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Cancer risks in a population with prolonged low dose-rate γ-radiation exposure in radiocontaminated buildings, 1983 - 2002

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Most people are aware of the fact that exposure to ionizing radiation may cause cancers. Acute radiation exposure has been found to increase cancer risks in many populations including Japanese atomic bomb survivors and workers who had received exposures from their work. It remains uncertain, however, whether chronic low dose-rate radiation exposure can lead to cancers in a general public setting. A Swedish study found elevated risk of acute lymphocytic leukemia among children and young adults living in uranium-containing alum shale concrete houses with high indoor radon concentrations, which is one of the few studies on the association between radiation exposure and cancer in the general public.

In 1982, several ^{60}Co orphan sources were recycled in the steel scrap industry in the northern Taiwan, and more than 20,000 tons of various contaminated steel products were employed in over 200 residential, industrial, and school buildings. It was not until August 1992 when radioactive contamination was brought to public attention by a local newspaper that these contaminated buildings were identified. The rates of exposure measured in 1994 in these buildings ranged from 0.5 to 270 μSv/hours, up to more than 1,000 times the background radioactivity (0.08 – 0.1 μSv/hours) in general Taiwanese construction. Therefore, we conducted a study to evaluate risks of developing cancers in people who had lived in these radiocontaminated buildings (RCBs) for more than 10 years.

Upon the discovery of these RCBs, the Atomic Energy Council, the Department of Health (DOH), and a research team began to establish an exposure registry which enrolled people who had stayed in these buildings. We used the National Identification Numbers to trace all individuals with official residential occupancy in the RCBs since 1982 when they first moved in. Moreover, individuals identified by home owner records or reported by other registrants to have resided in those buildings, but not registered by

the official household registration, were further evaluated for details of their occupancy and exposure through extensive contacts and interviews. Those who left before the beginning of the registration in 1992 were traced by the household registration, police records, and other approaches. At the end of 2002, 7,271 people (including 3,461 men and 3,810 women) were registered.

We identified cancer patients through the National Cancer Registry, which was established in 1979 by the DOH. An exposure assessment system, the Taiwan Cumulative Dose (TCD), had been established in the beginning of the exposure registration and applied to exposure reconstruction on an individual basis. With the restriction of insufficient information on exposure, TCD could not be applied to 1,025. The average excessive cumulative exposure was 47.8 mSv (ranging from < 1 mSv to 2,363 mSv), and when the exact exposure duration for each individual was taken into consideration, the estimated dose-rate of excess exposure was 10.5 mSv/year on average (< 1 to 1,413 mSv/year).

A standardized incidence ratio (SIR) adjusted for age and gender was calculated with the observed number of cancer patients as the numerator and the expected number of specific cancer patients as the denominator. Specific cancer risks associated with cumulative exposure were analyzed by a model accounting for age at initial exposure, attained age, sex, and the lag of the excess cumulative exposure.

We followed up the 7,271 exposed people for 16.1 ± 4.0 years on average (< 1 to 20 years), with initial exposure at 17.2 ± 16.0 years of age. A total of 141 cancer patients were found, but 46 developed the diseases within the minimal latent periods and were not attributable to the exposure from RCBs. On the basis of the remaining 95 patients, we found that staying in RCBs was associated with increased risks of thyroid cancers (7 patients, SIR = 2.6, 95% confidence interval [CI] 1.1 – 5.4) and non-Hodgkin's lymphoma (5 patients, SIR = 5.4, 95% CI 1.8 – 12.6) and a trend of developing leukemia except chronic lymphocytic leukemia (CLL) (7 patients, SIR = 2.2, 95% CI 0.9 – 4.6), for both genders combined. (Table 1) On the other hand, the exposed population had lower risks for all cancers combined excluding leukemia (SIR = 0.8, 95%, CI 0.6 – 0.9) and all solid cancers combined (SIR = 0.7, 95% CI 0.6 – 0.9).

