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■ 論 文 ■

Effective Dose Equivalent due to Inhalation of Indoor Radon-222 Daughters in Korea

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ABSTRACTS

Effective dose equivalents resulting from inhalation of indoor radon-222 daughters at 12 residential areas in Korea were assessed by a simple mathematical lung dosimetry model based on the measurements of long-term averaged radon concentrations at 340 dwellings. The long-term averaged indoor radon-222 concentrations and corresponding eqilibrium equivalent radon concentration(EEC_{Rn}) measured by passive time-integrating CR-39 radon cups are in the range of 33.82~61.42 Bq/m^3(median : 48.90 Bq/m^3) and of 13.53~24.57 Bq/m^3(median : 19.55 Bq/m^3), respectively. The effective dose equvalent conversion factor for the exposure to unit EEC_{Rn} derived in this study was estimated 1.07×10^{-5} $mSv/Bq \cdot h \cdot m^{-3}$ for a reference adult and agreed well with those recommended by the ICRP and UNSCEAR. The annual average dose equivalent to the lung (H_{LUNG}) from inhalation exposure to measured EEC_{Rn} was estimated to be 20.90 mSv and resulting effective dose equivalent(H_E) was to be 1.25 mSv, which is about 50% of the natural radiation exposure of 2.40 mSv/y to the public reported by the UNSCEAR.

Key words : lung dosimetry, inhalation exposure, CR-39 radon cup, EEC_{Rn}, regional lung dose, effective dose equivalent.

INTRODUCTION

Recently, human exposure due to inhalation of indoor radon-222 and its daughters are of great concerns in the worldwide scientific communities as well as in public and has become one of the active researches[1~7]. This concern resulted from the findings, that the radon daughters may cause an excess lung cancer, which was deduced from the radioepdmiological studies for 25,000~30,000 uranium miners in several countries[4~6].

The radon-222(hereinafter refered to radon), produced from the radioactive decay of a trace amount of Ra-226 in the primodial U-238 decay chain, is an inert radioactive gas decaying into short-lived daughters(Po-218, Bi-214, Pb-214 and Po-210). Radon is currently believed as the main source of human exposure to natural radiation [5, 6].

According to the recent report of the UNSCEAR to the general assembly in 1988〔5〕, the annual effective dose equivalent(H_E) to the general public due to inhalation of radon and its daughters reaches 1.10 mSv, which is almost 50% of total annual exposure of 2.40 mSv from natural radiation and is much higher than those from artificial radionuclides from industrial activities including nuclear power generation〔8〕.

It is now generally believed that there exists a statistical linear non-threshold relationship between the excess lung cancer incidences in uraniume miners and their accumulated radon daughters exposures〔4~6〕, and thus it is important in the public health point of view to evaluate the excess lung cancer risk of general public from long term continuous exposure of low levels of indoor radon daughters.

In this study, the long-term averaged indoor radon concentrations have been measured at 340 indoor locations in 12 residential areas by passive time-integrating CR-39 radon cups. A simple mathematical lung dosimetry model has been derived to estimate the lung and effective dose equivalent to the residents from inhalation of the indoor radon and its daughters as the first step to assess the resulting excess lung cancer risk of general public in Korea.

MEASUREMENT OF CONCENTRATIONS OF RADON AND ITS DAUGHTERS

Membrane filtered CR-39 radon cups(in short CR-39 radon cup, size : 4cmϕ×3cm H, membrane filter as diffusion barrier to discriminate Rn-220 and the radon daughters, pore size of 0.45 μm) described elsewhere〔9, 10〕 were placed at 340 dwellings in the 12 residential areas in Korea for 3 or 4 months from April until October, 1990. This type of time-integrating radon measurement using passive radon cup is especially effective in estimating the indoor radon exposure, because it is resulted from long term continuous inhalation of indoor radon and its daughters〔11〕. The number of alpah tracks per unit area of a CR-39 plastic detector(allyl diglycol carbonate : $C_{12}H_{18}O_7$, 0.6 μm thick) is proportional to the number of radon atoms diffused onto the detector surface〔12〕, and can be converted into a radon concentration in the air by applying the radon detection factor obtainable either by theory or by experiment〔10〕.

