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Radiation: An Energy Carrier

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Preface to English Edition

After nuclear accidents such as Three Mile Island in USA, Chernobyl in Ukraine, and Fukushima Nuclear Power Plant in Japan, many people were evacuated and lost their homes, because of radioactive fall-out from the damaged reactors. Even today, a number of people cannot return to the places they lived before the accident. Although the initial impact of the accidents was quite large, the harm caused by exposure to radiation seems gradually disappearing. Nevertheless, these accidents make people more nervous of the exposure to radiation. The number of people who feel that radiation is "scary/fearful" has increased, along with the number of people who refuse to accept nuclear power plants. In fact, all of the nuclear power plants in Japan were stopped for several years after the Fukushima accident at 2011. At that time, a shortage of electricity could be avoided, because the electricity generated by the nuclear plants has been replaced by that generated in thermal power plants burning coals and oil. The coal and oil plants are not desirable due to environmental impacts and resource issues, but people accepted this provisional measure.

In recent years, due to concerns about global warming, many governments have decided not to build new power plants burning coal and tried to replace them with renewable energy mostly solar cells and window power. Any power source has disadvantages or creates some risks. The number of people who is affected by global warming is far larger than the number of people who suffered in nuclear accidents. Generally, the negative effects or demerits of using powerful technology necessary to sustain modern civilization seem to be compensated by insurance. The typical example is traffic accidents; the number of people involved is quite large. Nevertheless, most people accept the risk of traffic accident and compensate their potential harm by money from insurance. On the other hand, the risk to use nuclear power seems to be discussed on completely different base from other risks accompanying with utilization of energy or power. Many people refuse to accept nuclear reactors. Probably that is because they are afraid of after-effects of exposure to radiation which could appear for themselves later, on their children through influence of genes, cancer risk in offspring and so on, which most people believe, cannot be covered by insurance.

Utilization of large energy or power always accompanies some risk when the energy or power is released by accidents in a different way from the original purpose. Therefore, the risk should be shared by the beneficiaries. One of the main reasons for hesitating to use nuclear power is that people have not accepted this principle, or the risk of radiation is considered to be an exception from the principle. There seem two major reasons for that. One is that people fair "radiation" without having clear reason. The other is that "radiation" is mysterious and it is difficult to evaluate the risk, i.e., what kind of effects occur and how the effects of the radiation exposure appear.

Therefore, it is quite natural that there are pros and cons on the acceptance of nuclear energy. Unfortunately, the debate is often conducted without sufficient knowledge or correct understanding of radiation. The debate should consider long-term energy security with sufficient knowledge or correct understanding of radiation.

Based on above-mentioned general background, the first Japanese edition of this book was published aiming at assisting readers (1) to understand "radiation," i.e., what radiation is or means and why radiation is dangerous, (2) to get correct understanding that the radiation is carrying energy, and (3) to accept that the radiation is not "scary" but "dangerous but controllable and useful." Hopefully, this English translation will help readers to do so. Chinese translation will be also published by University of Science and Technology of China Publishing House as ISBN 978-7-312-05302-3.

The author very much appreciates Dr. Richard More for his review of English writing.

Osaka, Japan Tetsuo Tanabe
February 2022

Preface

The purpose of this book is to explain "radiation" from somewhat different viewpoint than the traditional images like "radiation is incomprehensible, scary, fearful, dangerous, hazardous, etc.," and to give a more accurate understanding that the radiation carries energy, and to help people realize that the radiation is not "scary" but rather "dangerous but well-understood, controllable, and can be useful to humanity."

Many introductory books or textbooks have been published on subjects such as radiation physics, radiochemistry, radiobiology, and radiolysis. In recent days, information about radiation can be obtained very easily on various websites. Some of these books and websites are listed in bibliography at the end to this book. The author has obtained useful information from these sources. Nevertheless, there are not many books that discuss the effect of exposure to radiation, based on the idea that radiation carries energy and the exposure to radiation means that energy is deposited or absorbed in an exposed object. In many published books, the biological effects of the exposure to radiation are the main themes using a specified term of "absorbed dose," "dose equivalent," or "equivalent dose," which often enhances the feeling that "radiation is scary." Furthermore, the effects caused by a lower dose of the radiation exposure that are difficult to see are often not discussed.

The aim of this book is to help readers to understand "radiation" from a broader viewpoint, focusing on the fact that radiation carries energy, and deposits energy in an exposed object. What effects appear after the exposure and why these effects appear are quite differently depending on characters or properties of the object.

Although the contents may be not easy to understand without knowledges of mathematics, chemistry, and physics, as taught in high school, the author tries to explain or describe radiation science as simply as possible and to give correct information for understanding radiation.

