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Introductory Chapter: Radiation Exposure, Dose and Protection

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1. Introduction

Radiation sources are known to be basically of two origins, that is, the natural or background radiation and artificial or man-made radiation. Natural or background radiation sources are grouped as those from cosmic; these are radiation from the space. The dose from cosmic source of radiation could vary from one location to another, i.e., the dose values vary in different parts of the world and also change with altitude. The exposure also decreases in intensity with depth in the atmosphere or increase with increase altitude [1].

Other natural source group is the terrestrial radiation, which is from soil, water and vegetation. These are radionuclides such as ^{238}U , ^{234}Th and ^{40}K , and they contribute mostly to the external dose to human body. Radon is another example of naturally occurring radionuclide which is found in rock formations and can release higher levels of radiation that can pose health risks particularly lung cancer.

The third source of natural radiation is the internal radiation, and these are ^{40}K , ^{14}C and ^{210}Pb inside the body. These radionuclides enter the body through the ingestion of food, milk and water or by inhalation.

The artificial or man-made radiations are those that originate from various activities of man such as in consumer products, examples which include building materials, television receivers and tobacco products. Other activities are nuclear power plants for electricity/power generation, testing and using of nuclear bombs, decommissioning of radioactive waste, and industrial activities such as mining, security inspection systems use in cargo scanners and personnel security systems and medical purposes.

Also radiation can be categorized into types; they are ionizing and nonionizing radiation. Nonionizing radiation is the type of electromagnetic radiation with no enough energy to ionize atom, while ionizing radiation is radiation that carries enough energy to detach electrons from atoms causing the atom to become charged or ionized. Ionizing radiation has more energy than nonionizing radiation, that is, enough to cause chemical changes, and thereby causing damage to tissue. The ionizing radiation is further categorized into four types: alpha particles, beta particles, gamma rays and X-rays. The effects of ionizing radiation at high-dose levels are well known, while the effects of ionizing radiation at low doses are not yet clear. Ionizing radiation is used for diagnostic and therapeutic medical purposes, and there are advantages and disadvantages attached to the use of ionizing radiation for this purpose; the advantage lies in being able to diagnose and treat diseases; however, it can damage human cells and cause harm. Radiation doses of about 10 Sv and above received in a short period can cause the organs and tissues in the body to cease to function and may lead to death [2].

These two categories of radiation, ionizing and nonionizing, can cause damage to humans. Ionizing radiation can cause cancer, heart and brain problems, while nonionizing radiation can cause burning of retinas, skin cancer as a result of long exposure to the sun [3].

Examples of natural sources of ionizing radiation include metal mining, radon exposure, cosmic rays from the sun and radioactive rocks and soils, while examples of artificial sources of ionizing radiation includes nuclear reactors, medical equipment such as X-rays. Sources of natural nonionizing radiation are sunlight and thermal radiation, while man-made sources of nonionizing radiation are microwave oven, cell phones and power lines.

Most of the man-made exposure to radiation is from medical procedures. This can be shown from the NCRP Report No. 93, 1987, on the ionizing radiation exposure of the population of the United States. Natural sources of radiation accounted for 82%, and medical sources are responsible for 11% of the remaining and 18% from man-made radiation (NCRP Report No. 160), and most of the exposure is from diagnostic X-rays such as examinations of computed tomography, conventional radiography and fluoroscopy and interventional fluoroscopy. The average dose from the use of radiation for treatment purposes is much less than that from diagnostic purposes even though quite a number of exposures may be used in certain treatments such as cancer; only a small number of people are involved, and exposures are limited to small areas where treatment is necessary [4].

Medical use of radiation is known to be the greatest artificial source of doses to human beings at large. Following the improvement in technology and health-care, this has led to an increase in the usage of radiation; this can be measured by the frequency of procedures and by the levels of individual and collective doses. Medical X-rays are responsible, in Western countries, for at least some 300 man Sv per million inhabitants, representing approximately 90% of man-made source. The common sources of radiation exposure to the population are the natural sources and medical irradiation [5].

The risk of radiation exposure from X-ray such as malignancy, skin damage and cataract is high with increasing number of examination performed. There is an increase in the number of procedures performed and the possibility of more complicated procedures such as interventional procedures that can lead to higher doses to patients and staff. The increasing number of computed tomography (CT) procedures performed also can lead to increase in the collective dose.

Since the diagnostic X-rays take the highest portion of the medical use of radiation or in which human are exposed apart from the natural sources, it is therefore necessary that people or the population are protected which therefore necessitate the need for a radiation protection to be considered in order to eliminate the damage from unnecessary exposure. Even though, the doses from diagnostic radiology are much less than in the treatment of diseases, there is a need to monitor that the dose to the patient is not too low or too high for a particular procedure. According to the International Commission on Radiation Protection (ICRP), radiation protection involves the use of three techniques, and these are justification of practices, optimization of protection and the use of dose limits/levels. Since dose limits do not apply to medical exposure, optimization and justification are therefore important in patients using radiation for medical purposes.

