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1 Peaceful Use of Radiation and SDGs

Sustainable Development Goals (SDGs) are development goals adopted in the UN Summit which was held in September 2015. Recently, SDGs are becoming more popular among young generations. As you know, since the Japanese Government promotes actions to achieve SDGs, we have many opportunities to recognize SDGs as “my own issue” through elementary school, junior high school and universities as well as companies and local government. The year 2023, when I am writing this article, corresponds to just in the middle year between the adopted year (2015) and the goal year (2030) of SDGs. This is why, SDG Summit 2023 attracts attention to review the perspective of SDGs, which is held at UN Headquarter for the first time in 4 years.

Although SDGs are thus getting popular and well recognized in public, some people don’t get it when they hear SDGs are related to peaceful use of radiation. This article is to show you the International Atomic Energy Agency (IAEA)’s activities aiming to achieve SDG goals through use of radiation/nuclear power, since I have been engaged in the IAEA until recently.

Even in Japan, we often hear the IAEA’s activities such as inspections to the Zaporizhzhia Nuclear Power Plant, IAEA Comprehensive Report on the Safety Review of the ALPS-Treated Water at the Fukushima Daiichi Nuclear Power Station. Based on its professional expertise, the IAEA develops many activities not only in the field of nuclear power but also in the other fields.

I have been engaged in the activities of the IAEA Technical Cooperation Department for 3 years from 2020. And I had an opportunity to recognize the IAEA’s wide range of activities in no time. As 2020 was the start year of COVID-19 pandemic, the IAEA Director General (DG), Rafael Mariano Grossi, immediately established the Zoonotic Disease Integrated Action (ZODIAC) initiative to help countries prevent pandemics caused by viruses that originate in animals and can be transmitted to humans. This initiative has provided Real Time RT-PCR which is a nuclear-derived method for detecting the presence of COVID-19 virus. I was amazed by the IAEA’s quick action and extensive field of activities.

As the IAEA is placed as the specialized agency in the nuclear field within the United Nations family, it facilitates support to the Member States, paying attention to achievement of 2030 Agenda, one of the UN action plans. While SDGs are composed of 17 goals and 169 targets, the IAEA advocates direct contribution to 9 out of 17 SDG goals (SDG 2, 3, 6, 7, 9, 13, 14, 15 and 17), using Nuclear Science and Technology (NST). Let’s have a look at the IAEA’s international cooperation for each SDG below.

SDG2— Zero Hunger

The IAEA contributes to improvement of food security and agriculture, collaborating with the Food and Agriculture Organization of the United Nations (FAO). For example, the IAEA assists the Member States to introduce the Sterile Insect Techniques (SIT) to protect crops by releasing sterilized mass-reared males that cannot produce offspring, which leads to reduction the number of insect pests. Furthermore, the IAEA helps the Member States to breed new plant varieties by irradiation, which are drought tolerant and/or disease resistant.

SDG3—Good Health and Well-being

To reduce deaths from noncommunicable diseases such as cancer, the IAEA helps the Member States strengthen nuclear medicine, radiation oncology and radiology facilities, as well as provide education and training to medical staff. Above all, under the “Rays of Hope” initiative, advocated by the DG in 2022, the IAEA helps low- and middle-income countries mostly in Africa strengthen radiation safety and regulatory infrastructure to increase access to cancer care, as well as provide guidance, technical advice, training and equipment.

SDG13—Climate Action

Nuclear technologies play a key role in climate change mitigation. Since nuclear power does not generate carbon dioxide during operation, which is regarded as clean energy. The IAEA works to increase awareness of the role of nuclear power in reducing greenhouse gas emissions and in the other applications of nuclear energy such as hydrogen production, and assists countries to adapt to the consequences of climate change through the development of crops with increased resilience.

SDG14—Life below Ocean

To sustainably manage and protect oceans, in turn, support coastal communities, the IAEA assists marine monitoring using nuclear and isotopic techniques, and promotes technical cooperation and better understanding so that the Member States can use nuclear-derived technologies to tackle with the ocean phenomena such as ocean acidification, harmful algal blooms and microplastic pollution. In particular, the IAEA Marine Environmental Laboratories in Monaco help many countries use isotopic techniques such as marine plastic tracing and impact assessment of marine lives to address plastic pollution in the oceans, which is mainly through the NUclear TEChnologies for Controlling Plastic Pollution (NUTEC Plastics) initiative, advocated by the DG in 2021.[1]

SDG15—Life on Land

Desertification, degrading land and eroding soils can jeopardize agriculture and livelihoods in developing countries. The IAEA supports the Member States by accurate assessment of soil erosion using isotope techniques, providing tools to reverse land degradation and restore soils.

