J. Korean Asso. Radiat. Prot.
Vol. 21, No. 3 : (1996)

■ 기술논문 ■

Prediction of Fatal Radiation-Induced Cancer for Korean Using the BEIR V Method

Won-Tae Hwang, Moon-Hee Han, Gyuseong Cho*
Korea Atomic Energy Research Institute
*Korea Advanced Institute of Science and Technology**

(Received 14 October 1996 ; Accepted 28 February 1997)

BEIR V 방법을 이용한 한국인의 방사선에 의한 암사망 예측

황원태, 한문희, 조규성*
한국원자력연구소, 한국과학기술원*

Abstract - The lifetime fatal radiation-induced cancer for Korean has been estimated for both single and continuous radiation exposure using the BEIR V method. In case of single exposure, the major radiation-induced cancer type for young and old age is digestive and respiratory cancer, respectively. For the whole population of Korean, the major radiation-induced cancer type is digestive cancer. In case of 1 mGy/yr continuous exposure from birth to death, the contribution of total radiation-induced cancer mortality to natural cancer mortality is about 3%.

Key words : radiation-induced cancer, radiation exposure, BEIR V method, natural cancer

요약 – BEIR V 방법을 사용하여 한국인이 단일 및 연속 방사선피폭을 받았을 경우 일생동안 방사선에 의한 암사망을 평가하였다. 단일피폭시 지배적으로 나타나는 암은 젊은층 피폭의 경우는 소화기암, 노령층피폭의 경우는 호흡기암이었다. 한국인 모든 집단이 피폭받았을 경우, 지배적으로 나타나는 암은 소화기암이었다. 출생에서 사망까지 1 mGy/yr의 피폭을 연속적으로 받았을 경우, 방사선에 의한 모든 암의 발생은 자연 암발생의 3% 정도였다.

중심단어 : 방사선에 의한 암, 방사선피폭, BEIR V 방법, 자연암

Introduction

Exposure to low-LET ionizing radiation may cause cancers. Radiation-induced cancer studies have been established by the data of the atomic bomb survivors of Japan, Canadian and U. S. patients examined by fluoroscopy during the treatment for tuberculosis, and other medical disease[1]. The Fifth Committee on the Biological Effects of Ionizing Radiations of National Research Council, the BEIR V Committee, developed risk models for radiation-induced cancer mortality based on the study of the atomic bomb survivors between 1950 and 1985, and Canadian fluoroscopy between 1950 and 1980[2]. The BEIR V Committee believes that the use of absolute (additive) risk model is no longer tenable and recommends the use of relative (multiplicative) risk model[3]. In relative risk model, radiation-induced cancer risk is predicted from relative risk factor, and statistical data of natural cancer mortality and life expectancy of the relevant population. Since these statistical data are different between nations and vary with age, radiation-induced cancer risk may represent different results in varied populations and ages at exposure.

The objective of this study is to assess the lifetime radiation-induced cancer mortality for Korean using the relative risk model that is recommended by the BEIR V Committee. The calculations are performed for the following cases.

(1) 0.1 Gy single (acute) exposure for each age

(2) 0.1 Gy single exposure for whole population

(3) 1 mGy/yr continuous (chronic) exposure from birth to death

Relative Risk Model

In relative risk model, radiation-induced cancer mortality is expressed as multiplication of the natural mortality for a specific cancer and the relative risk function of the relevant cancer type[4].

$$\varepsilon(D, a_0, a, s) = \varepsilon_0(a, s) \times R(D, a_0, a, s) \quad (1)$$

where,

ε : radiation-induced cancer mortality

ε_0 : natural cancer mortality

R : dose-response function

D : exposure dose [Gy]

a_0 : age at exposure

a : ages since exposure

s : sex of the subject

Since the ethnic and environmental characteristics are included in the natural cancer mortality, ε_0, thus the relative risk function R may be applied to varied populations with greater confidence than could be done using the absolute risk model. The BEIR V Committee presented relative risk functions for several particular types of fatal cancers in the following form[2].

$$R(D, a_0, a, s) = \alpha(a_0, a, s)D + \beta(a_0, a, s)D^2 \quad (2)$$

where α and β are constants dependent on cancer type. If $\beta=0$, the linear risk function holds.