In this study the radon detection factor of the CR-39 radon cup was determined in a series of calibration experiments, in which radon cups were exposed to the air of known radon concentrations up to few thousands Bq/m^3 inside the calibration chamber for several hours to several days. Details of this experiment were described elsewhere〔9, 10〕.

The radon detection factor, K_{Rn} is the quotient of the alpha track density to the radon exposure of the CR-39 plastics as follows :

$$K_{Rn}=\frac{\delta_{Rn}-\delta_B}{E_{Rn}}\ \left(\frac{\#\ \text{tracks/cm}^2}{\text{Bq d m}^{-3}}\right)$$

$$E_{Rn}=\int_0^T C_{Rn}\ dt$$

$$=\frac{1}{V}\int_0^T Q_{Rn}\ \{1-\exp(-\lambda_{Rn}t)\}dt\ \ (\text{Bq d m}^{-3}) \qquad (1)$$

where, δ_{Rn}, δ_B is the number of tracks registered per unit area of the exposed and non-exposed CR-39, respectively(tracks/cm^2), E_{Rn} is the time-integrated concentration of radon, i, e., radon exposure of CR-39 from time 0 to time T(Bq · d ·m^{-3}), V is the volume of radon chamber(m^3), Q_{Ra} is the radioactivy of Ra-226 source which emanates radon inside the chamber (Bq) and λ_{Rn} is the decay constant of radon (h^{-1}).

The indoor radon concentration(C_{Rn}) is, than, obtained by follows ;

$$C_{Rn}=\frac{\delta_s}{K_{Rn}\ T}(Bq/m^3) \qquad (2)$$

where, δ_s is the track density on CR-39 (tracks/cm^2).

MODELLING OF LUNG DOSIMETRY

Mathematical lung model

Many investigations have been made to quantitavely estimate the doses and health effects due to the inhalation of radon daughters, but the results are much depending on the mathematical lung models and assumptions for the absorption, transfer and removal of submicron-sized radon daughters in the lung[1, 7, 13].

In this study, a simple mathematical lung dosimetry model, based primarily on the ICRP compartmental lung model[14, 15] and Jacobi-Eisfeld lung dosimetry model[16], was used to estimate the regional lung dose equivalents(H_{TB}, H_p, H_{lung}) and the resulting effective dose equivalent(H_E).

This model adopts a reference adult[17] and the best estimated values recommended by the the OECD/NEA[1], ICRP[4] and UNSCRAER[5] for the main parameters such as indoor residence fraction, mean breathing rate and unattached radon daughter fraction for the regional lung dose estimation. Figure 1 shows the mathematical lung model schematically describing the deposition, radioactive decay, biological removal and retention of inhaled radon daughters in the lung regions, and Table 1 lists the condition and assumptions adopted in this model. This model excludes the external part of a respiratory tract, the naso-pharingeal(N-P) region, because it is just used as a passage to the anatomical lung.

The mathematical balance among the regional deposition, radioactive decay, biological transfer and removal of radon daughters of unit concentration inhaled (1.0 Bq/m^3) can be expressed by the following first order ordinary differential equations.

- Tracheo-Bronchial(T-B) region

$$\frac{dQ_{TB}}{dT}=(1.0)\ \{f_u(1-d_{u,NP})\ d_{u,TB}+(1-f_u)\ (1-d_{a,NP})\ d_{a,TB}\}\ \lambda_d-(\lambda_d+\lambda_{TB,B}+\lambda_{TB,P})\ Q_{TB} \qquad (3)$$

