Risk of Gradual Exposure Likely Received in Severe Nuclear Power Plant Accident

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In the area of Hama-Dori of Fukushima prefecture, the return of displaced people who are expected to be responsible in regional revival is only slight because they fear an influence of the radiation exposure even at low level during lifetime of their children. In this paper, risk of gradual exposure likely received in severe nuclear power plant accident has been evaluated to provide a guide to think about how to act, by considering that the process of cancer progression after the damage of DNA due to active oxygen is the same between a natural and radiation induced cancers. The evaluated risk of radiation exposure by 100 msV/y in a lifetime is $2.7 \times 10^{-6}$/year and one order magnitude lower than a recent traffic accident.

**KEYWORDS:** Risk, Radiation Exposure, Nuclear Power Plant, Accident, DNA Damage, DNA Repair,

1. Introduction

Eight years have passed since the great East Japan earthquake of March 11, 2011, and new urban development and industry creation have progressed in the disaster area. However, it should be noted that in the area of Hama-Dori, Fukushima prefecture where the evacuation order issued against the TEPCO (Tokyo Electric Power Company Holding, Inc.) Fukushima Daiichi nuclear power plant accident has been lifted, the return of displaced people who are expected to be responsible in regional revival is only slight. Although the living environment such as infrastructure is not well equipped, there are not a few people who hesitate even with a temporary return in the younger generation. The biggest reason seems to be to fear the influence of the radiation exposure of their children in the un-decontaminated forest near the home and at the time of crossing the “difficult-to-return zone” on the way of homecoming destination. So, the author wanted to provide a guide to think about how much people don’t need to worry about, and think about the risks.

We would like to look back on the evacuation of residents in the event of an accident. March 11th. At 16:45, TEPCO informed a severe accident of loss of core cooling system at the Unit1 reactor of the Fukushima Daiichi Nuclear Power Plant (hereafter abbreviate to 1F1 reactor). Since the accident did not converge, the emergency declaration was issued at 19:03, and both of the government and the local measures headquarters were set up. At 20:50, Fukushima Prefecture issued evacuation orders to residents within a 2 km radius of the 1F site, followed by the 21:23 Prime Minister’s evacuation ones within 3 km and instructions for indoor evacuation to
residents within 10 km. On March 12, evacuation orders were extended to 10 km of 1F site, and were also issued for residents of the second power plant (2F site). Additively, evacuation ranges were extended to 20km of 1F and 10km of 2F after a hydrogen explosion of the 1F1 reactor in the evening. On March 14, the emergency reactor isolation cooling system of Unit 2 of 1F (1F2) was stopped at 11:30 after the hydrogen explosion of 1F3 and 1F4. Then long time seawater injection to the reactor and trial of exhaust of gas to suppress the reactor pressure resulted in sudden pressure dropping with abnormal sound around 6:10 on March 15th. It is presumed that the leak of a large amount of radioactive material occurred at this time. At 11:00, residents within 20-30km of 1F site were instructed to evacuate indoors.

The radiation monitor told the amount of radioactive material leaked outside. The reference level of evacuation order was discussed, referring to the recommendation described in ICRP-103 to determine it between 20 and 100 millisievert per year (mSv/y). The Japanese government have selected to be the lowest 20 as a reference level for the resident evacuation together with the decontamination level of 1 to be subsidized: after that, this level was recommended by the IAEA team to take as the final target after a natural decay of radioactive materials. Three evacuation zones were taken very widely on April 22 in 2011 and resident evacuation was conducted. In the end, up to 160,000 people, including other residents, were evacuated from their home in Fukushima prefecture. The time and expense for decontamination projects also became enormous because the decontamination target area became too wide.

If the risk of gradual exposure of 100 mSv/y during multiple years might be sufficiently low, both areas for evacuation instruction and decontamination will be narrower. Recently, it becomes well known that the cancer is well suppressed by innate functions such as repair of damaged DNA together with apoptosis and immunity, especially after the researches on DNA repairing mechanism have received the Nobel Prize in 2015. Therefore, the author has decided to evaluate the risk of gradual exposure of 100 mSv/y by taking into consideration of the cancer suppression functions.

