{infant}=\frac{0.2}{2}=0.1$$

$$(\mathrm{MeV\ g^{-1}\ trans^{-1}})\ \cdots\cdots\cdots\cdots\cdots(3.21)$$

The value of $(Y_\beta\bar{E}_\beta+Y_{\beta'}\bar{E}_{\beta'})$ for I-133 is given as 0.41 (Mev/trans)

so,

$$\mathrm{SEE}(T\leftarrow S)^a=\frac{0.41}{20}=0.021$$

$$(\mathrm{MeV\ g^{-1}\ trans^{-1}})\cdots\cdots\cdots\cdots\cdots\cdots(3.22)$$

$$\mathrm{SEE}(T\leftarrow S)^i=\frac{0.41}{2}=0.205$$

$$(\mathrm{MeV\ g^{-1}\ trans^{-1}})\cdots\cdots\cdots\cdots\cdots\cdots(3.23)$$

3.3. The Values of H_{50} for I-131 and I-133

Combining eqt. 3.9. to eqt. 3.16 and eqt. 3.20 to eqt. 3.23 with eqt. 2.4, the results can be obtained as Table 3.1.

Table 3.1. The Values of Us, SEE and H_{50} for I-131 and I-133 in Thyroid

Radionuclide Age Pathway		I-131		I-133	
		Adult	Infant	Adult	Infant
Us per intake of unit activity(trans. Bq^{-1})	Oral	2.91×10^5	2.95×10^5	2.10×10^4	2.65×10^4
	Inhalation	1.83×10^5	1.86×10^5	1.43×10^4	1.46×10^4
SEE(MeV g^{-1} trans.$^{-1}$)		0.01	0.1	0.021	0.025
H_{50} per intake of unit activity(Sv Bq^{-1})	Oral	4.7×10^{-7}	4.7×10^{-6}	8.7×10^{-8}	8.9×10^{-7}
	Inhalation	2.9×10^{-7}	3.0×10^{-6}	4.8×10^{-8}	4.9×10^{-7}
Weighted H_{50} per intake of unit activity(Sv Bq^{-1})($=0.03\times H_{50}$)	Oral	1.4×10^{-8}	1.4×10^{-7}	2.6×10^{-9}	2.7×10^{-8}
	Inha · tion	8.8×10^{-9}	8.9×10^{-8}	1.4×10^{-9}	1.5×10^{-8}

4. Calculation of H_{50} for Cs-134 and Cs-137

4.1. Metabolism of caesium

From the experimental data, whether adults or infants, of caesium entering the transfer compartment (blood), the retention fraction 0.1 is translocated to one tissue compartment and the remainder to another compartment. For adult, caesium is retained each compartment with the removal half-life 2 days and 110 days, respectively. Therefore, the retention of caesium for adults is shown as follows:

$$R(t)=q(t)/I_0=0.1\,e(-0.693\,t/2)+0.9\,e(0.693\,t/110)\cdots\cdots\cdots\cdots\cdots(4.1)$$

In the case of infants, it is important to note that infant's removal half-lifes of caesium which are 1 day and 20 days respectively is short compared with adult's. So

$$R(t)=0.1\,e(-0.693\,t/1)+0.9\,e(-0.693\,t/20)\cdots\cdots\cdots\cdots\cdots\cdots(4.2)$$

Metabolic diagram of caesium is shown as follows:

4.2. Calculation of Us and SEE

(1) Us

Before caesium enters the transfer compartment (Fig. 4.1), it decays along the G-I tract or lung for the short time. Using the factors in the Fig. 3.3 and the formula in Appendix of ICRP Pub. 30, the value of Us in lung can be calculated as next formula.