Table 1. Standardized incidence ratios for the exposed population, 1983 – 2002*

Cancer site	Men				Women				All			
	Cases				Cases				Cases			
	Observed	Expected	SIR	(95% CI)	Observed	Expected	SIR	(95% CI)	Observed	Expected	SIR	(95% CI)
All cancers	42	53.8	0.8	(0.5, 1.0)	53	60.9	0.9	(0.7, 1.1)	95	114.9	0.8†	(0.7, 1.0)
All cancers except Leukemia	36	52.0	0.7‡	(0.5, 0.9)	52	59.3	0.9	(0.7, 1.2)	88	111.6	0.8‡	(0.6, 0.9)
Solid cancers	32	50.9	0.6‡	(0.4, 0.8)	50	58.5	0.9	(0.6, 1.1)	82	109.5	0.7‡	(0.6, 0.9)
Tongue	0	1.1	-	-	1	0.3	3.7	(0.1, 20.7)	1	1.5	0.7	(0.02, 3.7)
Oral	1	1.4	0.7	(0.02, 4.0)	0	0.2	-	-	1	1.7	0.6	(0.02, 3.3)
Nasopharynx	1	2.0	0.5	(0.01, 2.7)	0	1.0	-	-	1	3.1	0.3	(0.01, 1.8)
Esophagus	1	1.8	0.6	(0.01, 3.2)	1	0.3	3.6	(0.1, 20.3)	2	2.2	0.9	(0.1, 3.3)
Stomach	5	4.9	1.0	(0.33, 2.4)	2	3.1	0.6	(0.1, 2.3)	7	8.2	0.8	(0.3, 1.8)
Colon	2	4.0	0.5	(0.1, 1.8)	3	3.8	0.8	(0.2, 2.3)	5	7.9	0.6	(0.2, 1.5)
Rectum	3	3.1	1.0	(0.2, 2.8)	2	2.7	0.7	(0.1, 2.7)	5	5.9	0.8	(0.3, 2.0)
Liver	5	8.9	0.6	(0.2, 1.3)	3	3.7	0.8	(0.2, 2.3)	8	13.1	0.6	(0.3, 1.2)
Lung	7	7.6	0.9	(0.4, 1.9)	3	4.5	0.7	(0.1, 2.0)	10	12.5	0.8	(0.4, 1.5)
Connective	1	0.5	2.1	(0.1, 11.9)	1	0.4	2.3	(0.1, 12.6)	2	0.9	2.2	(0.3, 7.9)
Skin	2	1.5	1.4	(0.2, 4.9)	1	1.5	0.7	(0.02, 3.6)	3	3.0	1.0	(0.2, 2.9)
Melanoma skin	0	0.2	-	-	1	0.2	5.4	(0.1, 30.1)	1	0.4	2.8	(0.1, 15.7)
Non melanoma skin	2	1.4	1.5	(0.2, 5.3)	0	1.4	-	-	2	2.8	0.7	(0.1, 2.6)
Breast	0	0.0	-	-	12	12.1	1.0	(0.5, 1.7)	12	11.2	1.1	(0.6, 1.9)
Cervix Uteri	0	0.0	-	-	12	12.9	0.9	(0.5, 1.6)	12	11.9	1.0	(0.5, 1.8)
Corpus Uteri	0	0.0	-	-	3	1.5	2.0	(0.4, 6.0)	3	1.4	2.2	(0.5, 6.4)
Prostate gland	1	3.4	0.3	(0.01, 1.7)	0	0.0	-	-	1	3.8	0.3	(0.01, 1.5)
Kidney	2	1.3	1.5	(0.2, 5.5)	0	1.1	-	-	2	2.4	0.8	(0.1, 3.0)
Thyroid glands	1	0.5	2.0	(0.1, 11.1)	6	2.3	2.6†	(1.0, 5.7)	7	2.7	2.6‡	(1.1, 5.4)
Leukemia (all types)	6	1.8	3.4‡	(1.2, 7.4)	1	1.5	0.7	(0.02, 3.7)	7	3.3	2.1†	(0.8, 4.3)
Leukemia except CLL	6	1.7	3.6‡	(1.3, 7.8)	1	1.5	0.7	(0.02, 3.8)	7	3.2	2.2†	(0.9, 4.6)
Acute lymphocytic leukemia (ALL)	3	0.4	6.8‡	(1.4, 19.8)	0	0.4	-	-	3	0.8	3.6†	(0.7, 10.4)
Acute myelocytic leukemia (AML)	2	0.6	3.3	(0.4, 11.8)	1	0.5	1.8	(0.05, 10.1)	3	1.2	2.5	(0.5, 7.4)
Chronic myelocytic leukemia (CML)	1	0.3	3.9	(0.1, 21.9)	0	0.2	-	-	1	0.5	2.2	(0.1, 12.1)
Multiple myeloma	1	0.3	3.9	(0.1, 21.5)	0	0.2	-	-	1	0.5	2.2	(0.1, 12.3)
Malignant Lymphoma	3	0.9	3.3	(0.7, 9.7)	2	0.7	2.9	(0.04, 8.1)	5	1.6	3.1‡	(1.0, 7.2)
Non-Hodgkin's lymphoma	3	0.5	6.3‡	(1.3, 18.4)	2	0.4	4.6	(0.6, 16.5)	5	0.9	5.4‡	(1.8, 12.6)

*Latent period considered; † 0.05 < p < 0.1; ‡ p ≤ 0.05; SIR: standardized incidence ratio; CI: confidence interval; —: not applicable

The exposed men had an increased risk for all leukemia combined (6 patients, SIR = 3.4, 95% CI 1.2 – 7.4), and the patients were diagnosed 6 to 18 years (mean 13.3 ± 4.7 years) after initial exposure, while the ages at initial exposure were 5 (two cases), 15, 39, 52 and 70 years old, respectively. The exposed women had a trend of developing thyroid cancer (6 patients, SIR = 2.6, 95% CI 1.0 – 5.7), and the patients were diagnosed 10 to 16 years (mean 12.5 ± 2.4 years) after initial exposure, while the ages at initial exposure were 9, 30, 32, 34, 51, and 67 years old, respectively. All thyroid cancers were of the papillary cell type.