- Pulmonary(P) region

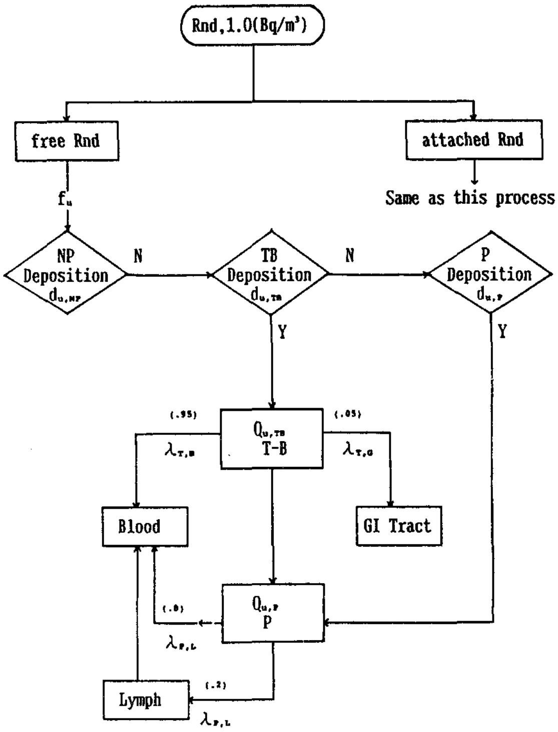

Fig. 1. Geometrical lung model describing the inhalation, deposition and removal process of Rn-222 daughters.

Table 1. Conditions used for evaluation of regional lung dose per unit exposure to Rn daughters for an adult.

Paremeter	Condition	Ref.
● annual average residence fraction(R)	- home：0.65(～6,000h) - indoor：0.20(～1,500h) - total：0.85(～7,500h)	4,5
● mean breathing rate(B) of an adult(age 30)	0.75m^3/h	1,4,5
● mean acitivity median aerodynamic diameter(AMAD)	0.15μm	2,4,5
● indoor equilibrium factor(F)	0.4	5,10
● unatteched radon daughter fraction(f_u)		1,2,4
- RaA	0.1(10%)	
- RaB,RaC	0(0%)	
● composition of indoor radon daughters		10,18
- C_1：C_2：C_3	1.0：0.8：0.6	
● regional lung tissue mass		
- Tracheo-Bronchial region(M_{TB})	46g	1,18
- Pulmonary region(M_p)	980g	17,18

$$\frac{dQ_P}{dT}=(1.0)\ \{Q_{TB}+f_u\ (1\text{-}d_{u,TB})\ (1\text{-}d_{a,TB})d_{u,P.}$$
$$+(1-\ f_u)\ (1\text{-}d_{a,NP})\ (1\text{-}d_{a,TB})\ d_{a,P}\}\ \lambda_d$$
$$-(\lambda_d+\lambda_{P,B}+\lambda_{P,L})\ Q_P \qquad (4)$$

The definations and values of parameters used in eqns (3) and (4) are shown in Table 2, 3 and 4. The solutions of eqns (3) and (4) with constant inhalation condition($dQ/dT=0$) can be written in simple form as follows.

$$Q_{i,k}=F_{i,k}\frac{\lambda_{i,d}}{\lambda_{t,k}}(Bq/m^3) \qquad (5)$$
$$F_{i,TB}=f_u\ (1\text{-}d_{u,NP})\ d_{u,TB}+(1\text{-}f_u)\ (1\text{-}d_{a,NP})\ d_{a,TB}$$
$$F_{i,P}=Q_{TB}=(1\text{-}F_u)\ (1\text{-}d_{a,NP})\ (1\text{-}D_{a,TB})\ d_{a,p}$$

where, k denotes the lung region (1：T-B, 2：P), $F_{i,k}$ is the retention fraction of radon daughter in the region k, $\lambda_{i,d}/\lambda_{t,k}$ is the modifying factor incorporating the radioactive decay, biological removal of inhaled radon daughters in the region k of the lung.

The total concentration retained in the region k is then the sum of concentration of the radon daughters having concentration ratio of C_1：C_2：C_3 in air. Therefore, the total concentration of radon daughters retained in k region of the lung is given by

$$Q_{TB}=(0.1680f_u+0.040)C_1+0.0175C_2+0.0211C_3$$
$$Q_P=(0.0286f_u+0.171)C_1+0.1128C_2+0.1246C_3 \qquad (6)$$

