Chapter 42

Radiation Disasters and Their Health Effects

Field of expertise: Radiation Science

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Summary

Radiation disasters, which occur less frequently than natural disasters, pose the risk of exposure across national and prefectural borders when large-scale disasters occur. It is highly expected that promoting radiation education contributes to disaster prevention and mitigation through fostering both human resources who can respond to radiation disasters and a society that prevents reputational damage based on correct understanding. It is required as the future tasks to elucidate and accumulate the scientific knowledge about radiation effects especially in low dose areas for which knowledge is currently lacking, to further the development of radiation education.

Keywords: radiation disaster, nuclear power plant accident, deterministic effect (tissue reaction), stochastic effect, low dose/low dose-rate exposure, medical exposure, radiation education

Introduction

The effects of radiation exposure on the human body are understood based on the lessons learned from past radiation exposure cases. It is necessary to accurately evaluate the exposure dose and dose rate when a radiation disaster occurs and to investigate the relationship of biological and health effects with radiation exposure. It is difficult to conclude the radiation effects of low-dose areas by epidemiological studies alone, and verification by the experiments using state-of the-art life science technology is also required.

1: Problems Revealed by the Great East Japan Earthquake

What happened?

Nuclear power generation utilizes a fission reaction between uranium-235 contained in nuclear fuel and neutrons, and the neutrons emitted from this reaction react with other uranium-235 to induce fission in a chain reaction. If the number of neutrons becomes excessive, nuclear fission will go out of control, resulting in a large-scale radiation disaster such as the Chernobyl nuclear accident. Therefore, control rods that absorb neutrons are used to control the fission to react within an appropriate range. When power generation in the nuclear power plant is suddenly stopped due to a natural disaster or other reason, electric power is required to function both the control rods and the cooling system in order not to leak radioactive materials outside the reactor.

The 2011 off the Great East Japan Earthquake caused a shaking with a seismic intensity of 6-upper in the area where the Fukushima Daiichi Nuclear Power Plant (FNPP) was located. FNPP lost its external power supply due to the collapse of the steel tower from the shaking caused by the earthquake, but Tokyo Electric Power Company (TEPCO) reported that the power supply from the emergency power generation triggered an automatic shutdown system for all the reactors that were operating at the time of the earthquake. However, FNPP finally lost all the power supply due to the tsunami that arrived about 50 minutes after the earthquake, and the reactor cooling function in the two emergency shutdown systems stopped working. As a result, the core was damaged from the temperature rising and a large amount of hydrogen was generated. In addition, the increased pressure caused the structure to distort, resulting in radioactive materials and hydrogen leaking into the reactor building. Because of the ventilation system reducing the pressure inside the building and the hydrogen explosion, radioactive materials were released into the environment from the reactor building resulting in a radiation disaster. In this way, the FNPP accident became a multi-hazard disaster in which a natural disaster indirectly caused a radiation disaster.

The reality of the damage

The International Atomic Energy Agency (IAEA) and the Organization for Economic Co-operation and Development/the Nuclear Energy Agency (OECD/NEA) classify abnormal events and accidents at nuclear facilities into seven levels according to their severity by the International Nuclear Event Scale (INES). The FNPP accident was considered to be the level 7 serious accident which is the same level as the Chernobyl accident. However, the total amount of radioactive material released by the FNPP accident is $77 x 10^{16}$ becquerels (Bq), which is about 6.8 times less than that of the Chernobyl accident ($520 x 10^{16}$ Bq). In the Chernobyl accident, the nuclear fission went out of control and the nuclear fuel fragments were released into the environment. By contrast, in the FNPP accident, radioactive materials leaked from the reactor were released into the environment and suppressed the release of fuel fragments. It is thought that this was the cause of lower release of radiation in the FNPP accident.

2: Paradigms Destroyed by the Earthquake

Conventional wisdom and necessary responses

Human health effects of radiation exposure are estimated with reference to the epidemiological surveys of past radiation exposure cases. The Life Span Study (LSS) of atomic bomb (A-bomb) survivors of Hiroshima and Nagasaki is the representative epidemiological survey, which was conducted on a large-scale and continuously. The result of LSS has been referenced by various international organizations as an international gold standard.