Relative risk function

Leukemia. Relative risk function is independent on sex. The latency period is about two years. Risk is zero during the latency period. A linear-quadratic fit is used[2].

$$R(D, a_0, t) = (0.243D + 0.271D^2)\, e^{\gamma(a_0, t)} \quad (3)$$

$\gamma=4.885, \quad t\leq 15, \quad a_0\leq 20$
$\gamma=2.380, \quad 15<t\leq 25, \quad a_0\leq 20$
$\gamma=4.885, \quad t\leq 25, \quad a_0>20$
$\gamma=4.885, \quad 25<t\leq 30, \quad a_0>20$

where t is the elapsed time in year since the exposure, i.e. $t=a-a_0$.

Respiratory cancer. The latency period is about ten years. A linear fit is used〔2〕.

$$R(D,\ a_0,\ t,\ s)=0.636D\ e^{(-1.437\ln(t/20)+\gamma)} \quad (4)$$

$\gamma=0$, for male
$\gamma=0.711$, for female

Breast cancer. The latency period is about ten years. Breast cancer is applied only to female. A linear fit is used〔2〕.

$$R(D,\ a_0,\ t,\ s)= 0.636D\ e^{(\gamma_1-0.104\ln(t/20)-2.212\ln^2(t/20)-\gamma_2(t-20))} \quad (5)$$

$\gamma_1=1.385, \quad a_0<15$
$\gamma_1=0, \quad a_0\geq 15$
$\gamma_2=0, \quad a_0<15$
$\gamma_2=0.0628, \quad a_0\leq 15$

Digestive cancer. The latency period is about ten years. A linear fit is used〔2〕.

$$R(D,\ a_0,\ t,\ s)=0.809\ D\ e^{(\gamma_1-\gamma_2)} \quad (6)$$

$\gamma_1=0$ for male
$\gamma_1=0.553$, for female
$\gamma_2=0$, $a_0\leq 25$
$\gamma_2=0.198(a_0-25)$, $25<a_0\leq 35$
$\gamma_2=1.98$ $a_0<35$

All other cancers. The latency period is about ten years. A linear fit is used〔2〕.

$$R(D,\ a_0,\ t,\ s)=1.220\ D\ e^{-\gamma} \quad (7)$$

$\gamma=0 \quad a_0\leq 10$
$\gamma=0.0464(a_0-10), \quad a_0>10$

Dose rate effectiveness factor (DREF)

Relative risk functions are derived from high dose and dose rate of low-LET ionizing radiation. In the BEIR V method, relative risk function for radiation-induced cancers are linear except for leukemia. When a linear function of relative risk is applied to risk for exposure at low dose and dose rate, the estimates are too high by at least a factor of 2 and perhaps by a factor of 10 as agreed by the NCRP and the UNSCEAR Committee 〔4〕.

Lifetime Radiation-Induced Cancer Risk

Evaluation of the lifetime radiation-induced cancer mortality at the age of the exposure requires two kinds of statistical data for life expectancy from the relevant population. One is the yearly natural cancer mortality for each cancer type and the other is the percentage of liveborn living at the beginning of age interval. These statistical data derived from the life expectancy data for the Korean population in 1994 are given in Table 1 and Table 2 〔5〕. The lifetime radiation-induced cancer mortality due to the exposure at age a_0 is estimated by the following equation 〔4〕.

$$U(a_0, D, s)= \sum_a \frac{N(a, s)}{N(a_0, s)}\varepsilon_0(a, s)\ R(D, a_0, a, s) \quad (8)$$

where
U : lifetime radiation-induced cancer mortality
N : the number of persons survived

where the summation is from age at exposure through the entire life expectancy.

