

Review Article

Radiation Hazard, Safety, Control and Protection

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Abstract:

The field of Radiology and Nuclear medicine has advanced from era of X-rays to today's modern imaging techniques, most of which use the ionizing radiation. With the benefits of better diagnosis and treatment, it has caused manifold increase in radiation exposure to the patients and the radiology and nuclear medicine personnel. Many studies done till date have clearly documented the harmful effects of ionizing radiation from radiation exposure, especially cancer. This is more important in paediatric population as their tissues are more radiosensitive, and they have more years to live. Diagnostic and therapeutic radiological procedures including nuclear medicine are integral part of modern medical practices, exposing both patients and medical staff to ionizing radiation. Without proper protective measures, this radiation causes many negative health effects. Hence, proper knowledge and awareness regarding the radiation hazards and radiation protection is mandatory for health professionals, especially the nuclear medicine and radiology professionals. International Commission on Radiation Protection (ICRP) has recommended two basic principles of radiation protection, justification of the practice and optimization of protection.

Key words: Radiation, Hazard, Safety.

Introduction:

Ionizing radiation is a type of energy released by atoms that travels in the form of electromagnetic waves (gamma or X-ray) or particles (neutrons, beta, alpha). The spontaneous disintegration of atoms is called radioactivity, and the excess energy emitted is in the form of ionizing radiation. Unstable elements which disintegrate and emit ionizing radiation are called radionuclides. Radioactive material has to be handled with care because exposure to radiation can increase the risk of cancer and has other harmful effects. Within the nuclear medicine and radiology department, staff will be exposed to radiation from radiopharmaceuticals, X-ray of patients, calibration sources, and radioactive waste. The exposure of staff must not be exceeding legally defined limits for radiation workers. In addition the exposure of staff should be "As Low as Reasonably Achievable" (ALARA)¹. This is the important ALARA principle. In a well managed department which take the ALARA principle seriously, staff will only be exposed to a small fraction of the legal limit.

Exposure to radiation can be external, from radioactive material outside the body, or internal if the material

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gets inside the body. Staff must understand how they are exposed to external radiation from radioactive sources, and how to avoid radioactive contamination on themselves or their personal clothing, or on work surfaces such as benches and counting equipment.

Sources of Radiation:

People are exposed to natural sources as well as man-made sources on daily basis. Natural radiation comes from many sources including more than 60 naturally-occurring radioactive materials found in soil, water and air. Radon, a naturally-occurring gas, emanates from rock and soil and is the main source of natural radiation. Every day, people inhale and ingest radionuclides from air, food and water. On average, 80% of the annual dose of background radiation that a person receives is due to naturally occurring terrestrial and cosmic radiation sources.

Human exposure to radiation also comes from man-made sources ranging from nuclear power generation to medical uses of radiation for diagnosis or treatment. Today, the most common man-made sources on ionizing radiation are medical devices, including X-ray machines.

Radiation exposure:

Radiation exposure may be internal or external. Internal exposure occurs when a radionuclide is inhaled, ingested or otherwise enters into the bloodstream. Internal exposure stops when the radionuclide is eliminated from the body, either spontaneously or as a result of treatment. External exposure may occur when airborne radioactive material is deposited on skin or clothes. This type of radioactive material can often be removed from the body by washing. Radiation exposure can also result from radiation from an external source, such as medical radiation exposure from X-ray, CT scan. External radiation stops when the radiation source is shielded or the person moves outside the radiation field. Radiation exposure can be classified into three exposure situations. The first, planned exposure situation, from the deliberate introduction and operation of radiation sources with specific purposes, as is the case with the medical use of radiation for diagnosis or treatment of patients or the use of radiation in industry or research. The second type of situation, existing exposures, is where exposure to radiation already exists, and a decision on control must be taken—for example, exposure to radon in homes or workplaces or exposure to natural background radiation from the environment. The last type, emergency exposure situation, results from unexpected events requiring prompt response such as nuclear accidents or malicious acts.