The European Union Council Directive 97/43/Euratom (the Council of the European Union, 1997) also laid emphasis on the need of these two principles of justification and optimization. The principle of justification implies that the advantages to the patient and the society during a radiological procedure must be more than the risks for the patient and the need to consider alternative techniques that do not involve medical radiation exposure [6].

The principle of optimization is to keep the dose 'as low as reasonably achievable' (ALARA principle) economic and social factors being taken into consideration (ICRP 60) [7]. Also ICRP in its recommendation in Publication 73 (ICRP 73) introduced the need for establishment and use of diagnostic reference levels (DRLs) to ensure that implementation guidance is available. The purpose of DRLs is not to be used when considering the dose to individual patients but to prevent delivery of unnecessary high doses as well as to be used in estimating radiation doses as a form of quality assurance [7].

The International Commission on Radiological Protection (ICRP) defined DRL as 'a form of investigation level, applied to an easily measured quantity, usually the absorbed dose in air, or tissue-equivalent material at the surface of a simple phantom or a representative patient,' while the Council of the European Union defined DRL as 'dose levels in medical radiodiagnostic practices or, in case of radiopharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment.'

DRLs settings for diagnostic radiology should not be based on patient's doses measured from only well-equipped hospitals but in all types of different hospitals, clinics and practices. DRL values are to be established by using the 75th percentile, taking into account of values that are too low or too high. DRLs are to be set locally, regionally or nationally and recorded on regular basis to allow for comparison over some time and also for the purpose of establishing database. According to Vassileva and Rehani [8], DRLs are indicators for a typical practice in a country or in a region, and since equipment and procedures can vary between different facilities in countries or regions, it is therefore a good practice to establish national or regional DRLs. DRLs should be reviewed wherever DRLs are constantly exceeded and that corrective actions are taken when appropriate.

In most countries with established National Diagnostic Reference Levels (nDRLs), the responsibility lies with the government national authorities and institutes responsible for radiological protection and nuclear safety. They perform the function of collecting data from different hospitals or clinics with medical imaging facilities, analysis of the data and then give update on the DRL values. The established DRL values are reviewed periodically, and recommendations are made based on the findings.

2. Reason for DRLs

From the article on historical background on DRLs, Wall and Shrimpton [9] reported that national surveys of patient doses on X-ray examinations conducted in Europe and the USA in the 1950s showed high variations in doses from different hospitals which came about the need for quantitative guidance on patient exposure. It was reported that in the late 1980s, the dose guidelines started first in the USA and then in the UK and then followed in Europe, and the reference doses were incorporated into working documents giving *Quality Criteria for Diagnostic Radiographic Images* for adult and pediatric by European countries study groups of radiologists and physicists.

In 1997, the need to develop the DRLs then followed, (Council Directive 97/43/EURATOM, 1997) which is defined as dose levels in diagnostic radiology to patients of standard-sized groups or standard phantoms, for particular examinations and as well considering different types of equipment [6]. The DRL values should not be exceeded for standard procedures when good and normal practice is applied. The main aim of a DRL is to serve as a control in using radiation for diagnostic purposes and by avoiding unnecessary exposure to radiation. In 1989, national reference

doses were first suggested for some radiographic examinations. This was followed by the investigation in the levels in patient doses by ICRP in 1990 and further developed into development of DRLs in ICRP Publication 73.

The list of medical exposure according to the United Kingdom nDRLs required by the Ionizing Radiation Regulations in 2000 include adult and pediatric computer tomography examinations, general radiography and fluoroscopy which include diagnostic examinations on adult and pediatrics and interventional procedures on adult and dental radiography.

3. Regulatory bodies on the use of ionizing radiation and DRLs

The regulatory bodies on the use of radiation include the following organizations:

3.1 United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR

UNSCEAR, which was established in 1955 with the mandate to undertake broad assessments of the sources of ionizing radiation and its effects on human health and the environment, provides the service of assessing global levels and effects of ionizing radiation as well as providing scientific basis for radiation protection. The use of radiation for medical purposes could be of positive applications; it is a reality that X-rays can cause biological harm or injury to humans [10]. Reports from developed countries indicated that the use of ionizing radiation for diagnostic purpose is estimated to be about 1 mSv per capital annual. At this dose level, the estimated annual additional cancer mortality is 0.5 per 10,000 persons of a general population basing on the additive risk model of the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR). In its report in 2008, UNSCEAR Report No. 1 reported an increase in the total number of diagnostic medical examinations from 2.4 to 3.6 billion; this is an increase of almost 50% from its previous study in 1991–1996. The use of high-dose X-ray techniques such as the computed tomography scanning is leading to growth in the annual number of procedures in many countries thereby increasing the collective dose. It is estimated that the total collective effective dose from medical diagnostic examinations have increased by 1.7 million man Sv, that is, it rises from about 2.3 million to about 4 million man Sv, which gives an increase of about 70% [11].