$$Us\text{(in lung)}=I_0\left\{\frac{D_{Np}F_a}{\lambda_a+\lambda_R}+\frac{D_{Np}F_b}{\lambda_b+\lambda_R}+\frac{D_{TB}F_c}{\lambda_c+\lambda_R}+\frac{D_{TB}F_d}{\gamma_d+{}_R}+\frac{D_PF_e}{\lambda_e+\lambda_R}+\frac{D_PF_n}{\lambda_h+\lambda_r}+\frac{D_PF_h\lambda_hF_i}{(\lambda_h+\lambda_r)(\lambda_i+\lambda_r)}\right\}$$

where

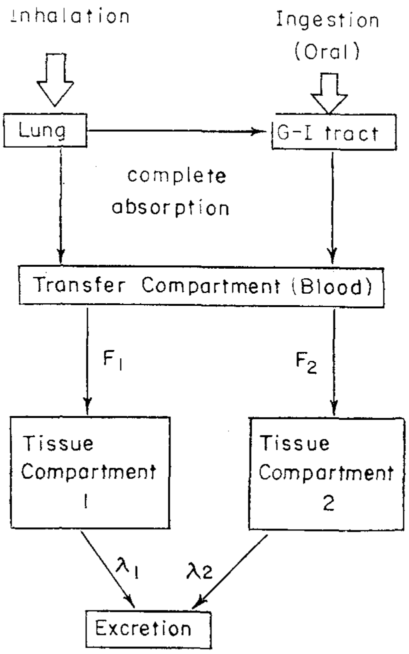
$\lambda_n=\dfrac{0.693}{T_n}$ (T_n : removal half-time in n compartment, $n=a,b,\cdots i.$).

λ_R : radioactive decay const.

F_n=the fraction leaving the region n.

and

$$Us\text{(in G-I tract)}=I_0\frac{1}{\lambda_{ST}+\lambda_R}$$



Age	Adult	Infant
$\lambda_1(d^{-1})$	0.347	0.693
$\lambda_2(d^{-1})$	6.3×10^{-3}	0.035
F_1	0.1	0.1
F_2	0.9	0.9

λ_i : Removal constant (i = 1, 2)

F_i : Retention fraction (i = 1, 2)

Fig. 4.1. Compartment Model of Caesium.

Table 4.1. The Values of Us/I_0 of Cs-134 and Cs-137(trans, Bq^{-1})

Pathway / Age / Radionuclide / Organ		Oral($\times 10^6$)		Inhalation($\times 10^6$)	
		Adult	Infant	Adult	Infant
Lung	Cs-134	—	—	0.0189	0.0189
	Cs-137	—	—	0.0189	0.0189
Total Body	Cs-134	10.7	2.22	6.75	1.4
	Cs-137	12.4	2.26	7.79	1.42

where

λ_{ST} : the biological clearance rate in stomach($=24d^{-1}$)

From the data in Fig. 3.3, the values of Us in lung or G-I tract are calculated. So

$$Us(\text{lung}) = 1.89\times10^4\, I_0(\text{trans.}) \cdots\cdots (4.3)$$

$$Us(\text{G-I tract}) = 3.60\times10^3\, I_0(\text{trans.}) \cdots\cdots\cdots\cdots\cdots (4.4)$$

Passing through the transfer compartment, caesium is rapidly and completly absorbed in the total body. The value of Us in the total body is obtained by putting eqt. 4.2 into eqt. 3.8. In the same manner as iodine, the fraction of deposition in respiratory system is also given as 0.63.

So

$$Us(\text{inhal.}) = 0.63\ Us(\text{oral})$$

The values of Us/I_0 for Cs-134 and Cs-137 are summarized in Table 4.1.

Compared with values of Us in lung or total body, Us in G-I tract is small and negligible.

(2) SEE

Cs-134 and Cs-137 also emit β^- particles and γ-rays which give rise to X-rays and β-like particles when they interact with target organs.

In the case of a lung source for adults,

$$^{*}\text{SEE}(T\leftarrow\text{lung})^a = \text{SEE}(L\leftarrow L)^a_\beta + \text{SEE}(L\leftarrow L)^a_{\beta'} + \text{SEE}(T\leftarrow L)^a_\gamma + \text{SEE}(T\leftarrow L)^a_x \cdots (4.5)$$

$$= \frac{\bar{E}}{M_L}\ \frac{\bar{E}}{M_L} + \sum_\gamma Y_\gamma E_\gamma \left\{\text{SAF}(L\leftarrow L)_\gamma + \text{SAF}(O.T\leftarrow L)_\gamma\right\} + \sum_x Y_x E_x \left\{\text{SAF}(L\leftarrow L)_x + \text{SAF}(O.T\leftarrow L)_x\right\} \cdots\cdots\cdots\cdots\cdots\cdots (4.6)$$

*Lung and Other tissues will be abbreviated to L and $O.T$, respectively.

where

M_L= the mass of lung(1,000 g)

SAF= Specific Absorbed Fraction$\left(=\dfrac{AF}{M_T}\right)$

The summations $\sum_\gamma$ and $\sum_x$ mean the sum of SEE for photons which have various energies and different fractions.