Chapter 1 describes what is written in the book, in particular, what "radiation" is or means. The following chapters provide detailed descriptions necessary to correctly understand radiation. All chapters are to be independent for easy reading so that readers can start with any chapter among Chaps. 2–9 with free choice. It is not necessary to read them sequentially.

Chapter 2 explaines that radiation is consisting of high energy particles and/or electromagnetic waves referred as energetic quanta (EQ) or quantum particles. Accordingly, in the most of the book, "radiation" is referred as EQ. In Chap. 3, details of EQ sources are described. Chap. 4 shows the effects of EQ exposure mostly appears as damage in objects, and this is discussed separately for inorganic and organic materials, and for living beings, based on physical and chemical processes of damaging and recovering. Chapter 5 describes reduction of absorbed dose including shielding and decontamination. The detection and measurement of EQ, which are essential for the discussion of EQ, are summarized in Chap. 6. Chapter 7 provides examples of how Q are used in various fields in view of the theme of this book, "radiation carries energy." In Japan, the use of EQ in the medical field is progressing, and the average absorbed dose of EQ for medical purposes has reached more than half of the annual EQ exposure in nature. Details of the medical use of EQ can be found in many books published (some are listed at the end).

Once the readers have understood that radiation consists energetic quanta (EQ) and carries energy, they note an interesting connection with the history of life on the earth and energy storage and consumption, which is described in Chap. 8. The development of living beings in the earth's history has been influenced by EQ from the sun. Chapter 9 describes "energy and radiation" focusing on the energy sources and shows that risks accompany the utilization of all energy sources.

It should be noted that the use of solar energy is a use of "radiation," and that the sun itself and the Earth's atmosphere are converting high-energy radiation, which is dangerous to mankind, into low-energy and useful radiation.

The author also hopes that after reading this book, readers can agree that although radiation (EQ) is dangerous or sometimes toxic, it is controllable and should be used as a long-term energy source which will allow human beings continue to exist on the earth. Since utilization of nuclear energy as an energy source for the earth is realized in nature as solar energy, it is logical that nuclear power, either fission or fusion reactors, could be artificial energy sources if there is sufficient effort to ensure their safety. Nevertheless, it should be realized that when using a large amount of energy, some risk is always present. The risks have appeared as pollution and global warming caused by waste heat and exhaust gases from the power plants burning oils or coals. There is no doubt that nuclear energy can be used as an energy source in long term, but it is mandatory to consider how to handle the risks that go with it.

Osaka, Japan Tetsuo Tanabe
December 2017

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Chapter 1
Radiation Carries Energy

Abstract The main subject of this book is to introduce radiation as an energy carrier and being dangerous but controllable and useful. The purpose is to remove scary feelings on radiation, with making people understand what radiation is or means and why it is dangerous or hazardous. An additional target is to convince the readers that it is possible to avoid the radiation exposure and the radiation can be controllable and used beneficially as energy sources under safety regulations. The first chapter is the general introduction on what is written in this book.

Keywords Dose · Dose equivalent · Energetic quanta · Energy carrier · Exposure · Radiation

1.1 Is "Radiation" Scary?

Most people say that "radiation" is scary, or they fear it. However, if they were asked "why", little could answer and most would say "it is based on common knowledge", or "it is dangerous but we do not know why or what is the radiation". Or intellectual people may say "Because it is difficult to estimate what kind of and how effects appear on the radiation exposure to human beings".

There is no wonder that people fear the radiation when they see the appearance of damage on residents suffered by nuclear bombs in Nagasaki and Hiroshima, Japan, and world nuclear bomb tests in open air. They were exposed to the radiation with doses ranging from very low levels to over lethal doses. However, effects of the radiation exposure with the dose level of lower than 1 mSv hardly appear or are very much scattered from mostly nothing to a few in canceration for example.

After the accident at Fukushima Daiichi Nuclear Power Plant (Fukushima Nuclear Power Plant, Tokyo Electric Power Company), many residents were evacuated and lost their place to live. This makes people more nervous on the radiation exposure. Still, not a small number of the suffered residents could not come back to their places. Although the initial impact of the accidents was quite large, the direct impact of the radiation exposure seems gradually disappear. And the number of people directly influenced by the radiation exposure caused by radioactive materials released by the accident was not so large. Nevertheless, the accident makes people more nervous

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of the radiation exposure and the number of people who decline to accept nuclear power plants has increased.