Table 2. Paramaters used in the lung dosimetry modelling

Symbol	Unit	Description	Remarks
$q_{i,k}$	Bq/m^3	Concentration of ith Rn-d retained in region k of lung k=1 : T-B 2 : P	eqn.3,4,5
f_u	-	Unattached fraction of Rn-d in air RaA : 0.1 RaB and RaC : 0.0	
$d_{u,k}$ $d_{a,k}$	-	Deposition fraction of unattached(u) or attached(a) Rn-d in region k of lung k=NP : N-P region TB : T-B region P : P region	Table 4
λ_d	m^{-1}	Decay constant of ith Rn-d	Table 3
$\lambda_{TB,B}$	m^{-1}	Biological removal constant of Rn-d from T-B region to Bloods	Table 3
$\lambda_{TB,G}$	m^{-1}	Biological removal constant of Ra-d from T-B region to G.I.tracts	Table 3
$\lambda_{P,B}$	m^{-1}	Biological removal constant of Ra-d from P region to blood	Table 3
$\lambda_{P,L}$	m^{-1}	Biological removal constant of Ra-d from P region to Lymph system	Table 3
$\lambda_{t,k}$	m^{-1}	Effective removal constant in region k of lung $(\lambda_{t,k}=\lambda_d+\lambda_{b,k})$	eqn. 5

LUNG DOSIMETRY

Given that radioactivities of radon daughters were uniformly distributed in the regional lung tissue mass, the absorbed dose in the region k of the lung, incurred by the potential alpha energy released from the radon daughters under constant inhalation condition(0.75 Bq/m^3 at indoor), can be estimated by the energy absorption in tissue,

$$D_k = 1.6\times10^{-10}\frac{Q_k\ B\ E_p}{M_k}(\mathrm{Gy\ h^{-1}/Bq\ m^{-3}}) \qquad (7)$$

where, 1.6×10^{-10} is the conversion factor (g-Gy/MeV), B is the mean breathing rate of the reference adult in indoor(0.75m^3/h), E_p is the potential alpha energy released from unit Bq of radon daughters(34,520MeV/Bq) given in Table 5 and M_k is the mass(g) of the lung region k(k=1 : T-B, k=2 : P).

The absorbed doses (Gy $h^{-1}/Bq\ m^{-3}$) from retained radon daughters in T-B and P region of the lungs (Q_{TB}, Q_p), assuming the unattached fraction of RaB and RaC be 0, are then given by

Table 3. Radioactive decay constants and biological removal constants of radon daughters[10,13, 18].

(1) Decay constant (λ_d)

Nuclides	Half-life(min)	λ_d(l/min)
RaA(Po-218)	3.05	0.2272
RaB(Pb-214)	26.8	0.0258
RaC(Bi-214)	19.7	0.0352

(2) Biological removal constants(λ_d)

Regions	Compartment(rate)	T_b(h)	λ_b(m^{-1})
T-B	Bloods (0.95)	0.24	0.048
	G.I.tracts(0.05)	4.8	2.4×10^{-3}
P	Bloods(0.8)	$1.0^{1)}$	0.012
	Lymph sys.(0.2)	12.0	9.62×10^{-4}
	G.I.tracts	negligible	

1) from Ref. 18

Table 4. Deposition fraction of inhaled radon daughters in respiratory tracts[14, 19].

Rn-d	d_{NP}	d_{TB}	d_P
● unattached(u) (f_u : 0.1)	0.5	0.5	0
● attached(a) (AMAD : 0.15μm)	0.03	0.05	$0.15^{a)}$

a) from Ref. 19.

$$D_{TB}=9.00\times10^{-8}\{(0.1680f_u+0.040)C_1+0.0175C_2+0.0211C_3\}$$

$$D_P=4.23\times10^{-8}\{(0.0286f_u+0.171)C_1+0.1128C_2+0.1246C_3\} \quad (8)$$

The regional lung dose equivalents(H_{TB}, H_P, H_{LUNG}), and the resulting effective dose equivalent (H_E)(Sv h^{-1}/Bq m^{-3}) are then calculated as follows.

$$H_{TB}=9.00\times10^{-8}\{0.1680f_u+0.040)C_1+0.0175C_2+0.0211C_3\}QF$$

$$H_P=4.23\times10^{-8}\{0.0286f_u+0.171)C_1+0.1128C_2+0.1246C_3\}QF$$

$$H_{Lung}=H_{TB}+H_P$$

$$H_E=H_{Lung}\ W_T\ (W_T=W_{TB}=W_P=1/2\ W_{Lung}) \quad (9)$$

where, QF is the quality factor, W_T, is the weighting factor[4,5].