2. Background

The ICRP member who came to Fukushima after the nuclear accident advised that it would be a good indication of the amount of natural radiation exposure to evaluate a radiation safety in Fukushima[1]. Incidentally, it is 2.4 mSv per year on the global average, about 5 mSv if Scandinavia. The author evaluated[2] the risk of 1 mSv exposure per year to be 4.5 x10^{-7}, based on the ICRP recommendation on cancer death’s probability ”0.5% per 100 mSv” that was assessed from the data of the epidemiological survey of Hiroshima and Nagasaki atomic bomb survivors. However, the author recently noticed not to answer to the question: “How about risk become, if the exposure of 1 mSv per year will continue for some ten years?”

On the other hand, there were irradiation experiments to examine the influence by changing the dose rate of the radiation against mouse. The result for mutation rates due to radiation obtained with a lot of mice was reported by Russel[3] of the Oak Ridge National Laboratory of United States in 1959, and the radiation-induced mutation rate of the chromosome distinguishing a natural mutation was by the Kakinuma et. al. [4] of National Institute of Radiological Sciences at Chiba in 2018. In both experiments, they compared mutation rates of the groups irradiated with different dose rate up to the same cumulative dose exposure and clarified that the low-dose-rate irradiation group indicated lower mutation rate than the high-dose-rate one. The results show that the LNT hypothesis insisted by H.J. Muller[5] and advocated by ICRP: ”radiation dose
effect has no threshold and is proportional to the cumulative dose" is not approved in some condition such as low dose rate. In that case, the risk of low-dose long-term exposure (referred to as "gradual exposure") should be lower than previously thought and is worthy of reassessment.

Therefore, the author took notice of a process of multi-stage suppression functions of the canceration described by Dr. Kazuko Uno [6] of the Louis Pasteur Research Centers. The process is shown in Fig. 1. It indicates that any cancer due to radiation, tobacco, mutagens, pollutants and so on originates from DNA damage, and the following process to canceration is common. That is, there is a suppression function for cancer generation in the person, starting from the antioxidant action, most of the DNA damaged by the active oxygen is repaired, also, the cells with abnormal genes that can come from failure of repairing the damaged DNA is orchestrated to be self-death (i.e., apoptosis). In addition, mutated cells are almost killed by natural killer cells and T-lymphocytes, a type of lymphocyte under the immunity function. With such ability, human natural cancers are being suppressed. It still accounts for 30% of the cause of death. In other words, the cancer mortality rate is also reflected in the effect of human cancer suppression. This suppression effect is supposed to be effective not only in natural cancer but also in cancer by radiation. On the other hand, it is easily imagined that a lot of genes are damaged in a large amount of radiation momentarily in the case of the atomic bomb, and the function of suppression will not catch up sudden and massive damages.

Then, based on the index suggestive of DNA damage and the mortality rate of natural cancers, it is thoughtful that the risk of gradual exposure could be assessed.

![Fig. 1](Fig_1.png)

Process of canceration and multistage suppression mechanism.

3. The origin of the defense function against human cancer

The birth of life is said to be 3.8 billion years ago in evidence of the formation of the oceans and the carbon isotope ratios of the old sedimentary rocks found in Greenland. The organism is believed to have been anaerobic bacteria found in the hydrothermal vent. 3.5 billion years ago, the cyanobacterium, which produced the starch of
self-nourishment by the photosynthesis in the carbon assimilation and was able to utilize it in oxygen respiration, was born. Oxygen is a very excellent element considering energy efficiency. By using this, organisms evolved from single-celled to multicellular, to plants and animals. Oxygen, on the other hand, has a very high toxicity for organisms. As a result, organisms have increased their ability to defend against active oxygen in the course of evolution. It is an antioxidant effect seen many in plants, and a repair function of damage DNA of flora and fauna. In addition, the apoptosis and the immunity function have been acquired. On the other hand, the organism uses its oxygen as a defense function. One of the white blood cells, neutrophils use this reactive oxygen to kill the fungus.