For the total body source,

$$\text{SEE}(T\leftarrow T.B)^a = \frac{\bar{E}_\beta}{M_T}\ \frac{\bar{E}_{\beta'}}{M_T} + \sum_\gamma Y_\gamma E_\gamma \text{SAF}(T\leftarrow T.B)_\gamma + \sum_x Y_x E_x\, \text{SAF}(T\leftarrow T.B)_x \cdots\cdots\cdots (4.7)$$

Because of the differences between adults and infants in weight and height, the value of AF for adults should be corrected by using factor $R_m f_r$.

Therefore, in case of a lung source for infants,

$$\text{SEE}(T\leftarrow L)^i = \text{SEE}(L\leftarrow L)^i_\beta + \text{SEE}(L\leftarrow L)^i_{\beta'} + \left\{\text{SEE}(T\leftarrow L)^a_\gamma + \text{SEE}(T\leftarrow L)^a_x\right\}$$

$$R_m f_r = \frac{\bar{E}_\beta}{M_L} + \frac{\bar{E}_{\beta'}}{M_L} + \left\{\sum_\gamma Y_\gamma E_\gamma\ \text{SAF}(T\leftarrow L)_\gamma + \sum_x Y_x E_x\ \text{SAF}(T\leftarrow L)_x\right\} R_m f_r \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4.8)$$

where

$$R_m=\frac{M^{\text{adult}}}{M^{\text{infant}}},$$

M_L=the mass of infant lung(=150 g)

f_r=correction factors for the absorbed fraction of energy in the infant organs compared to the adult organs for photons.

For the total body source,

$$\begin{aligned}\text{SEE}(T\leftarrow T.B)^i &= \frac{\bar{E}_\beta}{M_T}+\frac{\bar{E}_{\beta'}}{M_T}\left\{+\sum_\gamma Y_\gamma E_\gamma \text{SAF}(T\leftarrow T.B)^a_\gamma\right. \\ &\quad \left.+\sum_x Y_x E_x \text{SAF}(T\leftarrow T.B)^a_x\right\} \\ &\quad R_m f_r \quad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (4.9)\end{aligned}$$

where

Table 4.2. The Value of SEE for Cs-137(MeV g^{-1} $trans^{-1}$)

Radiation	$\beta(\times10^{-4})$				$\gamma+\beta'+x(\times10^{-6})$			
Age	Adult		Infant		Adult		Infant	
Source Target	Lung	T.B	Lung	T.B	Lung	T.B	Lung	T.B
Gonads	—	—	—	—	5.7×10^{-2}	4.7	0.4	33
Breast	—	—	—	—	2.7	3.9	9.5	19
Red Marrow	—	—	—	—	2.5	4.2	9.4	19
Lung	1.9	2.7×10^{-2}	13	0.19	95	4.0	5.4×10^2	17
Thyroid	—	—	—	—	2.6	3.9	7.8	16
Bone Surface	—	—	—	—	2.0	3.9	7.0	17
SI Wall*	—	—	—	—	0.59	4.9	1.9	19
ULI Wall	—	—	—	—	0.8	4.8	2.8	20
LLI Wall	—	—	—	—	0.17	4.9	0.54	19
Uterus	—	—	—	—	0.21	4.9	0.84	22
Adrenals	—	—	—	—	4.9	5.2	9.8	17

* T.B: Total Body SI; Small Intestine
ULI; Upper Large Intestine LLI; Lower Large Intestine

Table 4.3. The Value of SEE for Cs-134(MeV g^{-1} trans. $^{-1}$)

Age Source Target	Adult($\times10^{-5}$)		Infant($\times10^{-5}$)	
	Lung	Total Body	Lung	Total Body
Gonads	0.014	1.1	0.098	7.9
Breast	0.62	0.9	2.2	4.1
Red Marrow	0.59	1.0	2.2	4.6
Lung	23	0.9	120	4.0
Thyroid	0.61	0.9	1.8	3.8
Bone Surface	0.46	0.9	1.6	4.1
SI Wall	0.14	1.2	0.45	4.6
LLI Wall	0.04	1.2	0.13	4.6
Uterus	0.05	1.2	0.2	5.5
Adrenal	1.3	1.1	2.6	3.9
Bladder Wall	0.039	1.1	0.094	3.9

M_T=the mass of infant total body (10,000 g).