In this way, the IAEA's field of activities covers not only nuclear power but also other fields related to atoms for peace and development such as food, health care, soil and marine environment. Although I was not so conscious of such a broader field of activities when I was in charge of radiation in Japan, the experience in the IAEA has made me conscious of peaceful use of radiation/nuclear power. I hope this article provides you the opportunity to recognize SDGs as "your own issue".

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[1] This initiative also assists the Member States in plastic waste recycling by radiation technology as well as marine plastic monitoring.

2 Radiation Risk for Diseases of the Circulatory System

Recommendations by the International Commission on Radiological Protection (ICRP) have been the basis of national radiation protection regulations and standards implemented in Japan and many other countries. ICRP reviews the radiation protection system, taking into account scientific developments and social situations. This paper briefly explains why ICRP came to recommend a threshold dose for diseases of the circulatory system (DCS) in 2011, significance of the recommendation, and recent relevant developments.

ICRP has always considered, since the 1950s, that the ocular lens, bone marrow and gonads represent among the most radiosensitive tissues, whereas ICRP had considered, by the 1980s, that the circulatory system is not highly radiosensitive because radiation effects occur after radiotherapy at fractionated doses of >40 Gy. However, in the 1990s, the excess risk of DCS mortality at ≥2 Gy was reported in Japanese atomic bomb survivors [1], and therefore ICRP put DCS risks on the radar. A paper came out in 2010 that reported the excess risk of DCS mortality at ≥0.5 Gy [2], leading ICRP to classify DCS as tissue reactions and recommend a threshold dose, in 2011 for the first time [3]. Non-cancer effects that are assumed to exhibit threshold-type dose-response relationships and are considered attributable to injury in populations of cells are referred to as tissue reactions (called “deterministic effects” in the 2007 general recommendations [4] or earlier), and equivalent dose limits have been recommended to prevent its occurrence. ICRP recommended 0.5 Gy as a threshold for DCS, assuming that 1% of exposed individuals develop cardiovascular and cerebrovascular diseases, respectively, >10 years after exposure of the heart and the brain to 0.5 Gy independent of the rate of dose delivery. However, this recommendation was intended to serve as a precaution to medical practitioners, and dose limits were not recommended: this was because effects at low dose, mechanistic underpinnings and target organs remain uncertain.

ICRP justified 0.5 Gy as the 1% level dose, given the meta-analysis excess relative risk per unit absorbed dose (mERR/Gy) of 0.10 (95% confidence intervals (CI): 0.07, 0.13) for DCS incidence that was based on the four studies and described in the 2010 report [5], and natural baseline incidence of 30–50%. It can be considered still valid, because the paper published in 2023 reported mERR/Gy of 0.09 (95% CI: 0.05, 0.13) for DCS incidence. On the other hand, regarding DCS mortality risk, the 2010 report [5] described mERR/Gy of 0.08 (95% CI: 0.04, 0.12) based on the 8 studies that is similar to mERR/Gy for DCS incidence, but the 2023 paper [6] described mERR/Gy of 0.20 (95% CI: 0.13, 0.26) based on the 54 studies that doubled mERR/Gy for DCS incidence. Save a single study [7], cohort studies with long follow-up have not found significant dose thresholds, and it also remains unclear whether injury in populations of cells underlie DCS. This necessitates further discussions as to whether classification of DCS as tissue reactions and its threshold of 0.5 Gy are sound, and how we consider differences in DCS risks between incidence and mortality.

ICRP has considered that there is no dose protraction effect for DCS (i.e., dose protraction does not change the magnitude of effects) [3]. However, the meta-analysis of the 93 epidemiological studies showed that mERR/Gy in descending order of low dose rate exposure > acute exposure > fractionated exposure [6], and the rodent study has found the greater magnitude of radiation damage to the aorta in descending order of exposure in 25 fractions > acute exposure > exposure in 100 fractions >> chronic exposure [8]: these studies suggest that dose protraction effects are not a simple function of dose rate or the number of fractions. Taken together, it has been shown that ERR/Gy for DCS at lower dose is greater than that at higher dose [9,10]. This thence necessitates further discussions as to how we consider the potential difference in effects with dose and dose rate.