RESULTS AND DISCUSSIONS

Concentrations of indoor radon and its daughters

Long term indoor radon concentrations in 340 dwellings were obtained from the number of tracks per unit area of a CR-39 read by a microscope and the radon detection factor, 0.164± 0.005(tracks cm^{-2}/Bq d m^{-3}) determined in the calib-

Table 5. Potential alpha energy per atom of Rn-222 daughters[1,4].

Nuclide	Half-life (sec)	Potential alpha energy, E_p (Mev/atom)	(MeV/Bq)¹⁾	fraction
Po-218 (RaA)	184	13.7	3620	0.105
Pb-214 (RaB)	1608	7.69	17800	0.515
Bi-214 (RaC)	1182	7.69	13100	0.380
Po-214 (RaC')	0.00016	7.69	0.002	⟨⟨0.00001
		Total	34520	100.0

1) $\frac{(\text{MeV/atom}) \times T_{1/2}}{\ln 2}$

2) Equlibrium factor, $F = \frac{0.105C_A + 0.515C_B + 0.380C_C}{C_{Rn}} = \frac{EEC_{Rn}}{C_{Rn}}$

ration experiment [10]. Figure 2 is an example of the enlarged photograph of radon alpha tracks on the surface of the chemically etched CR-39.

It is shown that the long-term averaged indoor radon concentrations in the 12 residential areas range from 33.82Bq/m^3 to 61.42Bq/m^3 with geometric mean of 48.90 Bq/m^3 as shown in Table 6. Figure 3 implies that the distribution of indoor radon concentration seemed to follow log-normal distribution, as reported in Sweden[5] and in USA[6].

It is the daughters which are more important in lung dosimetry, because radon is chemically inert and give much less exposure to lung than radon daughters do[2,6]. The concentration of radon daughters is usually given in terms of equilibrium equivalent concentration of radon (EEC_{Rn}) and was simply obtaind by multiplying an equilibrium factor (F) between indoor radon and its daughters.

$$EEC_{Rn} = F\ C_{Rn} \qquad (10)$$

The UNSCEAR[5] recommends an indoor equilibrium factor of 0.4, and this F-factor measured at several indoor locations s in Deajon area appeared to be 0.36± 0.12 in this study, which could be assumed to be 0.4[10].

The long-term average indoor EEC_{Rn}'s in 12 residential areas estimated in this manner vary from 11.53 Bq/m^3 to 24.57 Bq/m^3 as tablulated in Table 6 and the mean value is 19.56 Bq/m^3.

The indoor radon concentrations and the corresponding EEC_{Rn}'s obtained in this study may not be representative values in Korea, because the number of samples are not enough to cover wide area of the Korean and the measurements were limited for 3~4 months in an year.

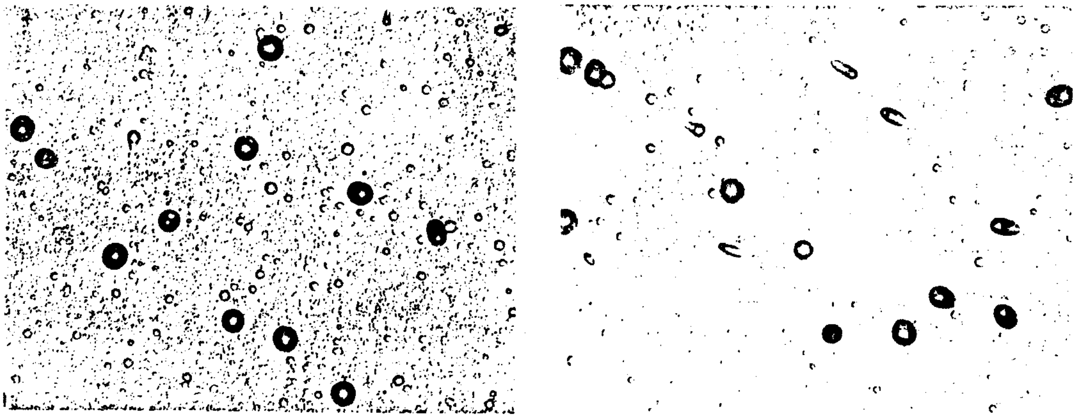

Fig. 2. Enlarged views of radon alpha tracks on the CR-39 surface(×200).

：The elliptical shape of tracks were produced when incident alpha particles collide onto the CR-39 surface between 10°(minimum critical angle)〔10〕 and 90° to the surface.