Like Cs-137, two sources, lung and total body, should be also considered for Cs-134. The way to calculate the SEE of Cs-134 is just same as that of Cs-137 which was shown in eqt. 4.6 to eqt. 4.9. The difference between them is only energy of emitted radiations. Table 4.2 and Table 4.3 represent the values of SEE for Cs-137 and Cs-134, respectively.

4.3. The values of H_{50} for Cs-137 and CS-134

Eqt. 2.4 should be transformed properly for the calculation of H_{50}(oral) and H_{50}(inha.)

In the case of Cs-137, for a target T,

$$H_{50}^T(\text{oral}) = 1.6\times10^{-10}Us(\text{oral})\ [\text{SEE}(T\leftarrow T.B)_\beta + \{\text{SEE}(T\leftarrow T.B)_{\beta'} + \text{SEE}(T\leftarrow T.B)_\gamma + \text{SEE}(T\leftarrow T.B)_x\}\times 0.94] \quad \cdots\cdots(4.10)$$

Where

0.94 is γ decay fraction of Cs-137.

and

$$H_{50}^T(\text{inhal.}) = 1.6\times10^{-10}[Us(\text{lung})\times\{\text{SEE}(L\leftarrow L)_\beta + (\text{SEE}(T\leftarrow L)_{\beta'} + \text{SEE}(T\leftarrow L)_\gamma + \text{SEE}(T\leftarrow L)_x)\times 0.94\} + Us(\text{inha.})\times\{\text{SEE}(T\leftarrow T.B)_\beta + \text{SEE}(T\leftarrow L)_{\beta'} + \text{SEE}(T\leftarrow L)_\gamma + \text{SEE}(T\leftarrow L)_x\times 0.94\}] \cdots\cdots\cdots\cdots\cdots(4.11)$$

Inserting the values in Table 4.1. and Table 4.2. into eqt. 4.10 and eqt. 4.11, the calculated results are listed in Table 4.4.

For lack of accurate decay scheme for Cs-134, the SEE of β' particles and X-rays which are occured by γ-ray can not be calculated. So the simple formula of H_{50} for Cs-134 are given as follows:

$$H_{50}^T(\text{oral}) = 1.6\times10^{-10}\times Us(\text{oral})\ \{\text{SEE}(T\leftarrow T.B)_\beta + \text{SEE}(T\leftarrow T.B)_\gamma\} \quad \cdots\cdots(4.12)$$

$$H_{50}^T(\text{inha.}) = 1.6\times10^{-10}[Us(\text{lung})\ \{\text{SEE}(T\leftarrow L)_\gamma + \text{SEE}(L\leftarrow L)_\beta\} + Us(\text{inha.})\times\{\text{SEE}(T\leftarrow T.B)_\beta + \text{SEE}(T\leftarrow T.B)_\gamma\}]\cdots\cdots(4.13)$$

The results obtained by eqt. 4.12. and eqt. 4.13. are shown in Table 4.5.

Total weighted H_{50} for Cs-134 and Cs-137 are expressed as follows:

$$\text{weighted } H_{50\cdot T} = \sum_T W_T\ H_{50\cdot T}\cdots\cdots(4.14)$$

where

W_T : weighting factor of organ T. (Table 2.1)

Table 4.4. The Value of H_{50}/I_0 for Cs-137 for Adult and Infant (Sv/Bq)

Age Pathway Target	Adult($\times10^{-8}$)		Infant($\times10^{-8}$)	
	Oral	Inhalation	Oral	Inhalatien
Gonads	1.4	0.88	1.8	1.1
Breast	1.2	0.78	1.3	0.83
Red Marrow	1.3	0.83	1.3	0.83
Lung	1.3	0.88	1.2	1.3
Thyroid	1.3	0.79	1.2	0.77
Bone Surface	1.3	0.79	1.2	0.79
SI Wall	1.4	0.91	1.3	0.83
LLI Wall	1.4	0.91	1.3	0.85
ULI Wall	1.4	0.90	1.3	0.83
Remainder(W_T : 0.12)	1.5	0.95	1.4	0.89