Radiation effects are classified into two types, one is the deterministic effect (tissue reaction) and another is stochastic effect. The deterministic effect appears under exposure to a certain dosage (threshold dose). Symptoms become worse as the exposure dose increases. On the other hand, the stochastic effect has no threshold dose and its incidence increases as the exposure dose increases. The symptom will not appear when radiation-induced damage can be repaired in the cells constituting tissue and organs, while the symptoms will appear as a deterministic effect when radiation induced cell death due to the residual irreparable damage. The worsening of symptoms with dosage in the deterministic effect is thought to be due to the increasing radiation-induced cell death. In the case of the stochastic effect, if cells with radiation-induced gene mutation survive, such cells potentially have a risk to be the origin of radiation-induced carcinogenesis by accumulating other changes. The mortality analysis of LSS revealed that cancer mortality increased from the range exceeding 100 mSv compared to spontaneous cancer mortality, and the mortality subsequently increased depending on the exposure dose. It is internationally agreed that it is difficult to estimate the risk of radiation carcinogenesis using epidemiological data in the dose range of less than 100 mSv because the incidence of radiation carcinogenesis less than 100 mSv is similar to that of spontaneous carcinogenesis. Therefore, from the viewpoint of radiation protection, the risk of radiation carcinogenesis of less than 100 mSv is estimated by a linear non-threshold model (LNT model) extrapolated from the data in the high dose range.

Childhood thyroid cancer increased in the Chernobyl accident. Since the distribution of foods such as milk contaminated with radioactive iodine was not restricted, the radioactive iodine taken into the body accumulated in the thyroid gland and caused internal exposure. The internal exposure dose was estimated to be 300 mSv or more, and exposures exceeding 1 Sv (= 1,000 mSv) were also reported.

The risk of health effects can be suppressed by reducing the exposure dose when a radiation disaster occurs. “Low dose” is often defined as 200 mSv or less. Since the threshold dose for the deterministic effects was set as 500 mSv, it is important to focus on reducing the risk of the stochastic effects such as leukemia and solid tumors in case of low dose exposure. Therefore, the monitoring is necessary to limit the distribution of food contaminated with radioactive substances resulting in reducing internal exposure.

3: A New Approach

Evacuation orders after the FNPP accident and restrictions on the shipment of foods that exceed the standard values are effective to reduce radiation exposure, and these are lessons learned from the Chernobyl accident. According to the Fukushima Prefectural Health Survey, 99.8% of the survey subjects, excluding those who have experience in radiation work, reported that the external exposure dose was 5 mSv or less (average 0.8 mSv, maximum 25 mSv), which is a lower dose than the threshold dose for the deterministic effects. This is consistent with the fact that no deterministic effects from the accident have been reported so far, indicating the importance of reducing the exposure dose when a radiation disaster occurs.

The inspection of meat contamination was always conducted after the livestock were slaughtered; therefore, the meat contaminated in excess of the food standard value must be disposed of. In addition, all livestock in the evacuation area (ex-evacuation zone) designated after the FNPP accident were euthanized. If it can be determined before the livestock are slaughtered that the contamination of edible parts exceeds the standard value, excretion of the radioactive substances from the body can be promoted by feeding non-contaminated, clean feed, and as a result, the meat can be shipped after the contamination decreased to below the standard value. We have established a technique for estimating the concentration of radiocesium in the muscles by counting from the surface of living cattle using the NaI survey meter. In addition, we obtained experimental findings that can estimate the feeding period of non-contaminated clean feed required for radiocesium to excrete below the standard value from the ratio of radiocesium concentration in blood and in muscle as well as the biological half-life (Suzuki et al., 2019). The practical application of this technology is expected to contribute to animal welfare because it can avoid unnecessary slaughter when radiation disasters occur, in addition to ensuring food safety.

Analysis using the plasma of cattle living in the ex-evacuation zone revealed that oxidative stress slightly increased. We also succeeded to evaluate the changes in antioxidant capacity, which is expected to be related to increasing oxidative stress, by the i-STrap method using electron spin resonance (Sun et al., 2018). Since it can be evaluated with a small amount of blood, it is expected to be put to practical use in triage, health effect evaluation, and estimation of exposure dose when a radiation disaster occurs.

4: Achievements and the Future

A new approach to disaster science

Through the experience of the public lecture held in Fukushima City after the FNPP accident and the nuclear accident consultation in the office of Miyagi Prefectural Government, it seemed that the general public had many misunderstandings related to radiation exposure at the time of the FNPP accident. It was strongly realized that the dissemination of correct and fundamental knowledge is an urgent issue to prevent reputational damage (Chida, 2019). Promoting medical exposure-related research is indispensable for low-dose exposure research as an important research platform. In addition, the ongoing research of wild Japanese macaques living in the ex-evacuation zone is expected to provide insights to further understanding of the low-dose radiation effects on the human body.

Conclusion - from the author

Unnecessary exposure during a radiation disaster should be avoided, but after a radiation disaster, there may be factors that bring about social changes such as low-concentration radioactive substances remaining after decontamination and treatment of tritiated water. Since there is no such thing as zero-risk in many events, including radiation, building acceptable risk standards based on accurate information can become the driving force for reconstruction from radiation disasters.

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