Evaluation of Averaged Annual Dose Rate Exposed by Natural Radiations for Each Country in the World

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Evaluation of averaged annual dose rate exposed by natural radiations for each country in the world has been performed on the basis of the fundamental data of UNSCRE 2000, considering that the present evaluation gives both of world and Japan averaged values which are consistent with both official authentication values. The result showed that the values of countries of north and east Europe are more than two times of the Japan average. As an application of the evaluated data set, the correlation between the natural exposure dose rates and the incidence of a cancer was investigated by using the age-standardized incidence data reported by IARC (International Agency for Research on Cancer) of World Health Organization. It was found that the incidence of cancers near human body surface generally indicate a negative or small positive correlation to the annual external dose rates than that to a smoking rate by country.

**KEYWORDS:** Natural Radiation, Dose Rate, Cosmic Ray, Gamma Outdoors, Gamma Indoors, Radon, Food, Cancer Incidence

1. Introduction

It has past about a half and 8 years after the TEPCO (Tokyo Electric Power Company) Fukushima Daiichi nuclear power plant accident. The accident have brought severe contamination of very wide areas in the Fukushima prefecture as well as neighboring prefectures in the Tohoku and Northern Kanto regions by radioactive cesium. Decontamination work has been completed in order to reduce the ambient radiation level in living environment of residents except for the difficult to return-back zone of Fukushima prefecture. As a result, the air dose rates of residential area have been reduced by 60% after decontamination and by 76% on the post-decontamination monitoring up to August of 2018\textsuperscript{[1]} and the evacuation orders have been lifted up to 10\textsuperscript{th} April 2019 by Okuma-machi at last. The values of air dose rate at the major monitoring posts in Fukushima prefecture became\textsuperscript{[2]} less than 0.23\,\mu Sv/h giving an annual exposure dose of 1 mSv/y in the most part of the decontaminated areas as shown in Table I. Although the decontamination of mountains and forests more than 20 meters away from the residential area and difficult-to-return zones remains, it can be mentioned that Fukushima residents are now able to work on a full-fledged reconstruction of their home town.

On the other hand, let's take a look at the old situation of Fukushima in 2012, when the Fukushima Office for Environmental Restoration was established in the Ministry of
Table 1. Measured air dose rates and recent excess annual dose rate in municipalities in Hamadori district. The data of air dose rates were taken from the homepage of Fukushima Prefecture[1].