The average lifetime radiation-induced cancer mortality for a particular population is

Table 1. Natural cancer mortality per 10^5 persons for the Korean population in 1994.

Age interval	Male			
	Leukemia	Respiratory	Digestive	Other
0~4	2.64	0.06	0.34	3.33
5~9	3.03	0	0.18	2.10
10~14	2.75	0.14	0.29	1.45
15~19	3.05	0.34	0.93	3.25
20~24	2.58	0.47	1.68	2.46
25~29	2.73	0.66	5.50	3.58
30~34	2.50	1.82	12.77	4.45
35~39	2.84	4.34	27.10	6.79
40~44	3.19	9.28	66.85	11.83
45~49	3.42	21.59	116.87	21.67
50~54	4.93	49.97	226.78	41.60
55~59	5.99	110.65	337.50	72.70
60~64	10.17	205.44	474.28	97.40
65~69	10.48	319.52	646.03	156.02
70~74	15.51	413.82	874.72	210.79
75~79	9.56	445.79	943.27	274.23
80~84	20.48	441.32	1266.22	448.76
85~	11.17	452.49	1307.19	541.87

Age interval	Female				
	Leukemia	Respiratory	Digestive	Breast	Other
0~4	1.98	0.26	0.19	0	3.33
5~9	2.01	0	0.13	0	2.10
10~14	1.91	0	0.21	0	1.45
15~19	1.52	0.05	1.16	0	3.25
20~24	1.64	0.27	2.51	0.36	2.46
25~29	1.58	0.79	6.17	0.79	3.58
30~34	1.65	1.18	10.38	2.88	4.45
35~39	2.12	2.17	14.91	4.30	6.79
40~44	3.07	4.34	21.99	6.28	11.83
45~49	3.80	7.18	40.81	10.29	21.67
50~54	3.46	15.24	63.10	9.82	41.60
55~59	4.76	22.97	98.50	10.66	72.70
60~64	4.22	36.69	152.38	10.87	97.40
65~69	6.29	56.41	212.04	9.34	156.02
70~74	5.95	80.04	311.72	12.58	210.709
75~79	3.26	110.42	381.23	7.96	274.23
80~84	13.59	165.78	646.83	15.40	448.76
85~	9.06	166.09	610.00	25.67	541.87

*International Classification of Diseases (ICD) indices as follows (parentheses represent 124 abridged tabulation number in Korean) : leukemia 204-208 (36), respiratory 160-165 (29-30), digestive 150-159 (23-28), breast 174-175 (31)

obtained by the summation of the multiplications of lifetime radiation-induced cancer mortality and the population fraction of the corresponding age [4].

$$\overline{U}(D, s) = \sum_{a_0} U(a_0, D, s) \cdot F(a_0, s) \qquad (9)$$

where,

$\overline{U}$: average radiation-induced cancer mortality for population

F : composition fraction of corresponding age

The composition fraction in percentage for the Korean population in 1994 is given in Table 2 [5].

Table 2. Life expectancy data for the Korean population in 1994.

Age interval	Male			
	Survival percentage at the beginning of the age interval		Percentage of population belong to the age interval	
	Male	Female	Male	Female
0~4	100.000	100.000	7.78	7.10
5~9	98.262	98.263	7.66	7.00
10~14	97.647	97.731	9.27	8.79
15~19	97.033	97.211	9.08	8.63
20~24	95.431	96.361	10.38	9.94
25~29	93.316	95.200	9.50	9.17
30~34	90.760	93.863	9.84	9.60
35~39	87.291	92.144	8.95	8.75
40~44	82.800	90.133	6.31	6.06
45~49	77.941	88.185	5.36	5.24
50~54	72.180	85.583	4.80	4.85
55~59	63.848	81.625	4.18	4.43
60~64	53.453	76.163	2.81	3.59
65~69	43.449	69.091	1.80	2.72
70~74	33.153	59.893	1.28	2.03
75~79	21.466	47.299	0.66	1.30
80~84	11.779	32.590	0.25	0.50
85~	4.747	17.483	0.09	0.30

Results and Discussion

The lifetime radiation-induced cancer mortality has been estimated for single and continuous exposure using the life expectancy data for the Korean population in 1994. For 0.1 Gy single exposure of low-LET ionizing radiation, the lifetime radiation-induced cancer mortality was calculated for each age and whole population. And lifetime radiation-induced cancer mortality was calculated for 1 mGy/yr continuous exposure from birth from death. For conservative estimation, the DREF of 2 was only applied to the case of continuous exposure.