The threshold doses that ICRP recommended in 2011 were 0.5 Gy for both of the lens and the circulatory system [3], so the circulatory system can be considered as highly radiosensitive as the lens. However, DCS pathophysiology and cells that populate the circulatory system are diverse, and mechanisms are uncertain. Increased radiation risks for ischemic heart disease have been observed in various western cohorts, and atherogenesis caused by chronic vascular inflammation has been proposed as a potential mechanism [11]. Hypertensive diseases, however, dominate in atomic bomb survivors, and mechanisms behind DCS other than ischemic heart disease hence need to be studied. Proposed candidate target organs include the heart, large blood vessels (e.g., aorta, carotid), kidneys and pancreas, but consensus has yet to be reached [11].

There are ongoing clinical trials of radiotherapy for ventricular tachycardia (a life-threatening arrhythmia), whilst elevated radiation risk of arrhythmia has been reported in the cohorts of radiotherapy patients and radiation workers. As such, radiation may represent a double-edged sword not merely for cancer but also for DCS, so that justification of radiation exposure and optimization of protection would be required for the circulatory system [12,13].

ICRP aims to publish the next set of general recommendations in the 2030s that supersede the 2007 general recommendations [4], and has initiated relevant discussions. Concerning DCS, Task Groups 111, 119 and 123, respectively, are discussing issues in relation to inter-individual differences of radiation sensitivity, implications of scientific evidence for radiation protection, and radiation effect classification. These outcomes are considered to serve as building blocks for the next set of general recommendations, and accordingly it is important to keep a close watch on ongoing discussions.

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3 Types and Roles of Safety Systems in Accelerator Facilities

The radiation generator, i.e., the particle accelerator, was invented in the first half of the 20th century for nuclear physics research and has progressed significantly up to the present. Today, accelerators are utilized not only in nuclear physics but also across various research fields, as well as medical and industrial applications. Before using accelerators regulated by Acts and Regulations [1], specific permission from the Nuclear Regulation Authority is required. Therefore, accelerator facilities must adhere to strict standards for radiation safety.

The safety systems in accelerator facilities vary based on the type, energy, and usage of the radiation. However, the primary goal of radiation safety management is to prevent hazards and ensure public safety, similar to facilities handling radioisotopes. This article introduces some safety devices commonly used in accelerator facilities for radiation safety.

Interlock System – Automatic Display Device

The law mandates the installation of interlock systems to prevent unintentional entry into the accelerator room. Additionally, automatic display devices at the entrance must indicate when the accelerator is in use.

Usually, accelerators are equipped with interlocks that allow the beam to be generated only when several conditions are met. Interlocks serve not only for radiation safety control but also to safeguard the entire accelerator from failure. For example, they ensure a safe shutdown of the accelerator in the event of abnormal situations caused by operational errors or malfunctions in certain equipment.

Access Control Device – Confinement Prevention Device

The access control device for the radiation-controlled area is linked to the interlock system. No one can enter the room during a beam being generated and a beam cannot be generated during someone entry into the accelerator room. If someone ever gets trapped, emergency escape is possible from the accelerator room. Many facilities have emergency stop buttons and safety switches inside the room.

Radiation Monitor

Accelerator facilities are designed so that the radiation generated by the accelerator does not escape from the controlled area. Even after operation, targets, slits, and beam dumps may become radioactive. In high-energy accelerator facilities, radioactivation of equipment, walls, air, and cooling water can be a serious concern. Radiation monitors are installed to measure the dose, reducing the risk of radiation exposure and preventing the release of activated materials externally. This is often one of the conditions of the interlock system.

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[1] Radiation generator as used in the Acts and Regulations means equipment which generates radiation by accelerating charged particles such as cyclotrons, synchrotrons, etc., which is prescribed in Cabinet Order (excluding those whose maximum dose equivalent rate at the position 10 cm away from the surface is not more than 600 nSv per hour).