| place          | Air Dose Rate (µSv/h) [2] | Annual Dose (mSv/y) |
|----------------|---------------------------|---------------------|
|                | 2011/3/31 | 2011/4/29 | 2012/4/1 | 2014/11/7 | 2015/4/19 | 2019/9/5 |                |
| Minamisouma-shi | Government Office          | 1.00 | 0.54 | 0.38 | 0.11 | 0.11 | 0.07 | 0.33 |
| Kawamata-machi  | Government Office          | 2.57 | 2.62 | 0.54 | 0.53 | (0.44, 0.45) | 0.25 | 1.18 |
|                 | Fire Center at Yamamiya    | 0.24 | 0.25 | 0.16 | 0.16 | (0.14, 0.14) | 0.04 | 0.19 |
| Hidate-mura     | Government Office          | 1.46 | 1.49 | 0.68 | 0.68 | (0.67, 0.67) | 0.36 | 1.69 |
|                 | *Nagadoro Community Center| 7.48 | 3.28 | 0.94 | 0.99 | 0.48 | 0.45 | (0.40, 0.41) | 0.22 | 1.03 |
| Tamura-shi      | *Tsushima Government Office| 11.5 | 5.16 | 5.41 | 0.55 | 0.55 | (0.62, 0.62) | 0.31 | 1.46 |
| Kawashiba-mura  | Government Office          | 0.36 | 0.26 | 0.14 | 0.13 | 0.10 | 0.09 | (0.10, 0.09) | 0.08 | 0.38 |
|                 | Kainosuka Bus Stop         | 0.53 | 0.29 | 0.15 | 0.16 | 0.08 | 0.09 | (0.10, 0.09) | 0.07 | 0.33 |
| Namie-shi       | Ikiyobashi Public Hall     | 1.70 | 1.69 | 0.59 | 0.59 | (0.54, 0.55) | 0.28 | 1.32 |
|                 | *Tsushima Elementary School| 0.31 | 0.17 | 0.13 | 0.07 | 0.07 | 0.07 | 0.33 |
| Katsurao-mura   | Government Office          | 0.41 | 0.25 | 0.2 | 0.12 | 0.12 | 0.12 | 0.56 |
| Futaba-machi    | Hatori Public Hall         | 1.75 | 0.81 | 0.78 | 0.38 | 0.38 | 0.38 | 1.79 |
| Oskuma-machi    | Oogawara Public Hall       | 3.06 | 2.99 | 0.27 | 0.27 | (0.26, 0.25) | 0.19 | 0.89 |
| Tomioka-machi   | Government Office          | 3.9 | 0.53 | 0.53 | 0.45 | 0.14 | 0.14 | 0.66 |
|                 | *Public Hall Yonomori Station| 5.90 | 5.93 | 2.95 | 2.94 | (2.78, 2.83) | 1.21 | 5.69 |
| Naraha-machi    | Kamishigekoka Public School| 1.36 | 1.34 | 0.43 | 0.43 | (0.43, 0.43) | 0.21 | 0.99 |
| Hiroshi-machi   | Shimokitasokyo Public Hall | 0.40 | 0.41 | 0.11 | 0.11 | (0.08) | 0.06 | 0.28 |
| Iwaki-shi       | Government Office          | 0.65 | 0.27 | 0.11 | 0.07 | 0.07 | 0.07 | 0.28 |

N.B. * Belong to a difficult-to-return zone and not decontaminated yet.

** Annual dose rates were roughly estimated by multiplying 4.7 to the dose rates on 2019/9/5.

The Environment, and full-scale decontamination began according to “Act on Special Measures concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District Off the Pacific Ocean Earthquake that Occurred on March 11, 2011” which was enacted on 30th August 2011. At that time, since the air dose rate of the radiation even in big town such as Fukushima-shi and Koriyama-shi exceeded 1 µSv/h, residents were worried about the influence of radiation exposure to their children and wanted to decontaminate as soon as possible. Then, the volunteer decontamination works were also made. In response to this situation, ICRP (International Committee of Radiation Protection) experts recommended[3] during a dialogue with residents that the radioactive contamination in Fukushima was much lower than that of Chernobyl, so it was better to compare with natural radiations. However, the amount of annual exposure dose rate by natural radiation known in Japan at that time was 2.4 mSv/y of world average reported in UNSCEAR 2000 report[4] and the averaged value 1.5 mSv/y or 2.1 mSv/y in Japan where annual exposure dose rates without intake of Radon were reported to be distributed from 0.81 mSv/y in Kanagawa Prefecture to 1.19 mSv/h in Gifu and mean value was 0.99 mSv/h[5]. They must be lower than annual exposure dose rate in Fukushima after the NPP accident and did not become helpful to reduce their worries about radiation influence. On the other hand, higher values which could be compared with that of Fukushima according to the expert’s recommendation were those of high dose region in the world such as 9.2 (6.2-32) mSv/y at Kerala and Madras in India, 5.5 mSv/y at Guarapari in Brazil, and 4.7 (0.49-610) mSv/y at Ramsar in Iran and 1.6-56 mSv/year at Yangjiang and Guangdong in China[4, 6]. The latter high-dose areas were a place where Japanese rarely visited, and the fact that rate of cancer death even in those places were not different from that of our familiar places did not seem persuasive. Then, one of the authors found a paper on an evaluation of dose rate by natural radiation in Europe[7] which gave some times higher than the Japan average, 2.1 mSv/y. Then, he explained European natural exposure dose rate by comparing with the air dose rate in
Fukushima in a dialogue meeting with the residents. However, a resident replied “I can not believe it” and claimed “Take back the original environment”. Certainly, the values given in Ref. 7 seemed too large comparing with the world averaged value of 2.4 mSv/y. Therefore, the authors have evaluated by their-selves the averaged values on annual dose rates exposed by natural radiation of individual countries in the world.