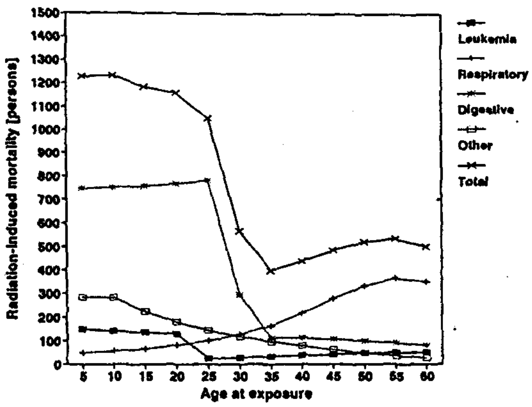

Fig. 1. Lifetime Radiation-Induced Cancer Mortality per 10^5 Males as a Function of Age at Exposure in Case of 0.1 Gy Single Exposure.

Figures 1 and 2 show the lifetime radiation-induced cancer mortality per 10^5 persons as functions of the age at the exposure and cancer type for the case of single exposure of the Korean male and female, respectively. For the most cancer types, the lifetime radiation-induced cancer mortality is high in the case of the exposure at young age except for respiratory cancer. It is mainly due to the fact that the remaining life expectancy of young people is long. Especially, the con-

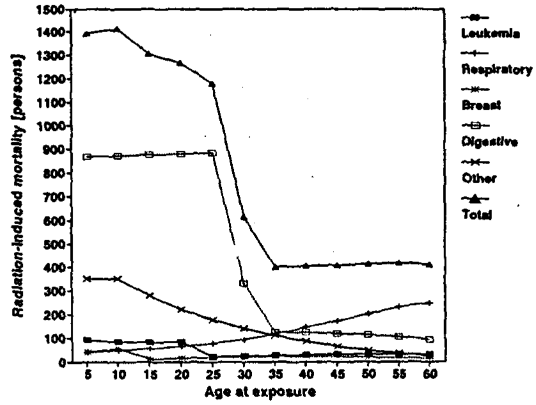

Fig. 2. Lifetime radiation-induced cancer mortality per 10^5 females as a function of age at exposure in case of 0.1 Gy single exposure.

tribution of digestive cancer to total radiation-induced cancer mortality is dominant in the case of the exposure at young age because of the high natural digestive cancer mortality that is shown in Table 1. Respiratory cancer shows high sensitive response in the case of the exposure at old age.

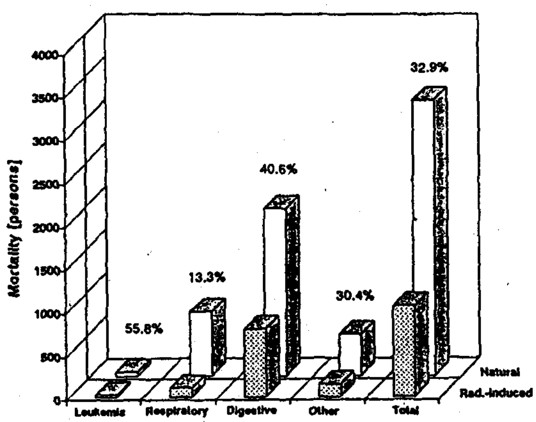

Fig. 3. Lifetime radiation-induced cancer mortality per 10^5 males for exposure at age 25 and the ratio of radiation-induced cancer mortality to natural cancer mortality in case of 0.1 Gy single exposure.