Table 4.5. The Value of H_{50}/I_0 for Cs-134 for Adult and Infant(Sv Bq^{-1})

Age Pathway Target	Adult($\times 10^{-8}$)		Infant($\times 10^{-8}$)	
	Oral	Inhalation	Oral	Inhalation
Gonads	1.9	1.2	2.7	1.6
Breast	1.6	1.0	1.4	0.86
Red Marrow	1.8	1.1	1.5	0.96
Lung	1.6	1.0	1.3	1.2
Thyroid	1.6	1.0	1.3	0.79
Bone Surface	1.6	1.0	1.4	0.85
SI Wall	2.0	1.3	1.5	0.96
LLI Wall	2.0	1.3	1.5	0.96
Remainder(Wt : 0.18)	2.1	1.3	1.3	0.81

Table 4.6. Total Weighted H_{50}/I_0 for Cs-134 and Cs-137 for Adult and Infant(Sv Bq^{-1})

Radionuclide Age Pathway	Cs-134($\times 10^{-8}$)		Cs-137($\times 10^{-8}$)	
	Adult	Infant	Adult	Infant
Oral	1.9	1.7	1.4	1.4
Inhalation	1.2	1.1	0.87	0.96

From Table 4.4, 4.5 and Table 2.1, the total weighted H_{50} per intake of unit activity (Sv/Bq) for Cs-134 and Cs-137 are listed in Table 4.6.

5. Discussion and Conclusion

By using the three-compartment model (Fig. 3.1), the values of Us for I-131 and I-133 were calculated. Many organs or tissues scarcely retain iodine (Fig. 3.2) but, only a thyroid is affected by the intake of iodine.

The values of SEE for infants, which is dependent on the mass of target organ (thyroid), are about ten times as much as those of adults. As a result, the values of H_{50} for infants are also greater than adults' by the factor of 10.

The Us for Cs-134 and Cs-137 were obtained by using empirical equations. The values of Us for adults are about five times as much as those of infants because biological half-life of infant (20 days) in total body is shorter than that of adult (110 days).

But the values of SEE for adults are by far smaller than those for infants on account of weighting the factor $R_m f_r$ to SEE of adults and the difference of mass between adult's organ and infant's. Consequently, H_{50} for infants are nearly same as those for adults.

Various metabolic parameters used in this paper quoted directly those of Westerners. They can be changed by the differences in diet, weight of organs and chemical composition of organs and tissues between Westerners and Korean. Therefore, the proper metabolic data for Korean should be established in order that the accurate estimation of internal dose effects for Korean can be done.

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預託線量値에서 본 成人과 幼兒와의 比較硏究

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요 지

국제 방사선 방어위원회(ICRP)에서 새로이 권고한 體內 被曝線量 算定法(ICRP Pub. 30)을 이용하여 I-131, I-133, Cs-134 및 Cs-137 네가지 핵종의 단위 방사능섭취당 荷重 預託線量(W_TH_{50})을 몸무게 70 kg, 나이 25세의 成人과 10 kg, 1세의 幼兒에 대하여 계산하였다.

經口 또는 吸入 경로를 통해 섭취된 요오드의 新陳代謝를 無機質, 甲狀線 有機質구역으로 구성된 三段階 區劃型 모델을 이용하여 묘사하였다. 이 구역들 사이의 전달방정식을 풀어 섭취후 각 구역들에 있어서 요오드의 양을 계산하였다.

Caesium은 섭취후 곧, 전달구역을 통해 전신에 퍼진다. 이 경우 전신에 있는 caesium의 生理學的 半減期에 의하여 전신을 두 組織구역으로 나눈 全身 區劃型모델을 이용하여 전신에서의 caesium의 양을 계산하였다.

계산결과, 經口 또는 吸入, 어떤 경로이든지 단위 방사능섭취로 인한 1-131・1-133의 荷重 預託 線量(W_TH_{50})은 幼兒의 경우가 成人보다 10배정도 많은 값을 나타냈다.

한편, Cs-134과 Cs-137에 대해서는 단위 방사능 섭취당 W_TH_{50}값은 成人과 幼兒가 서로 비슷한 값을 나타내었다.