2. Evaluation of National Averages of Natural Radiation Exposure Dose Rate

The United Nations reports in UNSCARE 2000[4] that the world average dose rate from natural radiation sources is 2.4 mSv/y which is composed of cosmic radiation 0.39 mSv/y, external terrestrial radiation 0.48 mSv/y, inhalation exposure by Radon and Thoron etc. 1.26 mSv/y and ingestion exposure by $^{40}$K, Uranium-and-thorium series in foods 0.29 mSv/y. It does not report any national-average dose rate for individual countries.

Instead, Ref. 4 gives tables of measured data for various countries in the world concerning the external exposure rates in indoors and outdoors from terrestrial gamma radiation (nGy/h), radon concentrations in dwellings determined in indoor surveys (Bq/m$^3$), thoron concentrations in outdoor and indoor air (Bq/m$^3$) together with the several kinds of data on ingestion exposure by $^{40}$K and uranium-and-thorium series in foods. However, the data of uranium-and-thorium series in foods seems to be insufficient to treat rigorously as an country-wide one as shown in Table II which gives sum of weighted concentration of nuclides adsorbed in organs of human body for estimating the effective dose equivalent. In the table, there are many blanks and listed countries are quietly limited, while the median and reference values may be obtained by averaging over many countries.

Table II. Sum of weighted concentrations (in unit of Bq) of nuclides adsorbed in organs of human body for uranium and thorium series radionuclides which are given in Table 19 of Annex B of UNSCARE 2000[4].

| Region        | Country       | U238 | Ra228 | Ra226 | Th232 | Th230 | Pb210 | Po210 |
|---------------|---------------|------|-------|-------|-------|-------|-------|-------|
| Africa        | Nigeria       | 34.5 | 24    | 9.5   | 11    |       |       |       |
| North America | Canada        | 21.9 | 8.1   | 6     | 7.7   |       |       |       |
|               | United States | 17.5 | 13.7  | 6.6   | 10    | 594   | 698   |
| South America | South America | 24.5 |       |       |       |       |       |       |
| East Asia     | China         | 38.8 | 23.3  | 14.1  | 13.6  |       |       |       |
|               | India         | 24.7 |       |       |       | 9.6   |       |       |
|               | Japan         | 19.6 | 11.5  | 5.3   | 7.7   | 447   | 769   |
|               | Nepal         | 23.2 |       |       |       |       |       |       |
| Europe        | Austria       | 11.4 |       |       |       |       |       |       |
|               | United Kingdom| 18.4 |       | 9.5   |       | 518   |       |       |
|               | Yugoslavia    | 11.0 |       |       |       | 7.9   |       |       |
|               | Finland       |       |       |       |       | 235   | 480   |       |
|               | Russian Federation | 272.0 | |       |       |       | 890   | 687   |
| Oceania       | Oceania Australia | 18.7 | |       |       |       |       |       |
| Median value Range | 22.5 | 12.9 | -    | 7.3   | 9.2   | 492   | 535   |
| Reference value | 22.5 | 13   | 25.5 | 5.9   | 7.7   | 479   | 468   |

N.B. Adsorbed in lung, liver, kidney, muscle and other tissue, and bones.
Present evaluation of exposure dose rate was made as follows. Data conversion from the base data $Q$ (Gy/h or Bq/m$^3$) to the annual exposure dose rate $D$ (mSv/y) was made by the following equation:

$$D = c \cdot k \cdot Q \cdot T$$  \hspace{1cm} (1)

Where $c$: conversion factor from Gy/h or Bq/kg to the annual exposure dose rate, 0.748 (nSv/nGy) in case of external exposure, $9.0 \times 10^{-6}$ (mSv/Bq m$^3$) in case of inhalation exposure by Radon and Thoron, $k$: a decay fraction of radon isotopes to the daughter nuclides contributing to actual radiation exposure, 0.4, $T$: annual exposure time, 20% outdoor in life, i.e. 1752 hours and 80% indoor 7008 hours.