As is the case with the study of H.J. Muller, the Nobel Prize has been awarded to the research of the cancer suppression function mentioned above, and those functions are admitted academically. Namely, the Nobel Prize in Physiology or Medicine for discovery of nature and mode of action of oxidation enzymes to Dr. A.H.T. Theorell[7] in 1955, to S. Brenner, R. Horvitz, J. Dr. Sulston[8] for their discoveries about how genes regulate tissue and organ development via a key mechanism called programmed cell death, or apoptosis in 2002, to B. A Beutle, J. A. Hoffman, R. Steinman[9] for their discoveries concerning the activation of the innate immune system in 2011, but the Nobel Prize in Chemistry was awarded to T. Lindahl, P. Modrich and A. Sancar [10] for their studies on damage DNA repair function in 2015.

4. Risk assessment

The mortality rate of natural cancers is the result of the damage of DNA in human life, reflecting the above-mentioned cancer suppression functions. Even in the case of the DNA damage caused by radiation exposure, human cells follows the same processes, so you can see the mortality rate of cancer by radiation, by comparing the initial process of the damage. Fortunately, good data indicating that double strand cleavage is a true cause of cancer were found for the present assessment in the text of "Introduction to Radiology" course in the Department of Radiation Biology and Health, University of Occupational and Environmental Health [11]. Fig. 2 shows a mechanism from DNA

![Mechanism of DNA Damage by Radiation to Cancer](image)

Based on Sohei Kondo's evaluation,
Number of natural double strand cleaves is 10 /cell/day
Number of radiation induced ones is 0.03 /cell/(mGy/day)
The ratio of the radiation induced to the natural one is 3/1000.

Fig. 2 A mechanism of DNA damage by radiation to cancer and numbers of double strand cleavages
damage by radiation to cancer and numbers of double strand cleavages. There’re few DNA damage due to direct attack and major indirect one induced by active oxygen produced by radical reaction between radiation and water. The DNA damages, containing natural damage, are classified to three types of base cleavage, DNA single strand cleavage and double-strand cleavage. The former two damaged DNAs are easily repaired on the basis of a pair of genes and do not cause biological effects. Double strand cleavage has no longer a clue of repair, so that many damaged DNA can not be repaired and some repair is performed based on the regularity of the gene sequence. This restoration can be said to be incomplete and underlying cancer. Therefore, the author has decided to evaluate cancer risk by considering the number of this DNA double strand cleavage.

Dr. Sohei Kondo[12] evaluated numbers of individual cleavages of both natural occurrence and radiation induced one. The numbers of DNA double-stranded cleavage are estimated to be 10 for the natural occurrence and 0.03 due to radiation exposure of 1 mGy/day (milli gray per day) on the basis of Kondo’s evaluation. Therefore, it was assumed that the man will die from cancer at this rate. As a result, the cancer mortality rate based on the radiation exposure was assessed to be 30% * 0.03/10 = 0.09%. In addition, gray of the amount of exposure is a unit of absorption dose indicating the energy (J) of radiation tissue 1kg absorbs, different from the equivalent dose (Sievert) exhibiting biological effects. Biological effects vary depending on the type and energy of the radiation, when converted from an absorption dose to an equivalent dose, but calculated by multiplying the coefficient of linear, gamma rays, X-rays and electron beams (beta line) in the case of the conversion coefficient is given in 1.0. Therefore, the amount of exposure of 1 mGy/day is 365 mSv as the annual exposure amount, the mortality rate is 0.09% in a lifetime of such exposure.

5. 100 mSv per year exposure risk

The standard that is often discussed in evacuation orders is the annual additional exposure of 20 - 100 mSv/y and try to calculate the risk of 100 mSv/y. In that case, the mortality rate is 0.09 * (100/365) = 0.025%. This value is one-twentieth of the risk 0.5% of 100 mSv of instantaneous exposure proposed by ICRP.