Among the people who received initial exposure before 30 years of age, those who were exposed to more than 50 mSv had higher risks for all cancers combined (relative risk [RR] = 5.6, 95% CI 1.5 – 20.1), and all solid cancers combined (RR = 9.0, 95% CI 2.0 – 40.8), as compared with those who had received less than 1 mSv of exposure. (Table 2) People with initial exposure after age 30 did not have an increased risk of developing cancer.

Table 2. Relative risks (RR) of cancer by different categories of Taiwan Cumulative Dose (TCD) and age at initial exposure*

	Cohort members	All cancers		All solid cancers		Leukemia except CLL		Thyroid cancers		Breast cancers		Combination of Thyroid/Breast	
		N§	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)	N	RR (95% CI)
Age at initial exposure													
≤ 30 years													
Gender													
Men	2,408	6	1	3	1	3	1	0	1				
Women	2,633	19	2.8‡(1.1, 7.0)	17	4.9‡(1.4, 16.7)	0	—	2	—	6		8	
Lag_TCD (mSv)‖													
< 1	1,962	4	1	3	1	2	1	1	1	1	1	2	1
1~50	2,489	15	3.4‡(1.1, 10.6)	13	3.9‡(1.1, 13.8)	0	—	1	—	3	3.3 (0.3, 31.9)	4	2.0 (0.4, 11.4)
> 50	590	6	5.6‡(1.5, 20.1)	4	9.0‡(2.0, 40.8)	1	—	0	—	2	16.0‡(1.4, 179.8)	2	8.1‡(1.1, 59.0)
Total	5,041	25		20		3		2		6		8	
> 30 years													
Gender													
Men	568	31	1	26	1	2	1	1	1				
Women	637	31	0.9 (0.6, 1.5)	30	1.1 (0.6, 1.8)	1	—	4	3.9 (0.4, 35.2)	6		10	
Lag_TCD (mSv)													
< 1	323	18	1	22	1	0	1	1	1	3	1	4	1
1~50	648	37	1.0 (0.6, 1.7)	31	0.9 (0.5, 1.6)	2	—	4	3.1 (0.3, 27.9)	2	0.5 (0.08, 3.0)	5	0.9 (0.2, 3.5)
> 50	234	7	0.6 (0.2, 1.4)	3	0.5 (0.2, 1.8)	1	—	0	—	1	1.5 (0.2, 14.3)	1	1.1 (0.1, 10.0)
Total	1,205	62		56		3		5		6		10	
All age													
Gender													
Men	2,976	37	1	29	1	5	1	1	1				
Women	3,270	50	1.2 (0.8, 1.8)	47	1.4 (0.9, 2.3)	1	0.2 (0.02, 1.6)	6	—	12		18	
Lag_TCD (mSv)													
< 1	2,285	22	1	25	1	2	1	2	1	4	1	6	1
1~50	3,137	52	1.3 (0.8, 2.2)	44	1.2 (0.7, 1.9)	2	0.8 (0.1, 6.0)	5	—	5	1.1 (0.3, 4.0)	9	1.2 (0.4, 3.4)
> 50	824	13	1.1 (0.6, 2.3)	7	1.2 (0.5, 2.9)	2	2.9 (0.4, 22.0)	0	—	3	4.3†(1.0, 19.8)	3	2.8 (0.7, 11.3)
Total	6,246	87		76		6		7		12		18	

*Poisson regression model: $\mu_i = P_i \times \exp(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i})$, where P_i was the person-years in the ith stratum, X_{1i} was age at initial exposure (two groups: ≤ 30 and > 30 years old), X_{2i} was attained age (four groups: 0–20, 21–40, 41–60, > 60 years old), X_{3i} was sex, and X_{4i} was lag of the excess cumulative exposure (three groups: < 1, 1–50, > 50 mSv); † 0.05 < p < 0.1; ‡ p ≤ 0.05; § Numbers of cancer cases; ||: excess cumulative exposure were lagged 2 years for leukemia and 10 years for other cancers; —: not applicable.

Compared with the reference population, the study population had lower risks of all cancers combined, all cancers combined excluding leukemia and all solid cancers combined. Most study population had resided in buildings constructed in the early 1980s, a period of rapid economic development in Taiwan. It was likely that the exposed population could have higher socioeconomic status than the general population, with healthier lifestyles and consequently lower cancer risks, a situation that has been described in other population studies.

Leukemia was the first cancer to be noted with higher incidences among the atomic bomb survivors, and in this study we observed excess risks of developing leukemia (except CLL) in men and malignant lymphoma in both genders combined. These observations are compatible to the report of the United Nations Scientific Committee on the Effects of Atomic Radiation. This study is unique in that it was on a general population, and in contrast to other occupational radiation exposure studies primarily on men, the study population comprises similar numbers of both genders. Our study population was large enough to detect certain increases in cancer risks associated with ionizing radiation, but the average follow-up period since initial exposure was still too short to observe the development of the whole spectrum of cancers. Further follow-up of the study cohort is necessary to confirm our findings and identify other types of cancers that may also be related to the protracted and low dose-rate ionizing radiation.