Safety-1

RADIOLOGICAL SAFETY IN HEALTH CARE : GUIDELINES, PRACTICE AND OUTCOME

1. Introduction:

After the latter part of the the 19th century, scientists truly began to make advances in the study of atomic structure and radiation. During the 1800s, Sir Issac Newton had proven his theories on gravity. Marie and Pierre Curie had begun their studies in chemistry and physics, and Dimitri Mendeleev had introduced the periodic system of elements. Just before the turn of the century, Wilhem Conrad Roentgen discovered the basic properties of X-Rays; the properties of ionizing radiation and the possibility of using radiation in medicine. Finally, in 1896, Henri Becquerel announced the discovery of radioactivity to the Academy of Sciences in Paris. By the early 1900s the study of radiation was a widely accepted scientific endeavor. Today, the use of radiation, be it naturally occurring or man-made, is widespread and reaches every segment of our society. Common examples include:

- Nuclear reactors used; to generate electricity; to power ships and submarines; to produce radioisotopes used for research, medical, industrial, space and defense applications, and as research tools for nuclear engineering and physics.
- Particle accelerators used to produce radioisotopes and radiation and to study the structure of matter, atoms, and common materials.
- Radioisotopes used in nuclear medicine, biomedical research, and medical treatment.
- X-rays and gamma rays used as diagnostic tools in medicine, as well as in diverse industrial applications, such as industrial radiography, luggage X-ray inspections, and nondestructive materials testing.
- Common consumer products, such as smoke detectors, luminous-dial wrist watches, luminous markers and signs, cardiac pacemakers, lightning rods, static eliminators, welding rods, lantern mantles, and optical glass.

All above activities involve harmful radiations to living systems, though beneficial to individual and society. Everybody is exposed to ionizing radiation from these natural and man-made radiation sources. It is convenient to think of the processes causing these exposures as a network of events and situations. Each part of network starts from a source. Radiation or radioactive material then passes through environmental or other pathways leading to the

exposure of individuals. Finally, the exposure of radiation or radioactive materials leads to doses to individuals. Protection can be achieved by taking action at the source, or at the points in the exposure pathways, and occasionally by modifying the location or characteristics of the exposed individuals.

2. Historical background of ionizing radiations to mankind:

Radiation from cosmic rays and naturally occurring radioactivity in the earth crust make up the natural radiation background environment in which all life forms have evolved. Society's recognition of radiation began in 1895 with the discovery of x-rays; naturally occurring radioactivity was observed in 1896. These discoveries marked the beginning of the study and use of radioactive substances in science, medicine, and industry. The discovery of radioactivity led rapidly to the development of medical radiology, industrial radiography, nuclear physics, and nuclear medicine. The discovery of x-rays brought with it the immediate recognition that this previously unknown form of energy would be of inestimable value in medicine. The first public announcement of this discovery included the classic radiograph of Frau Roentgen's hand. Thus, it is not at all surprising that x-rays were utilized for diagnostic purposes, and possibly for therapy within a few weeks of the announcement. Given the nearly ubiquitous fascination of the public with x-rays and their immediate and widespread application to medicine, it was inevitable that x-ray injuries would soon appear. Along with the injuries, came recognition of the hazard implicit in the use of x radiation and of the need for protective reassures. The most important provisions for x-ray protection were elucidated during the first decade after Roentgen's discovery.

The months following Roentgen's historic announcement of x-rays were marked by intense activity in studying the newly discovered phenomenon and applying it to medicine and various other purposes. The mysterious rays that could penetrate human flesh and reveal the inner structures of the body captivated the scientific and lay worlds. Despite an occasional ominous indication to the contrary, there was virtual unanimity within the medical, scientific and lay communities; all were certain that x-rays were totally without adverse effect. After all, what harm could there be from something that could not be seen, felt, tasted, heard, or detected in any way by the senses? By the 1920s, the use of x-rays in diagnostic medicine and industrial applications was widespread. Radium was being routinely used in luminescent dials painting of wristwatches. The doctors were using it for cancer therapy treatment. By the 1930s, biomedical and genetic research scientists were studying the effects of radiation on living organisms, and physicists were beginning to understand the mechanisms of spontaneous fission and radioactive decay. In the 1940s, research in nuclear physics had advanced to the point where a

self-sustaining fission reaction was demonstrated under laboratory conditions. These events led to the construction of the first nuclear reactors and the development of atomic weapons. Because low-level radiation effects are delayed by weeks, months, or years, data on low-level effects continued to come in slowly after the exposures in Hiroshima and Nagasaki, and after the Chernobyl accident.