After the accident, all nuclear power plants in Japan were stopped. Nevertheless, the shortage of electricity could be avoided because most of the electricity generated by the nuclear plants has been replaced by that generated by thermal power plants burning coals or oils which are not desirable due to environmental and resource issues but people have accepted.

Recent global warming is attributed to carbon dioxide (CO_2), though some scientists believe that it is not due to CO_2. The global warming is influencing the earth and will be more significant in the future. However, current people's concern on the burning fossil fuels seems much less compared to those on utilization of the nuclear power. Probably because any countermeasure to mitigate the global warming is believed to be taken. Does this mean that concerns on the global warming are less than those on utilization of nuclear power? Anyway, the purpose of this book is not to discuss what should be the energy sources, which are revisited in Chap. 9.

At the Fukushima accident, people lived within about 20 km from the Fukushima power plants or areas showing high radiation levels (air dose) were evacuated. The high air radiation dose area is distinguished from other areas based on absorbed dose rate or dose equivalent rate. In scientific fields handling radiation, such as medicine, health physic, radiobiology, radiology, and radiation chemistry, the term "**absorbed dose**" is used instead of "**absorbed energy**" to feature the energy given to living beings or specifically human beings by exposure of radiation using the unit of Gray (Gy). The absorbed dose equivalent given with the unit of Sievert (Sv) was introduced to normalize different effects of the kinds of radiation. These units are described in Sect. 1.2.4 in detail.

To avoid the radiation exposure is to keep away from radiation sources or materials including radioisotopes (RIs), or to install a shield that does not allow the radiation to pass through. Although the evacuation of residents near the Fukushima power plants was an unavoidable procedure, it was difficult to determine a critical absorbed dose rate above which the evacuation was required. (There is no so-called threshold in the absorbed dose rate to distinguish whether it is dangerous or not.) People tend to set the critical level to give less influence, even if it is too low. Ironically if the level was set lower, more people would fear the radiation exposure.

Often appeared is a rumor or misunderstanding that when a substance was exposed to radiation, it has been changed to be radioactive. This never happens and is completely wrong. The radioactivity is never transferred to the substance exposed to the radiation, totally different from the transfer of virus, the cause of disease. However, the rumor that people exposed to the radiation became radioactive unintentionally spread and those who believed the rumor being true often discriminates people evacuating from Fukushima. That is a very unfortunate event and should be avoided. Nevertheless, it is quite hard to delete the rumor once circulated and to convince people not to believe the rumor. One of the purposes of this book is to avoid such misunderstandings on the radiation.

There is no doubt that it is important to understand the radiation and correct understanding makes it possible to manage or handle the radiation safely. Nevertheless, it is

not easy to understand the radiation correctly or even to know whether one correctly understands it.

As for "radiation", many books have been published and some are listed at the end of this book as bibliography. Majority of the published books are on radiobiology and radiology discussing the biological effects of radiation exposure on living beings. The observable biological effects (damages and diseases) caused by the radiation exposure and the recovery of the damages and diseases are main targets. In most cases, the damages and diseases clearly observed are discussed. However, the effects caused by the radiation exposure starts in very tiny area with nm scales, and are hence invisible, until the damage area appears in cells and tissues. The processes to become visible damages are not explained well except the damaging processes in cells, in particular, DNA and genes. Therefore, the more one studied radiobiology, stronger impressions he would have that the radiation is scary. Once one feels scared on the radiation without any evidence, it is not easy to change his feeling by others. To avoid wrong rumors or misunderstandings on the effects of radiation exposure it is critically important to understand the radiation correctly, and the correct understanding makes possible to manage or handle the radiation safely. Nevertheless, it is not easy to understand the radiation correctly or even to know whether one correctly understands it.

Based on the above-mentioned background, the purpose of this book is to remove scary feelings on radiation, with making people understand what radiation is or means and why it is dangerous or hazardous. An additional target is to convince the readers that it is possible to avoid the radiation exposure and the radiation can be controllable and used beneficially as energy sources under safety regulations.

1.2 What is Written in This Book?

This book describes what is radiation or what radiation means, and the effects of radiation exposure on substances. The word "radiation" is generically used to represent high-energy particles like electrons and ions and electromagnetic waves. Exposure (to radiation) means that some or all of energy carried by the radiation is deposited to (absorbed in) a substance exposed to the radiation. The manner of the energy deposition or absorption in the substance by the exposure is quite different depending on types of the radiation, their carrying energy, and characters or properties of the substance. The term "exposure" is often limitedly used for the energy deposition or absorption in a human or human body exposed to the radiation. The effect of the heavy exposure of a human being appears as some disease like cancer, or even death of tissues, organs, and a human body, which makes people scared of the radiation.