All parameters were those adopted by the researchers in the health physics field etc. of Japan[8]. There were racked some values of the data base. In such a case, the authors supplemented with a measured data belong to the same quantity, for example, racked indoor gamma-ray data supplemented with a measured outdoor value of the same or neighboring country or with an assumed value. Exposure dose by cosmic rays was assumed to be 0.39 mSv/y for countries near the north pole and 0.35 mSv/y, otherwise, except for 0.30 mSv/y of Japan. Dose rate due to in-taken foods was also assumed to be world averaged value 0.29 mSv/y, except for 0.98 mSv/y of Japan on the basis of the recent evaluation by Y.Hosoi[9].

Table III. Comparison of annual exposure dose rate due to natural radiation. (unit: mSv/y)

| Object      | Radon | Cosmic rays | Indoor gamma | Outdoor Gamma | In-take foods | Total  |
|-------------|-------|-------------|--------------|---------------|---------------|--------|
| Japan       |       |             |              |               |               |        |
| Published[9]| 0.48  | 0.30        | -            | 0.33          | 0.98          | 2.09   |
| Present     | 0.53  | 0.30        | 0.07         | 0.28          | 0.98          | 2.16   |
| World average| UNSCARE2000[4]| 1.26 | 0.39        | -            | 0.48          | 0.29   | 2.42   |
| Present     | 1.17  | 0.39        | 0.08         | 0.44          | 0.29          | 2.37   |

Fig. 1. Comparison of national averaged values for annual exposure dose by natural radiations.
In Table III, the present results are given for the Japan and the world averages. Agreement between the widely published and the present values is so good within $+0.7\text{--}0.5$ difference that the authors believe that the present method is verified.

Figure 1 compares the calculated national average values for annual exposure dose rates. The figure shows that the value of Japan is in the intermediate and that those of northern and eastern Europe countries such as Finland, Estonia, Sweden, Luxemburg, Hungary and Albania are fairly high, exceeding 4 mSv/h. On the other hand, comparing the results with the old evaluated data of Ref. 7 (i.e., Atlas of Europe), the present results were found to be generally lower than their estimations, for example, the present 4.68 mSv/y for Finland and 1.69 mSv/y for United Kingdom are compared their about 7 mSv/y and about 2 mSv/y given in Figure 2 of Ref.7, respectively.

3. Discussion

3.1 Reliability of the evaluated result

The present results are generally lower than those of natural radiation ATLAS of Europe but agree well with the widely recognized averaged values of the world and Japan as shown in Table III. Accordingly, the former can be mentioned to be more reliable than the latter. The most difference is observed in the exposure dose of breathing radon gas. Table IV compares the conversion coefficients of raw dose rate by gamma-rays from ground and radon activity concentration to the annual dose equivalent. Large difference is found in the coefficient on Radon gas: that is about twice larger than the present. Especially, since the soil of north and east European contains a lot of granite, the difference is more obvious for Finland and Sweden.

Table IV Comparison of conversion coefficient to estimate annual dose equivalent.

| Raw Dose Quantity                  | Raw dose quantity unit | Conversion coefficient to annual dose equivalent (mSv/y) |
|------------------------------------|------------------------|--------------------------------------------------------|
| Gamma-ray dose rate indoors       | nGy/h                  | Green et. al.[7] 0.0049                                 |
| Gamma-ray dose rate outdoors      | nGy/h                  | Present 0.0052                                          |
| Radon activity concentration      | Bq/m$^3$               | 0.0012                                                 |
|                                   |                        | 0.0013                                                 |
|                                   |                        | 0.05                                                    |
|                                   |                        | 0.027*                                                  |