3. Radiation hazards:

The discoveries x-rays and radioactivity did not come without a price. Scientists learned that radiation is not only a source of energy and medicine, but it could also be a potential threat to human health if not handled properly. In fact, early pioneers in radiation research died from radiation-induced illnesses (too much exposure). For instance, Thomas Edison's assistant died from a radiation-induced tumor as a result of excessive x-ray exposure. Initially, the dangers and risks posed by x-rays and radioactivity were poorly understood. In March 1896, Edison reported eye irritation associated with the use of x-rays, and cautioned against their continuing use. He abandoned his own studies devoted toward an x-ray energized fluorescent light. Sadly, this action was too late to prevent the overexposure of his assistant, Clarence M. Daily, who developed acute x-ray dermatitis and died in 1904 as a result of his x-ray exposure. By the end of 1896, numerous reports on x-ray dermatitis and serious injuries had been published in the scientific and lay literature. One of these was a report by the American physicist, Thompson, who reported the deliberate exposure of the little finger of his left hand to the direct beam of an x-ray tube over a period of several days. His exposure resulted in pain, swelling, stiffness and blistering, causing Thompson to caution against over exposure or there may be cause for regret when too late. The therapeutic potential of x-rays and the emanations from radioactive materials were quickly realized; thus, as early as 1896, x-rays were used therapeutically, where tissue destruction was the desired effect. The prevailing opinion, however, seems to have been that the dermatitis and burns were not caused by the x-rays themselves; but rather, by other factors including: ultraviolet light, the flight of minute atoms from the target to the skin, cathode rays, electrical induction, oxidation by ozone or other byproducts of x-ray generation, or faulty technique. It is a little difficult to understand why there was any real dispute over the ability of x-rays to produce acute injury. By 1896, however, "X-ray burns" were being reported in the medical literature, and by 1910, it was understood that radioactive materials could cause such “burns”. By the 1920s, sufficient direct evidence (from radium dial painters, medical radiologists, and miners) and indirect evidence (from biomedical and genetic experiments with animals) had been accumulated to persuade the scientific community that an official body should be

established to make recommendations concerning human protection against exposure to x-rays and radium.

In this way, it was soon recognized that the use of radioactive materials would have to be controlled to protect the public, workers, and the environment from radiation exposures. As new uses for radioactive elements were discovered, potentially fatal incidents of overexposure increased. For example, during World War I, radium paint (a mixture of radium and phosphor) was used on military aircraft instruments to make them glow in the dark so they would be more visible to pilots flying at night. After the war was over, the industry that supported this technology changed their business to paint glow-in-the-dark clocks and watch faces. The young women who were employed in this profession had to form a fine point on their paint brushes by pulling the freshly-dipped brushes between their lips before applying the paint onto the watch faces. Unknowingly, they were swallowing small amounts of radium and damaging their bodies. Over a two-year period, nine women who had worked as dial painters died of severe and unexplained anemia, accompanied by destructive lesions of the mouth and jawbones. A dentist who had treated one of these women finally made the connection between inflammation of the jawbone marrow, and the radium dial painting.

4. International efforts towards radiation protection:

In 1915, the British Roentgen Society had adopted a resolution to protect people from overexposure to X-rays. This was probably the first organized effort for Radiation Protection at national level. By 1922, American organizations had adopted the British protection rules. Radiation protection was primarily a non-governmental function until the late 1940s. After World War II, the development of the atomic bomb, and nuclear reactors caused the nations to establish policies dealing with human exposure to radiation. In 1928, during the Second International Congress of Radiology meeting in Stockholm, Sweden, the first radiation protection commission was created. Reflecting the uses of radiation and radioactive materials at the time, the body was named the International X-Ray and Radium Protection Commission. It was charged with developing recommendations concerning radiation protection. In 1950, to better reflect its role in a changing world, the Commission was reorganized and renamed the International Commission on Radiological Protection (ICRP). In 1964, the Committee was chartered as the National Council on Radiation Protection and Measurements (NCRP). Throughout their existence, the ICRP and the NCRP have worked closely together to develop radiation protection recommendations that reflect the current understanding of the risks associated with exposure to ionizing radiation. Neither organization has official status, in that they do not have authority to issue or enforce regulations. However, their recommendations