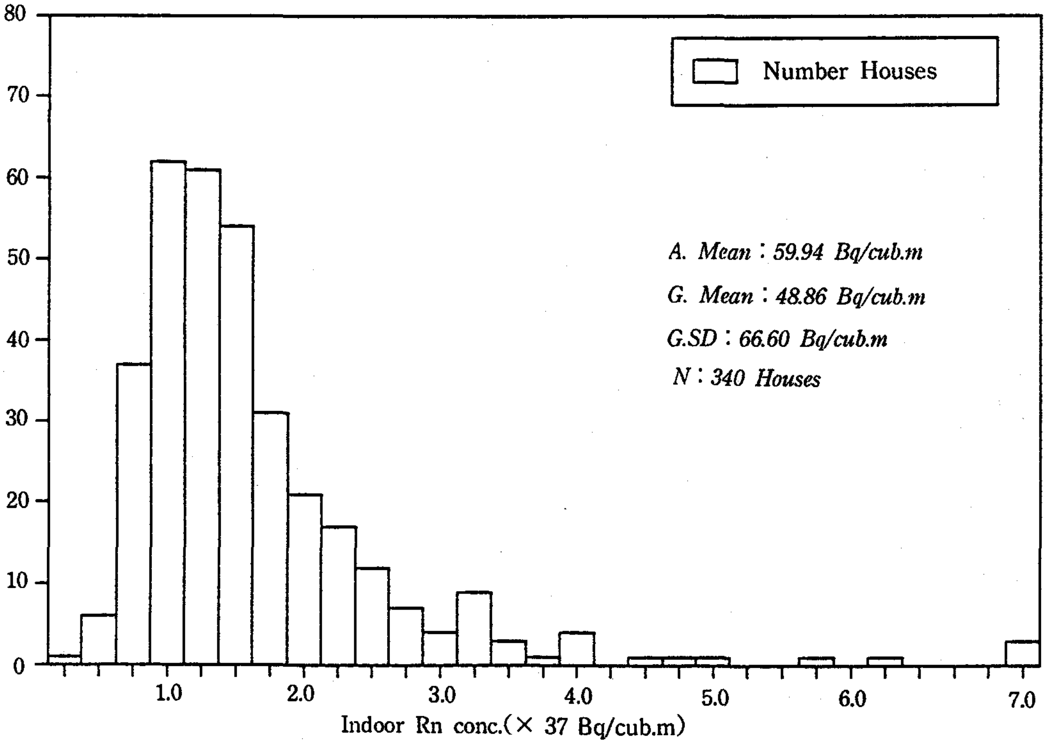

Fig. 3. Distribution of indoor radon concentrations at 340 dwellings in Korea.

Table 6. Indoor Rn-222 and Rn daughters' concentration in the 12 residential areas* in Korea. (Measured from April, '90 to October, '90.)

Areas*	No Sample	C_{Rn} Arith Mean (pCi/L)	C_{Rn} Median (pCi/L)	C_{Rn} Median (Bq/m^3)	EEC_{Rn} Median (Bq/m^3)
1. Ulsan	18	1.63	1.43	52.91	21.16
2. Kwangju	23	1.14	1.04	38.50	15.40
3. Taejon	37	1.32	1.18	43.66	17.46
4. Donghae	19	1.34	1.26	46.62	18.61
5. Sokcho	19	1.79	1.62	60.00	24.00
6. Seosan Dangjin	34	2.17	1.68	62.16	24.86
7. Inchon	16	1.13	1.07	39.60	15.84
8. Nonsan	31	2.31	1.66	61.42	24.57
9. Seoul	63	1.72	1.39	51.43	20.57
10. KAERI Indoor	30	0.98	0.914	33.82	13.53
11. Chunchon	32	1.68	1.45	53.65	21.46
12. Suwon	18	1.56	1.44	53.28	21.31
Total	340	Av.1.61	1.32	48.90	19.56

* including suburb area.

Dose assessment

From the simple mathematical lung dosimetry model used in this study, the conversion functions for the regional lung dose and effective dose equivalent(H_E) per unit exposure to EEC_{Rn} for an adult were determined by using eqn.(9). Dose conversion functions are given in Table 7.