Figures 3 and 4 show the lifetime radiation-induced cancer mortality per 10^5 persons for the exposure at the age of 25 and the ratio of radiation-induced cancer mortality to natural cancer mortality in the Korean male and female, respectively. Radiation-induced respiratory and digestive cancer depend on sex as represented in relative risk function. For both cancers, the ratio of radiation-induced cancer mortality to natural cancer mortality was is distinctly dependent of sex. Female is more sensitive to radiation exposure

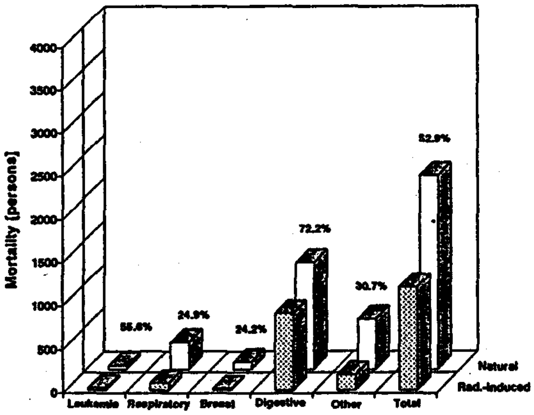

Fig. 4. Lifetime radiation-induced cancer mortality per 105 females for exposure at age 25 and the ratio of radiation-induced cancer mortality to natural cancer mortality in case of 0.1 Gy single exposure.

Table 3. Comparison of average radiation-induced cancer mortality per 10^5 persons between the Korean and the U.S. population in case of 0.1 Gy single exposure.

Radiation-induced	Korean population		U.S. population*	
cancer type	Male	Female	Male	Female
Leukemia	70	45	110 (50~280)**	80 (30~190)
Nonleukemia	746	789	660 (420~1040)**	730 (550~1020)
Total	816	834	770 (540~1240)	810 (630~1160)

*Reference [4]

**90% confidence limits are given in parentheses

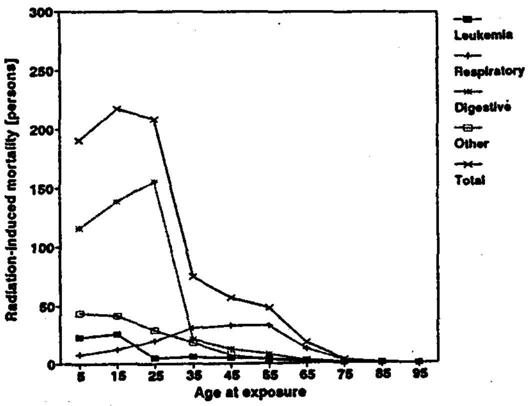

Fig. 5. Average lifetime radiation-induced cancer mortality per 10^5 males and females.

than male for both cancers. Total radiation-induced cancer mortality for female is 1.13 times higher than that of male, though natural cancer mortality of male is 1.43 times higher than that of female. For both sexes, the ratio of radiation-induced leukemia mortality to natural leukemia mortality is considerably high. It means that leukemia has high dose-response relationship.

Figure 5 shows the average lifetime radiation-induced cancer mortality per 10^5 persons of male and female in the Korean population. The contribution of digestive cancer is dominant as represented in the results of single exposure. Table 3 shows the average lifetime radiation-induced cancer mortality for both the Korean and the U. S. population. In this table, the results for the U. S. population was obtained by the BEIR V Committee using the statistical data of population in 1980. Radiation-induced leukemia mortality for the Korean population is lower than that for the U. S. population, while radiation-induced nonleukemia mortality for the Korean population is a little higher than that for the U. S. population [4]. Total radiation-induced cancer mortality is similar between the Korean and the U. S. population, though radiation-induced mortality of each cancer type is different.