In addition, the author has evaluated the risk by using the Japanese population data. The data on the basis of the evaluation is 126 million people and the number of deaths 1,370,000 people in 2018. The number of death in a year due to gradual exposure of 100 mSv/y can be calculated by multiplying mortality rate of 0.025 % to the number of deaths 1,370,000 people and resulted in the value 343 persons/year. The deaths of the traffic accident of this year were 3,532 persons/year, and the death of the gradual exposure was almost one-tenth of the traffic accident. In Japan, safety (i.e., risk) is often discussed in the number of deaths within one year per 100 thousand people. In the case of the present gradual exposure, the value is obtained by multiplying the ratio of 100 thousand to the total population to 343 deaths. The result is 0.27 death/year per 100 thousand people.

Accordingly, the risk of individual person is obtained as 2.7 x10^{-6}/year.

Anyway, it can be said that the above risk is one order magnitude lower than a recent traffic accident.

There are few people who are hesitant to decide how to act with only the numerical value of the risk. For example, if you face a problem, such as romance, you can avoid
the risk by moving away from the problem, while avoiding it also entails another risk. Therefore, it is also important to think by comparing the two. Moreover, since the radiation level of environment will go down with a natural decay of radioactive nuclides such as Cs-134 and Cs-137, the long-term risk decreases. In addition, it can be said that the influence of the gradual exposure decreases further, according to the WAM theory [13] that a DNA repair effect results in that the influence of damaged DNA saturates in the long term. The risk decreases in a short time by decontamination etc. So, I would like to receive the results of this evaluation as a conservative value.

In addition, as a clue to consider the reliability of this evaluation result, the author found the notes that the natural generation amount of DNA damage is 10,000 to 1 million pieces/cell/day and that DNA damage due to radiation is 0.04 strand-cleavage /cell/mSv/day (United States NCRP), in "Unified basic data on health effects of radiation"[14] compiled by the Ministry of the Environment and NIRS. These values will not contradict the data referenced in the present paper.

6. Conclusion

The author would like to mention a little about the correspondence after the nuclear power plant accident in March, 2011. After the accident, there were various remarks such as the optimistic opinion about radiation influence that it was okay even in 100 mSv and the pessimistic one that there was an influence in 1 mSv. The Government responded in accordance with the advice of the ICRP and the IAEA. However, it is unavoidable that people ignorant of radiation or parents with children will be more likely to put their trust in stringent standards, aiming to greater safety. For the criteria for evacuation orders, ICRP has recommended at an appropriate level of 20 -100 mSv/y, and the government has taken a minimum of 20 mSv/y. In addition, the decontamination area with the government support was also permitted to be above 1 mSv/y, while that value was a long-term target. As a result, the project became a tremendously big scale, it takes a lot of time of 7 years and money of 2.9 trillion yen to execute the project, and a large amount of decontamination wastes of 160 m$^3$ were accumulated in Fukushima [15]. Thus, it is undeniable that the desires to return of the inhabitants have withered completely.

Recently, the dose distribution become lower than 10 mSv/y even in place of high dose rate in Fukushima. It would be nice, if residents could be positive about their return by recognizing that the risk of $2.7 \times 10^{-7}$ and is two orders of magnitude lower than the risk of a recent traffic accident, if estimated from the risk of gradual exposure of 10 mSv/y where spatial radiation dose rate is correspond to 2 microsievert per hour, estimated with an old manner to have a tendency of 2-5 times overestimate of exposure dose. Although we do not know how much the risk of radiation exposure can be accepted in Japan where the concept of risk is not permeated, I would like to emphasize that the principles of the radiation protection according to ALARA will improve the present stagnant. ALARA is an acronym used in radiation safety for “As Low As Reasonably Achievable. The ALARA radiation safety principle is based on the minimization of radiation doses and limiting the release of radioactive materials into the environment by employing all “reasonable methods.

The author would also like to hope people and governments to use the present risk factor as a standard of judgment in such cases.
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