Biological Effects of Radiation:

Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or large dose, there will be some biological effects. Biological effect is in terms of the effect of radiation on living cells. All biological damage effects begin with the consequences of radiation interactions with the atoms forming the cells. There are two mechanisms by which radiation ultimately affects cells. These are commonly called direct and indirect effects. If radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is referred to as a direct effect. If a cell is exposed to radiation, the probability of the radiation interacting with DNA molecule is very small since these critical components make up such a small part of the cell. When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH). These fragments may recombine or may interact with other fragments or ions to form compounds, such as water, which would not harm the cell. However, they could combine to form toxic substances, such as hydrogen peroxide (H₂O₂), which can contribute to the destruction of the cell. Not all living cells are equally

sensitive to radiation. Those cells which are actively reproducing are more sensitive than those which are not. This is because dividing cells require correct DNA information in order for the cell's offspring to survive. A direct interaction of radiation with active cell could result in the death or mutation of the cell, whereas a direct interaction with DNA of a dormant cell would have less of an effect. This means that different cell systems have different sensitivities. Lymphocytes and other cells which are components of blood, are constantly regenerating and are most sensitive. Reproductive and gastrointestinal cells are not regenerating, as quickly and are less sensitive. The nerve and muscle cells are the slowest to regenerate and are the least sensitive cells. Cells of the human body, have a tremendous ability to repair damage. As a result, not all radiation effects are irreversible. In many instances, the cells are able to completely repair any damage and function normally. The biological effects on the whole body from exposure to radiation will depend upon total dose, type of cell, type of radiation, age of individual, stage of cell division, part of body exposed, general state of health, tissue volume exposed and time interval over which dose is received.

Biological effects of radiation are typically divided into two categories. The first consists of exposure to high doses of radiation over short periods of time produce acute or short term effects. The second represents exposure to low doses of radiation over an extended period of time producing chronic or long term effects. High dose tend to kill cells, while low doses tend to damage or change them. High doses can kill so many cells that tissues and organs may be damaged. This in turn may cause a rapid whole body response often called the Acute Radiation Syndrome (ARS). The initial signs and symptoms of acute radiation syndrome are nausea, vomiting, fatigue and loss of appetite. Below about 150 rad, these symptoms, which are not different from those produced by a common viral infection, may be the only outward indication of radiation exposure. At a dose 150-1100 rad, severe blood changes will be noted and symptoms appear immediately. Approximately 2 weeks later, some of those exposed may die. At about 300-500 rad, up to one half of the people exposed will die within 60 days without intensive medical attention (LD 50/60). Besides death, there are several other possible effects of high radiation dose. Effect on the skin including erythema, dry desquamation, and moist desquamation. Skin effects are more likely to occur with exposure to low energy gamma, X-ray, or beta radiation. Hair loss, also called epilation, is similar to skin effects and can occur after dose of about 500 rad. Sterility can be temporary or permanent in males, depending upon the dose. In females, it is usually permanent, but it requires high dose in excess of 400 rad. Cataracts appear to have a threshold of about 200 rad.

Low doses spread out over long period of time don't cause an immediate problem to any body organ. The effects of low doses of radiation occur at the level of the cell, and the results may not be observed for many years. There are three general categories of effects resulting from exposure to low doses of radiation. These are: genetic- the effect is suffered by the offspring of the individual exposed. Somatic- the effect is primarily suffered by the individual exposed. Since cancer is the primary result, it is sometimes called the carcinogenic effect. In-Utero- some mistakenly consider this to be a genetic consequence of radiation exposure, because the effect, suffered by a developing embryo/fetus, is seen after birth. However, this is actually a special case of the somatic effect, since the embryo/fetus is the one exposed to the radiation. Prenatal exposure to radiation may induce brain damage in fetuses following an acute dose exceeding 100 mSv between weeks 8-15 of pregnancy and 200 mSv between weeks 16-25 of pregnancy. Before week 8 or after week 25 of pregnancy human studies have not shown radiation risk to fetal brain development. The cancer risk after fetal exposure to radiation is similar to the risk after exposure in early childhood. The genetic effect involves the mutation of very specific cells, namely the sperm or egg cells. Mutations of these reproductive cells are passed to the offspring of the individual exposed.