Above 0 K, any matter including living beings releases and absorbs energy from its surrounding. The temperature of the matter is decided by the balance of the release and absorption of energy. To be exact, the temperature is determined by the power balance of input and output. Energy and power are often used in confusion and sometimes misused in discussion of radiation effects. However, both are different in

definition. The power is the amount of energy transferred or converted per unit of time and is transferred with the form of radiation (of electromagnetic waves), and conduction and convection of heat. The first one is well known as blackbody radiation which occurs even in vacuum, while the latter two require surrounding materials. Examples of the blackbody radiation are seen in infrared heaters or warming, and a thermometer to measure the temperature of a human body which is routinely used in airports. Heat conduction relies on energy exchange between mutually contacting materials through atomic and molecular motions. Convection is heat transport accompanied with thermal motion of fluid.

Radiation, as described later, carries energy as electromagnetic waves or particles, and transfers or interchanges its energy when it collides with or enter a substance. The energy transferred in unit time is the power. It may sound strange to hear that "energy transfer/interchange with radiation". This means that if high-energy radiation enters a substance, energy is given to the substance or the substance absorbs energy, while if low energy radiation enters a substance, the radiation is given energy from the substance, which is just the physical phenomena of heating and cooling of the substance by the radiation. Thus "radiation" discussed in this book is high-energy electromagnetic waves or particles. And deposition or absorption of all or some of their energy in human body under the exposure is "radiation exposure" that people fear.

The manner or process of energy deposition or absorption depends entirely on the types of radiation, its energy and intensity, and the nature of the substance, particularly its density and temperature. Furthermore, the energy deposition results in damage to the substance, i.e., the formation of defects, or disorders. While the substances whatever they are, living beings, organic materials, and inorganic materials have resilience to recover the damages, which makes the appearance of the damages or the effect of exposure complex as discussed in Chap. 4.

The energy range of radiation spreads very wide-ranging from 0 eV to more than 10^{20} eV as shown in Table 1.1 for the electromagnetic wave as an example of the radiation. Dangerous or scary radiation is those having the energy of above a few eV, while those having less are generally not hazardous.

The following sections in this chapter are devoted to explaining following nine subjects. In Sect. 1.2, four characteristics of radiation are introduced

1. Radiation is carrying energy and transfers energy as power,
2. Energy and intensity of radiation,
3. Radiation effect is different depending on the kind of radiation even if they carry the same energy, and
4. Physical units relating to radiation and radiation measurements.

In the remaining sections are summarized five important points of this book as an introduction to the radiation.

5. Energy emission from materials (black body radiation and radiation from radioactive materials),
6. The universe and natural radiation,

Table 1.1 Energy carried by EQ (electromagnetic waves) and corresponding wavelength and frequency

Energy		Frequency (Hz)	Wave length	Name	Purpose in use
10 MeV	Ionizing radiation			γ-ray	Medical treatment
100 keV		3 EHz		X-ray	Non-destructive inspection X-ray photography
1 keV		300 PHz	1 nm	Ultraviolet light	Disinfection
10 eV		3 PHz	100 nm		
				Visible light	
0.1 eV	Non-ionizing radiation	30 THz	10 μm		
10 meV		3 THz	100 μm	Infrared light	Heater
1 meV		300 GHz	1 mm	Sub-millimetric wave	
0.1 meV		30 GHz	1 cm	Millimetric wave	Radar
10 meV		3 GHz	10 cm	Centimetric wave	Satellite communication
1 meV		300 MHz	1 m	Ultra-high frequency wave (UHF)	Microwave
0.1 meV		30 MHz	10 m	Very high frequency wave (VHF)	FM broadcast, TV
10 neV		3 MHz	100 m	Short wave	Radio communication, Shortwave broadcast
1 neV		300 kHz	1 km	Medium frequency wave	AM broadcast, Ham radio
0.1 neV		30 kHz	10 km	Ultra-short wave	Marine radiocommunication
10 peV	Electromagnetic waves	3 kHz	100 km	Very low frequency wave	Long distance communication
0.1 peV		60/50 Hz	10 Mm	Commercial electricity	

1 EHz $= 10^{18}$ Hz, 1 PHz $= 10^{15}$ Hz, 1 THz $= 10^{12}$ Hz, 1 GHz $= 10^{9}$ Hz, 1 MHz $= 10^{6}$ Hz, 1 kHz $= 10^{3}$ Hz, 1 neV $= 10^{-9}$ eV, 1 peV $= 10^{-12}$ eV

7. Energy of radiation,
8. Radioactive materials in nature and artificial radiation sources,
9. Radiation shielding.