N.B. *) Dose equivalent for radon was finally estimated by adding the contribution of $^{222}$Rn, i.e. 0.1 mSv/y to the value calculated from Radon activity

3.2 Influence of natural radiation to cancer incidence

Cancer affects more than half of the population in Japan[10]. It is very interesting whether natural radiation is affecting the cancer incidence or not. Since the average dose of exposure from natural radiations in each country was clarified in the present work, the authors examined the correlation between the incidence of cancer and the amount of exposure dose rate in each country. The basic data of world cancer incidence were reported from International Agency for Research on Cancer, "Cancer Incidence in Five Continents, Vol. IX (2007), edited by Curado, M.P. et al.[11] Caner deaths are generally observed in any countries. The age-specific rate is calculated simply by dividing the number of cancer deaths observed in a given age category during a given time period by the corresponding number of person years in the population at risk in the same age category and time period. For cancer, the result is usually expressed as an annual rate per 100,000 person-years. The mortality and incidence of cancer are
influenced by various factors, such as place of residence, sex and age group etc. Data on mortality are often presented as rates. For a specific tumour and population, a crude rate is calculated simply by dividing the number of cancer deaths observed during a given time period by the corresponding number of person years in the population at risk. Since the age-structure of population and life of the resident are much different among the countries or regions in the world, direct comparison of the age-specific rates and their cumulative values seems to be less significant to discuss the cancer risk. Accordingly, an age-standardized rate (ASR) was proposed as a summary measure of the rate that a population would have if it had a standard age structure. Standardization is necessary when comparing several populations that differ with respect to age because age has a powerful influence on the risk of dying from cancer. The ASR is a weighted mean of the age-specific rates; the weights are taken from population distribution of the standard population. On the other hand, mortality to incidence ratio is considered to be somewhat related to geographical region. The regional location of the registry is important in evaluation of the statistic. Accordingly, age-standardized incidence (i.e., AS incidence) can be estimated by using the ASR and the regional mortality to incidence ratio.

In the present work, the AS incidence data repotted in Ref. 11 were used to estimate the correlation coefficient between the AS incidence data for cancers occurring near the surface of the human body and external dose rates of 33 countries. Additively, the correlation coefficients were estimated to total dose rates of 30 countries. Tobacco is well known to be the biggest factor of cancers. As a reference case, the correlation coefficient was first estimated between smoking rate[12] and the AS incidence for Trachea, bronchus and Lung of 42 countries. Figure 2 shows their gender correlation diagram, in which the AS cancer incidence is much dispersed in case of male. It can be seen in the figure that the higher the smoking rate, the higher the incidence of cancer. Both smoking rate and AS incidence of male are larger than those of female even at the same dose rate. The correlation coefficients are 0.23 and 0.35 for male and female, respectively.

Figure 3 shows negative correlation for the cancer such as melanoma and thyroid cancer. The results indicate negative or small positive correlation. But it is puzzled that the coefficient of thyroid for female is 0.23 near the reference for smoking. It may be relate to the higher incidence of female than that of male.

![Smoking Rate vs Lung Cancer ASI](image)

**Fig. 2** Correlation diagram between smoking rate and cancer incidence for cancer of trachea, bronchus and lung.
Fig. 3 Correlation diagram for cancer of melanoma and thyroid cancers against natural radiation external exposure dose rates.

Fig. 4 Correlation diagram between natural radiation exposure dose rates and incidence of cancer for trachea, bronchus and lung.

Fig. 5 Correlation diagram between natural radiation exposure dose rates and incidence of cancer for prostate of male and breast of female.

Figure 4 shows the result for the cancer of trachea, bronchus and lung against external and total dose rates. While the correlation coefficients of female are negative, those of male are positively large. Generally, the smoking rate of men is high, so it is likely to have had an impact and may bring the higher coefficient of male.