Other Radiation Measuring Devices

Similar to facilities handling radioisotopes, radiation workers must wear personal dosimeters when entering controlled areas in accelerator facilities. Additionally, other radiation measuring devices may be used, including hand-foot-cloth monitors to measure radioactive contamination on personnel leaving controlled areas and alarm meters to prevent unplanned radiation exposure.

Inspection and calibration of radiation measuring instruments were mandatory in 2023. However, inspections of other safety devices are also crucial. Although some safety devices are seldom used in daily accelerator operation, periodic inspections are necessary to ensure proper functionality in emergencies.

These safety devices work effectively only when used correctly by radiation workers. During facility training sessions, each worker should carefully go through the safety management system. It is also important to anticipate potential risks associated with tasks and understand how to respond to issues.

Up to this point, my focus has been on radiation safety systems. However, accidents related to radiation are exceedingly rare in accelerator facilities; other types of accidents are much more common.

The University Museum, the University of Tokyo, has two Van de Graaff accelerators: a 5MV tandem accelerator at MALT on the Asano campus and a 500kV tandem accelerator at the main museum on the Hongo campus. The 5MV tandem accelerator at MALT is a radiation generator regulated by the Act and Regulations and is located in the controlled area surrounded by thick concrete and steel shielding doors [1]. In contrast, the 500kV tandem accelerator at the main museum is exempt from the Act and Regulations due to its low radiation dose and energy. As a result, it is located in a glass-walled exhibition room, not in the controlled area, allowing visitors to easily observe its operation. Although the 500 kV tandem accelerator doesn’t pose an inherent danger as a radiation generator, both accelerators have ion sources with high voltages and electromagnets with high currents, which can be extremely hazardous if touched accidentally. Moreover, the beamlines, equipment, and racks are heavy and require careful handling. Furthermore, there are narrow areas, steps, and projections around the accelerators that may also have a risk of injury.

To use accelerators safely, just like any other experimental equipment, it’s important to understand potential hazards fully. Before operating an accelerator, read the manual and instruction carefully and receive proper guidance from experts familiar with the equipment.

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4 The Approach to Management in Small Quantity Nuclear Fuel Facilities

Among radioactive substances, materials such as uranium, thorium, and plutonium, which release high energy in the process of nuclear fission, are defined as nuclear fuel materials by the Nuclear Reactor Regulation Act. Moreover, because nuclear fuel materials can also be used in the production of nuclear weapons, the International Atomic Energy Agency (IAEA) carries out management of these materials internationally. Therefore, these materials are also called “internationally controlled materials” and together with related equipment are defined as international regulated items. To use these nuclear fuel materials, permission (or approval in the case of national university corporations) must be obtained from the Nuclear Regulation Authority.

Facilities that use nuclear fuel materials are classified as J facilities or K facilities based on the types and quantities of nuclear fuel materials that they can use. As shown in Table 1, facilities that use only a small amount of nuclear fuel materials are classified as K facilities, while others are classified as J facilities. As of 2023, the University of Tokyo has 2 J and 14 K facilities. Natural uranium mentioned in Table 1 refers to uranium that is naturally occurring, with a U-235 isotope composition of 0.720%. In contrast, depleted uranium has a lower U-235 isotope abundance, around 0.2%, compared to natural uranium.

This article explains the handling of nuclear fuel materials in K facilities, which are facilities that use only a small amount of nuclear fuel materials.

To ensure proper management of nuclear fuel materials, the Nuclear Reactor Regulation Act requires the creation of accounting provisions in advance. Nuclear materials accountancy administrator and appropriate persons should make sure that these provisions are readily available for review and ensure that their contents are communicated to nuclear fuel materials users.

Accounting provisions mainly include the following:

- Position and role of the nuclear materials accountancy administrator.
- Location of the nuclear fuel Material Balance Area (MBA) where nuclear fuel materials can be used.
- Records of receipts, shipments, and disposals.
- Inventory.
- Reporting to the Nuclear Regulation Authority.

In K facilities, it is necessary to submit nuclear fuel materials management report to the Nuclear Regulation Authority twice a year (1st half from January to June, 2nd half from July to December). This report should detail the inventory changes during the reporting period, which means how much material was received or shipped during that time.

Points to note when using nuclear fuel materials:

Workers should:

- Workers should record the quantity to decimal places (no rounding) each time they use, receive, or ship materials.
- Monthly, an inventory of the quantity by compound and supplier country should be recorded.