The effective dose equivalent(H_E) for unit exposure of indoor EEC_{Rn} was calculated to be 1.07×10^{-5} mSv $h^{-1}/Bq\ m^{-3}$, which corresponds to 6.70 mSv/WLM and 1.90 Sv/J h m^{-3}. This is in fairly good agreement with 1.02×10^{-5} mSv/Bq h m^{-3}reported by ICRP[4] and 0.96×10^{-5}mSv/Bq h m^{-3} given by UNSCEAR[5] as shown in Table 8.

By using the dise conversion factors in Table 8 and assuming that a reference adult is annually exposed to the EEC_{Rn}s in 12 areas given in Table 6, the annual dose equivalent to tracheo-bronchial region, pulmonary region, total lung and resulting effective dose equivalent to an adult residing 6,000 hours a year at indoor were calculated and tabulated in Table 9. These results show that the annual averaged effective dose equivalent(H_E) is 1.25 mSv.

Table 7. Conversion function per unit exposure of indoor Rn-222 daughters to a reference adult.

Dose	Absorbed dose : D		
	AMAD : 0.15 μm, Inhalation rate : 0.75 m^3/h		
	T-B	P	Lung
D(mGy/WLM)	$9.45f_u+3.77$ (4.715)	$0.077f_u+0.854$ (0.862)	$9.53f_u+4.62$ (5.57)
D(Gy/J h m^{-3})	$2.70f_u+1.07$ (1.34)	$0.022f_u+0.244$ (0.246)	$2.72f_u+1.31$ (1.58)
D(nGy/Bq h m^{-3})	$15.1f_u+6.03$ (7.54)	$0.123f_u+1.370$ (1.38)	$15.22f_u+7.40$ (8.92)
	Effective dose equvalent : H_E		
H_E(mSv/WLM)	$11.44f_u+5.5$ (6.69)		
H_E(Sv/J h m^{-3})	$3.26f_u+1.58$ (1.91)		
H_E(nSv/Bq h m^{-3})	$18.26f_u+8.88$ (10.71)		

- f_u : unattached fraction of RaA, assume f_u of indoor RaB and RaC to be 0.
- $H_E=D_{TB}$ QF $W_{TB}+D_P$ QF W_P, QF=20, $W_{TB}=W_P=0.06=1/2\ W_{Lung}$
- ( ) : value when $f_u=0.1$.
- for the assumed indoor radon daughters composition of 1.0 : 0.8 : 0.6.

Table 8. Dose conversion factors per unit indoor exposure of EEC_{Rn} to a reference adult.

unit($\times 10^{-5}$mSv/Bq h m^{-3})

H_{TB}	H_P	H_{Lung}	H_E	Remarks
15.0	2.00	17.0	1.02	ICRP-50('87)
14.0	1.82	16.0	0.96	UNSCEAR('88)
15.0	2.86	17.9	1.07	This study('90)*

* AMD=0.15μm, V=0.75m^3/h, R=7500 h/y,
f_u=0.1(RaA), 0.0(RaB, RaC).
RaA : RaB : RaC=1.0 : 0.8 : 0.6 (Table 1).

CONCLUSIONS

1. The long-term averaged indoor radon-222 concentration measured by CR-39 radon cup in 12 areas in Korea was 48.90 Bq/m^3(range : 33.82~61.42 Bq/m^3). The equilibrium equivalent concentration of radon(EEC_{Rn}) was estimated to be 19.55 Bq/m^3(range : 13.53~24.86 Bq/m^3), by assuming 40% equilibrium between indoor radon-222 and its daughters.
2. The effective dose equivalent (H_E) conversion factor for unit exposure of EEC_{Rn} was 1.07×10^{-5} mSv/Bq h m^{-3}, which corresponds to 6.70 mSv/WLM and 1.90 Sv/J h m^{-3}. This conve-

Table 9. Effective dose equivalent due to inhalation of indoor EEC_{Rn} in 12 residential areas in Korea.