Radiation Protection:

Radiation protection, also known as radiological protection, is defined by the International Atomic Energy Agency (IAEA) as "The protection of people from harmful effects of exposure to ionizing radiation, and the means for achieving this"². Ionizing radiation is widely used in industry and medicine, and can present a significant health hazard by causing microscopic damage to living tissue. Fundamental to radiation protection is the avoidance or reduction of dose using the simple protective measures of time, distance and shielding. The duration of exposure should be limited to necessary, the distance from the source of radiation should be maximized, and the source shielded wherever possible. To measure personal dose uptake in occupational or emergency exposure, for external radiation personal dosimeters are used, and for internal dose due to ingestion of radioactive contamination, bioassay techniques are applied. The International Commission on Radiation Protection (ICRP), develops and maintains the International System of Radiological Protection, based on evaluation of the large body of scientific studies available to equate risk to received dose levels. The system's health objectives are "to manage and control exposure to ionizing radiation so that deterministic effects are prevented, and the risks of stochastic effects are reduced to the extent reasonably achievable"³.

The ICRP uses the following overall principles for all controllable exposure situations⁴. Justification: No unnecessary use of radiation is permitted, which means that the advantages must outweigh the disadvantages. Limitation: Each individual must be protected against risks that are too great, through the application of individual radiation dose limits. Optimization: This process is intended for application to those situations that have been deemed to be justified. It means "the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses" should all be kept as Low As Reasonably Achievable (ALARA). ALARP is an acronym for an important principle in exposure to radiation and other occupational health risk and in the UK stands for "As Low As Reasonably Practicable"⁵. The aim is to minimize the risk of radioactive exposure or other hazard while keeping in mind that some exposure may be acceptable in order to further the task at hand.

There are three factors that control the amount, or dose, of radiation received from a source. Radiation exposure can be managed by a combination of these factors: Time: Reducing the time of an exposure reduces the effective dose proportionally. Distance: Increasing distance reduces dose due to the inverse square law. Shielding: Sources of radiation can be shielded with solid or liquid material, which absorbs the energy of the radiation. The term 'biological shield' is used for absorbing material placed around a nuclear reactor, or other source of radiation, to reduce the radiation to a level safe for humans⁶.

Internal dose, due to the inhalation or ingestion of radioactive substances, can result in stochastic or deterministic effects, depending on the amount of radioactive material ingested and other biokinetic factors. The risk from a low level internal source is represented by the dose quantity committed dose, which has the same risk as the same amount of external effective dose. The occupational hazards from airborne radioactive particles in nuclear and radio-chemical applications are greatly reduced by the extensive use of glove boxes to contain such material. To protect against breathing in radioactive particles in ambient air, respirators with particulate filters are worn. To monitor the concentration of radioactive particles in ambient air, radioactive particulate monitoring instruments measure the concentration or presence of airborne materials. For ingested radioactive materials in food and drink, specialist laboratory radiometric assay methods are used to measure the concentration of such materials. The radiation dosimeter is an important personal dose measuring instrument. It is worn by the person being monitored and is used to estimate the external radiation dose deposited in the individual wearing the device. They are used for Gamma, X-ray, beta and other strongly penetrating radiation.

Common types of wearable dosimeters for ionizing radiation include: Film badge dosimeter, Quartz fiber dosimeter, Electronic personal dosimeter and Thermo luminescent dosimeter^{7,8}.

Conclusions:

Radiation safety is a major concern in this modern era of diagnostic and therapeutic Radiology and Nuclear Medicine as well. Radiation protection is an integral component of the working infrastructure of any radiology and nuclear medicine department. The main principles of radiation protection are to provide adequate protection from undue exposure of radiation to personnel directly or indirectly involved with radiation, without unduly limiting the benefits of radiation exposure. The components of radiation protection include justification of the procedure involving the radiation exposure, use of minimum radiation exposure compatible with the procedure with provides adequate diagnostic information, shielding of the personnel and patient from unwanted radiation exposure and monitoring of radiation exposure to the occupational workers and the working environment. Regular surveillance of the concern department for radiation levels and monitoring of the radiation protection programmers and regular educational activities form an integral part of the responsibilities of the RCO and other administrative authorities of the department/hospital.

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