Table 1 Nuclear fuel materials that can be used in K facilities.

Uranium (U)		Thorium (Th)
Natural uranium	Depleted uranium	
Lower than 300 g.		Lower than 900 g.

- Safe handling and disposal methods should follow the instructions of the MBA's management (since there is no disposal mechanism for nuclear fuel materials, they must be stored within the department).
- Consult with the nuclear materials accountancy administrator before receiving or shipping materials to other departments or external entities (other MBAs). When receiving, submit a nuclear fuel material transfer report or a copy of it in accordance with the MBA's management instructions.

Nuclear materials accountancy administrators should:

- Conduct monthly inventory for each compound and supplier country, as stated in Accounting Provisions Article 8. If workers conduct the inventory according to the MBA's policy, the nuclear materials accountancy administrator should confirm the completion.
- A nuclear fuel material transfer report should be created and exchanged when receiving or shipping materials between K and J facilities.
- Create a nuclear fuel material management report in July and January and submit it to the Division for Environment, Health, and Safety.
- Consult with the Division for Environment, Health and Safety before making changes to accounting provisions or the nuclear fuel materials used.

Points to note when receiving and shipping materials include:

When receiving nuclear fuel materials, ensure that the type, supplier country, and quantity of the total amount of receiving materials with existing inventory do not exceed the amount approved by the Nuclear Regulation Authority.

When moving nuclear fuel materials between K facilities, it is not necessary to exchange nuclear fuel material transfer reports, it needs to confirm the total amount of receiving nuclear fuel materials plus existing inventory does not exceed the amount indicated in Table 1. When moving nuclear fuel materials between K and J facilities, it is necessary to exchange nuclear fuel material transfer reports. Normally, the format of the J facility's nuclear fuel material transfer report is used for creating these reports. However, the Division for Environmental, Health, and Safety can provide templates if needed.

Workers using nuclear fuel materials should not receive them without consulting the nuclear materials accountancy administrator in advance. Similarly, for shipment, confirm with the nuclear materials accountancy administrator before proceeding.

Finally, when using nuclear fuel materials, it is essential to adhere to established rules and manage the materials according to accounting provisions, including keeping accurate records in the inventory. This responsibility applies not only to nuclear materials accountancy administrators but also to workers of nuclear fuel materials.

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5 Characteristics of X-rays and Radiation Safety of X-ray Generators

X-rays, a type of photon radiation, are produced in an X-ray generator by hitting an appropriate material with high-speed accelerated electrons. X-rays have higher energy than ultraviolet rays, so strong X-rays, like other radiation, can have effects on living organisms through the formation of radicals. Therefore, when X-rays are used for research or other purposes, it is recommended that the workplace be monitored before, during, and after the work to check the radiation situation. In addition, it is known that even when periodic radiation measurements are considered “leak-free” by technical contractors, leaks can be easily detected. It has also been noted that one day significant radiation was inadvertently detected in a location that no one had imagined, and additional shielding was installed. Do you know where and how much radiation is actually present when you use an X-ray machine?

In recent years, the design of the X-ray generators available on the market has made them much safer. On the other hand, no matter how good the technology, there can be safety hazards in areas that are not related to the technology. It is important to recognize that there are not only “unintentional” accidents, where a user is too focused on something and fails due to lack of awareness or poor judgment, but also “reckless” accidents, where safety is sacrificed for the sake of work efficiency and results. University faculty and staff have a duty to protect students. One of the characteristics of a university is that it is a very special organization with a high degree of human mobility, and members who are immature as researchers and professionals may be engaged in risky work. It will also be important not to leave everything to safety devices and related systems, but to be aware of their possible malfunctions and failures, and to systematically check their functioning. Continued use of older equipment will require special care and attention. It is important to pass on a culture of safety from one generation to the next and to share problematic cases horizontally. In addition to pre-work safety training, it can be effective to actively demonstrate safety measures in daily activities, such as lab tours for visitors. In accordance with IAEA safety requirement, your university has already implemented a “graduated approach” for the management of x-ray generators. This is a very well-designed safety management method that is expected to become a standard in Japan in the future, and I hope that you will refer to the compact explanation in the FY2019 refresher material (to be reprinted in FY2023) and use it for further environmental management related to x-ray use.

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