often serve as the basis for the radiation protection regulations adopted by the regulatory authorities in the United States and most other countries. ICRP-1977, No. 26 (ICR77) adopted the weighted, whole-body dose equivalent (effective dose equivalent) concept for limiting occupational exposures. This approach reflected the increased understanding of the differing radio-sensitivities of various organs and tissues and was intended to sum exposures from external sources and from internally deposited nuclides. In 1979, the ICRP issued Publication No. 30, establishing the Annual Limit on Intake (ALI) system for limiting the intake of radionuclides by workers. The ALI is the activity of a given nuclide that would irradiate a person to the limit set in ICRP No. 26 for each year of occupational exposure. It is a secondary limit, based on the primary limit of equivalent whole-body irradiation, and applies to intake by either ingestion or inhalation. The recommendations of ICRP No. 30 applied only to occupational exposures. In 1983, the ICRP issued a statement clarifying the use of ALIs and Derived Air Concentrations (DACs) for members of the public. In 1985, the ICRP issued a statement refining dose limits for members of the public. In 1990, the ICRP issued Publication 60, which broadened its recommendations to include a wider range of exposure scenarios than had been previously addressed. The ICRP has adopted the international system of units (SI). Under this system, 1 Sv equals 100 rem. As such, 1 mSv equals 100 mrem. A new concept in the field of radiation protection, the ALARA (as low as reasonably achievable) for worker protection optimization has been introduced by ICRP in 1990. The ALARA principle suggests dose limits should be set at the lowest levels reasonably possible for a given scenario.

The International Atomic Energy Agency (IAEA) was chartered in July 1957 as an autonomous inter-governmental organization under the aegis of the United Nations. The IAEA gives advice and technical assistance to member states on nuclear power development, health and safety issues, radioactive waste management, and on a broad range of other areas related to the use of radioactive material and atomic energy in industry and government. As is the case for ICRP and NCRP, member states do not have to follow IAEA recommendations. However, funding for international programs dealing with the safe use of atomic energy and radioactive materials can be withheld if member states do not comply with IAEA recommendations. In addition, in matters related to safeguarding special nuclear material, the full weight of the UN can be brought to bear to “enforce” UN resolutions pertaining to the use of nuclear materials for peaceful purposes. Many of the IAEA recommendations adopt ICRP recommendations with respect to the Commission’s radiation protection philosophy.

IAEA has recently conducted a survey to judge the quality of x-ray diagnostic film and the radiation doses to the patients. In its report dated 28 May 2008, under title “X-rays often repeated for patients in developing countries”, IAEA has highlighted the issues related with the

patient dose in diagnostic x-ray examination. Patients in developing countries often need to have x-ray examinations repeated so that doctors have the image quality they need for useful medical diagnosis. The findings come from a survey involving thousands of patients in 45 hospitals and 12 countries of Africa, Asia and Eastern Europe. Poor image quality constitutes a major source of unnecessary radiation to patients in developing countries. The survey found that more than half (53%) of all x-ray images evaluated through the project were of poor quality affecting diagnostic information. One consequence is that patients then are given repeat examinations, which means exposing them to x-rays again, as well as entailing extra costs. The survey included patients receiving chest, pelvic, abdomen, skull, and spine x-ray examinations. In a paper just published in the June edition of the American Journal of Roentgenology, Rehani et al., report that considerable benefits were seen regionally after introduction of QA programmes. The quality of x-ray images improved up to 16% in Africa, 13% in Asia and 22% in Eastern Europe. At the same time, patient dose reductions ranging from 1.4% to 85% were achieved overall. Despite the finding that repeat x-ray examinations were often needed, patient doses in the 12 countries surveyed were in line with international diagnostic reference levels and similar to doses recorded in developed countries. Thousands of x-ray images were evaluated as part of the survey. (Worldwide each year, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimates that nearly two billion (2000 million) medical x-rays are done, in its report of 2000 and the indications are that it is getting almost doubled now in 2008).

In India, the procurement, storage, handling, transportation and disposal of radioactive materials are regulated under the Radiation Protection Rule (RPR), 1971 issued by the Government of India in exercise of powers conferred by section 30 of the Atomic Energy Act 1962. These rules provide a statutory basis for enforcing safety in the use of ionizing radiations for various applications. The RPR 1971 and amended RPR 1991, 1996, and 2004 specify general principles and criteria for radiation protection in handling radiation sources. Atomic Energy Regulatory Board (AERB) is the competent authority to issue guidelines on radiological protection and controlling radiological safety issues in all radiological and nuclear installation in India.