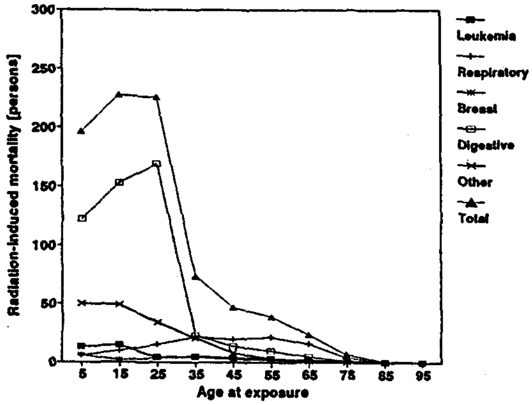

Fig. 6. Ratio of lifetime radiation-induced cancer mortality (RIM) to natural cancer mortality (NM) per 10^5 males in case of 1 mGy/yr continuous exposure from birth to death.

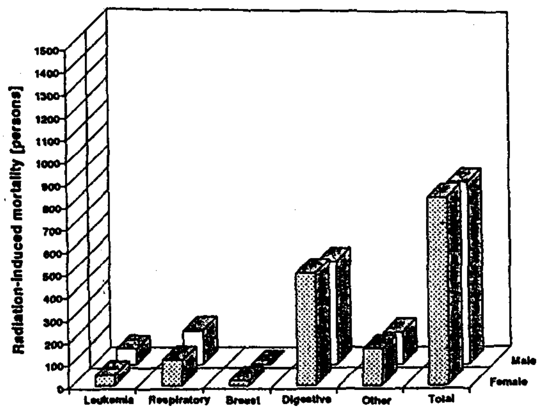

Fig. 7. Ratio of lifetime radiation-induced cancer mortality (RIM) to natural cancer mortality (NM) per 10^5 female in case of 1 mGy/yr continuous exposure from birth to death.

Figure 6 and 7 show the ratio of the lifetime radiation-induced cancer mortality to natural cancer mortality per 105 persons in case of 1 mGy/yr continuous exposure from birth to death in the Korean male and female, respectively. The contribution of total radiation-induced cancer is about 3% of total natural cancer mortality.

Conclusions

The lifetime radiation-induced cancer mortality for Korean has been estimated for single and continuous exposure using the relative risk model that is recommended by the BEIR V Committee. In case of 0.1 Gy single exposure, the major radiation-induced cancer type for young and old age is digestive and respiratory cancer, respectively. The ratios of total radiation-induced cancer mortality to total natural cancer mortality are 32.9% and 52.9% in male and female, respectively. In case of the 0.1 Gy single exposure of whole population, the major radiation-induced cancer type is digestive cancer. Total radiation-induced cancer mortality is similar between the Korean and the U. S. population. In case of 1 mGy/yr continuous exposure from birth to death, the contribution of total radiation-induced cancer mortality to natural cancer mortality is about 3%.

In this study, it should be noted that the statistical life expectancy data of a particular year have been considered. To conduct more reliable risk assessment, it is important to choose the control population carefully. Also the comparative study between model results and epidemiology results around nuclear reactor site is necessary.

References

1. G. R. Howe and J. McLaughlin, "Breast cancer mortality between 1950 and 1987 after exposure to fractionated moderate-

dose-rate ionizing radiation in the Canadian fluoroscopy cohort study and comparison with breast cancer mortality in the atomic bomb survivors study", *Radiation Research* **145**, 694～707 (1996).
2. Committee on the Biological Effects of Ionizing Radiations, *Health effects of exposure to low levels of ionizing radiation (BEIR V)*, National Academy Press, New York, Washington DC (1990).
3. C. R. Richmond, "Book review : Health effects of exposure to low levels of ionizing radiation : BEIR V", *Nuclear Safety* **32**, 551～554 (1991).
4. R. E. Faw and J. K. Shultis, *Radiological assessment*, pp. 104～164, PTR Prentice-Hall, Englewood Cliffs, New Jersey (1993).
5. 통계청, 한국인 사망통계연보 (1994).