3.2 International Atomic Energy Agency (IAEA)

IAEA develops safety standards to protect the health and minimize the danger to people's life and property associated with the use of ionizing radiation in medicine, etc. IAEA focuses on ensuring that radiation doses to patients commensurate with the medical purpose, thereby preventing patients from being exposed to unnecessary and unintended radiation. To ensure that radiation protection and safety of radiation sources in medical uses of ionizing radiation, the IAEA Safety Guide on Radiation Protection and Safety in Medical Uses of Ionizing Radiation (2018) was published to provide recommendations and guidance on fulfilling the requirements of IAEA Safety Standards series No GSR Part 3 [12].

According to the report from the IAEA office of Public Information and Communication, DRLs is a tool for comparing diagnostic imaging procedures in a country which include adults and children of different ages and weights in examinations in X-rays, CT, image-guided interventional procedures or nuclear medicine procedure. Each facility needs to set their DRL and then compare with

local, national or regional doses. The newsletter report also mentioned the need to track radiation dose data to improve practice and reduce doses without loss of diagnostic quality. As well as prevent unnecessary exposures.

International Atomic Energy Agency also states that DRLs should be set locally, regionally or even nationally. IAEA also agreed to set the nDRLs at the third quartile values, and they could not be considered as optimum dose but in identifying unusual practices. According to IAEA, the government is responsible for the establishment of DRLs and to involve health authority, the professional bodies and the regulatory body. IAEA also identifies DRLs as a tool in radiation protection of the patients.

3.3 The International Commission on Radiological Protection (ICRP)

The primary aim of radiological protection, as stated in ICRP Publication 60, is 'to provide an appropriate standard of protection for mankind without unduly limiting the beneficial practices giving rise to radiation exposure' [13].

According to the International Commission on Radiological Protection (ICRP) in its international recommendations, ICRP 60, (ICRP 19), the focus is on the principles of justification and optimization of all radiation exposures in diagnostic radiology. Another recommendation, which is the ICRP 85, [14], focused on the risk of skin damage from interventional radiology. In 2007 in its publication (ICRP Publication 103), ICRP presented the revised recommendations for radiological protection followed by ICRP Publication 118 (2012) published on deterministic effects of ionizing radiation. ICRP makes recommendations only, and it is the responsibility of government of individual countries to implement those recommendations through legislation appropriate for their own country.

3.4 World Health Organization (WHO)

According to the World Health Organization (WHO), there are established relevant guidelines that have to be considered in each type of diagnostic procedure [15–17]. Human exposure to radiation for medical research is considered as not justified unless it is in accordance with the provisions of the Helsinki Declaration [18] and follows the guidelines for its application prepared by the Council for International Organizations of Medical Sciences [19] and WHO [20].

The WHO in 2008 launched a Global Initiative on Radiation Safety in Health Care Settings (GIRSHCS), thereby facilitating the adoption and applications of regulations, in the evaluation of radiation medicine and medical imaging procedures. WHO also facilitates training on the use of appropriate technologies as well as publishing and disseminating guidance tools and technical documents. In 2012, the WHO presented report of its Radiation Risk Communication in pediatric imaging workshop on the need to develop and implement a risk communication tool in order to create the awareness of radiation risks and exposure in pediatric procedures [21].

3.5 National Council on Radiation Protection and Measurements (NCRP)

National Council on Radiation Protection and Measurements Report No. 160 (1993) focused on the biological effects of ionizing radiation such as cancer, cardiovascular disease and cataracts, while its Report No. 180 focused on the management of exposure to ionizing radiation and expressed radiation protection principles as justification, optimization of protection and numeric protection criteria, i.e., the management of dose to an individual. This means that the protection criteria is the first objective when there is a numeric protection for a specific exposure; then the optimization of protection should follow [22, 23].

4. Conclusion

The use and exposure of humans to ionizing and nonionizing form of radiation is of various purposes. Radiation exposure cannot be entirely avoided on this planet, taking into account how much radiation people receive from natural sources. The proper use of radiation can be of immense benefits. The sources and categories of radiation exposure, the various use of ionizing radiation and the principles of radiation protection to avoid unnecessary exposure to high level of radiation dose from the use of ionizing radiation have been discussed in this chapter.

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