Areas*	No Samples	EEC_{Rn} (Bq/m^3)	Annual mean dose(mSv/y)				
			H_{TB}	H_P	H_{Lung}	H_E1)	H_E2)
1. Ulsan	18	21.16	18.96	3.62	22.82	1.36	1.30
2. Kwangju	23	15.40	13.80	2.64	16.45	0.98	0.94
3. Taejon	37	17.46	15.67	3.00	18.65	1.12	1.07
4. Donghae	19	18.61	16.67	3.18	19.87	1.19	1.14
5. Sokcho	19	24.00	21.50	4.11	25.63	1.54	1.48
6. Seosan Dangjin	34	24.86	22.27	4.26	26.56	1.59	1.53
7. Inchon	16	15.84	14.20	2.71	16.91	1.02	0.98
8. Nonsan	31	24.57	22.00	4.21	26.23	1.57	1.51
9. Seoul	63	20.57	18.42	3.52	21.97	1.32	1.26
10. KAERI Indoor	30	13.53	12.12	2.31	14.45	0.86	0.83
11. Chunchon	32	21.46	19.22	3.67	22.92	1.38	1.32
12. Suwon	18	21.31	19.10	3.65	22.76	1.37	1.31
Total	340	Av.19.55	17.52	3.35	20.90	1.25	1.20

* including suburb area.

1) This study

2) ICRP-50(1988) Model.

rsion factor agreed well with 1.02×10^{-5} mSv/Bq · h · m^{-3} of the ICRP(1987) and 0.96×10^{-5} mSv/Bq · h · m^{-3} of the UNSCEAR report (1988).

3. The annual average effective dose equivalent (H_E) to the public in 12 areas from the exposure to the long-term averaged indoor EEC_{Rn} obtained in this study has been estimated to be 1.25 mSv(range : 0.83~1.53 mSv, depending on the area), when considering that the annual average indoor residence time of the public is 6,000 h and mean breathing rate at indoor is 0.75 m^3/h.
4. The indoor exposure to radon and its daughters appeared to contribute to nearly 50% of total natural radiation exposure which is currently recognized to be 2.40 mSv/y by the UNSCEAR report. It seems clear that the radon daughters are the single greatest natural radioactive sources to the public exposure in Korea. In this respect, it is recommended that an intensive nationwide program on indoor radon surveillance should be established for accurate evaluation of the public exposure to indoor radon and its daughters. The intensive program could finally provide the lifetime excess lung cancer risk in Korea, attributable to the long-term continuous exposure of the public to indoor radon daughters.

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한국인의 라돈-222 자핵종 호흡 실효선량당량 평가

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요 약

국내 12개 지역의 340여 실내에서 측정한 라돈농도로 부터 단순한 수학적 폐선량 평가모형을 이용하여 주민의 실효선량당량을 평가하였다. 수동적 시간적분형 CR-39 라돈컵으로 1990년 4월부터 10월까지 3~4개월동안 측정한 실내의 라돈농도는 지역별로 33.82~61.42 Bq/m^3(평균 : 48.90 Bq/m^3)의 분포를 보였으며, 이로 인한 라돈자핵종의 평형등가라돈농도(EEC$_{Rn}$)는 라돈과 라돈과 자핵종간의 평형인자의 값 0.4를 적용했을 때 13.53~24.57 Bq/m^3(평균 : 19.55 Bq/m^3)으로 예상되었다. 국제방사선방어위원회의 폐모형에 근거한 본 연구의 폐선량 평가모형에서 유도된 단위 평형등가라돈농도의 피폭당 실효선량당량환산인자는 1.07×10^{-5} mSv/Bq h m^{-3}으로 국제방사선방어위원회나 국제연합 방사선영향평가과학위원회(UNSCEAR)에서 권고한 값과 잘 일치하였다. 동 선량환산인자와 CR-39 라돈컵으로 측정한 실내의 평균 평형등가라돈농도를 년간 0.75 m^3/h의 호흡율로 호흡한 것으로 가정했을 때, 주민이 받는 년평균 폐선량당량 및 실효선량당량은 각각 20.90 mSv 및 1.25 mSv인 것으로 평가되었다. 동 피폭선량은 국제연합(UNSCEAR)에서 1988년에 발표한 일반인의 년평균 자연방사선피폭 실효선량당량인 2.40mSv의 거의 50 %에 상당하였다.

Key words : 폐선량 평가, CR-39 라돈컵, 호흡피폭, 평형등가라돈농도, 미부착 라돈자핵종분율, 폐선량, 실효선량당량.