Figure 5 shows the result for the prostate of male and the breast of female against the external and total dose rates. These organs are near surface of human body and the external exposure seems to be significant at first glance. However, the coefficients are negative. Against the total dose rate, both coefficients become positively large near result for smoking shown in Figure 2. Total dose rate contains the contributions of radon gas and foods ingested. The authors can't deny their affects to the organs, but the prostate may be influenced by some irritant materials in the urine. However, the breast
Fig. 6 Correlation diagram between natural radiation exposure dose rates and incidence of all cancers.

Table IV. Correlation coefficients between natural dose rate and cancer incidence.

| Natural Dose Rate | Melanoma | Thyroid | Trachea, bronchus & lung | Prostate | Breath | All |
|------------------|----------|---------|--------------------------|----------|--------|-----|
|                  | Male     | Female  | Male                     | Female   | Male   | Female |
| External         | -0.15    | -0.18   | 0.08                     | 0.23     | 0.19   | -0.04 |
| Total            | 0.08     | 0.18    | 0.16                     | 0.21     | 0.30   | -0.19 |

of female is also a very delicate organ. Its high incidence of cancer seems to be brought by high sensitivity as like in case of the cancer of trachea, bronchus and lung of male.

Figure 6 shows the results for all cancers. Some organs are within the human body and influence of the ingested radioactive nuclides from foods as well as radon gas must appear. Accordingly, larger values of the correlation coefficients seems to come from the internal exposures.

Table IV summarizes the calculated gender correlation coefficients between the dose rates and the different cancer incidences. The correlation coefficients for the external exposure dose rate by outdoor and indoor gamma-rays and cosmic rays are generally negative or small. The exceptions are cancer of trachea, bronchus and lung of male and thyroid cancer of female: the former 0.19 and the latter 0.23 are near to the reference values 0.23 for smoking of male. The correlation coefficients to total dose rate are higher than those to external exposure dose rate.

It is difficult to clarify whether the increase of the coefficient by internal exposure is actually due to radiation or accidentally apparent due to accumulation of some kinds of ambiguity in deriving the AS incidence such as ratio of mortality to incidence and deviation of the base data. In the present work, the authors used limited data on both of dose rate and the incidence of cancer, and there may be a problem that the age of each data was somewhat off. In future, more comprehensive and detailed analysis of data together with reliability and error analysis will solve the questions.

4. Conclusion

When explaining the influence of environmental contamination with radioactive materials due to nuclear accidents, it is very helpful for understanding its risk to compare the air dose of the contaminated area with the amount of exposure dose caused by natural radiation that has been received since birth of living organisms.

In the present work, the average value of annual natural exposure dose rate in each country in the world has been evaluated on the basis of the United Nations survey materials[4] and summarized in the figure. The result can be mentioned to be reliable
because of well-reproducing the world average and the published data on Japan, comparing with the Atlas of Europe[7]. The dose rate of Japan is generally lower than those of Europe. Especially, Northern and Eastern Europe where is a lot of granite soil imposes highly concentrated radon gas into environment and total dose rates become more than twice as much as Japan.

As an application of the present data, the correlation coefficients of the AS incidence of cancer to the external exposure dose rate were estimated. The negative or small positive coefficients mean that natural radiation generally has no significant effect on the incidence of cancer. However, different behaviors were observed in the cancers for trachea, bronchus and lung of male and thyroid of female. Another result observing positive correlation of the internal exposure due to radon gas and ingested foods was obtained by comparing between the coefficients of the external and those of the total dose rate, though its reasons are not clarified so far.

In radiation risk communication, the explain with natural dose rate was not always welcomed by the affected residents. There were typical two case: One was on the dialogue among residents and team of local government and government agencies where the residents did not received the explain by a parson belong to government as a safe sell, and another case of radiation education by the specialist where they received it with a pleasure because they held the impression of security. Anyway, the authors hope the present result will help the radiation risk communication. It is important to accumulate the facts that are scientifically correct and to gain resident’s confidence in the future.

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