5. Radiation quantities and their units:

The first radiation unit for x-rays was roentgen (R), introduced by the International X-ray Unit committee in 1928, that later become ICRU (IXRUC, 1928). The first official use of the term ‘dose’ together with an amended definition of the unit R occurred in the 1987 recommendations of the ICRU (ICRU, 1938). The ICRU suggested the concept of absorbed dose and officially

defined the name and its unit ‘rad’ in 1953 to extend the concept of dose to certain materials other than air (ICRU, 1954). The first dose quantity incorporating relative biological effectiveness (RBE) of different types of radiation used by the ICRU was ‘RBE dose in rems’ in 1956. The term dose equivalent was introduced with unit ‘rem’ in 1962 by ICRU. In ICRP 1977 recommendations, a new dose equivalent quantity for limitation of stochastic effects by defining a weighted sum of dose equivalents of various tissues and organs of human body was introduced, where, the weighted factor was named as ‘tissue weighting factor’. The commission named this quantity as “effective dose equivalent” by replacing unit Gray (Gy) with sievert (Sv) at its meeting held at Stockholm (ICRP, 1978). In 1991, ICRP decided to use ‘radiation weighting factors’, which were selected based on the RBE in inducing stochastic effects at low doses, instead of the of the quality factors used in the calculation of the dose equivalent, the commission named the new quantity “equivalent dose”. Accordingly, the effective dose equivalent was renamed “effective dose”.

6. Instruments:

Radiation cannot be seen, smell and felt by human’s natural sensors. Just because we can't smell it, see it, or feel it doesn't mean it isn't serious; in fact, the lack of such stimuli may make it even more serious. The use of radiation is most certainly serious business. Radiations can be measured and quantified its level in our environment by radiation monitors and sensors. Radiation sensors are mainly based on the ionization of gaseous materials (Ionization chambers, GM tubes and proportional counters), luminescence process (thermoluminescence, photo-luminescence, radio-luminescence, scintillations and chemiluminescence etc.), defects in semiconductor, chemical change, charge accumulation on certain materials, nucleation in superheated emulsion, calorimetric, changes in the constituents of blood samples of biological materials etc. Most of the area radiation survey meters are based on gas ionization process as shown in Fig.1. The radiation detectors used for personal monitoring for the record of radiation dose received by particular individuals are generally based on the thermoluminescence process, however emulsion film, charge accumulation and semiconductors based radiation dosimeters are also in use for specific situation as shown in Fig.2. For handling of radiological emergency situation, miniaturized personal dosimeters such as; self-indicating radiation alert detector with change in colour of the strip, radiation mobile phones, radiation wristwatch, radiation keys bunch and radiation pagers are now a days available as shown in Fig.3. For monitoring of mass population scintillator based portal monitors are used at the major airports, seaports and security posts at country boarder. Such portal monitors are shown in Fig.4.

Qualified physicists or radiological safety officers should inspect these equipments periodically from radiation safety and proper functionality point of view. Radiation detecting instruments should be periodically tested/calibrated by the accredited agency or reference laboratory. Routine maintenance of the radiological safety instruments should be done under supervision of Health Physicist / RSO of the institution.

Fig.1: Radiation Area Survey Instruments

Fig.2: Personnel Monitoring Instruments

Fig.3: Radiation Alert detectors for radiological emergencies

Fig.4: Radiation Portal Monitors

7. Radiological Limits:

Dose limit apply only in planned exposure situations but not to medical exposures of patients. Within a category of exposure, occupational or public, dose limit apply to the sum of the exposures from sources related to practices that are already justified. For occupational exposure, ICRP continues to recommend that the limit should be expressed as an effective dose of 20 mSv per year, averaged over defined 5 years period (100 mSv in 5 years), with the further provision that the effective dose should not exceed 50 mSv (30 mSv in India, AERB) in a single year. For public exposure in planned exposure situations, the limit should be expressed as an effective dose of 1 mSv in a year. However, in special circumstances a higher value of effective dose could be allowed in a single year, provided that the average over defined 5-year period does not exceed 1 mSv per year. The dose limits are given in the table 1.

Type of limit	Occupational	Public
Effective dose	20 mSv/year, averaged over defined period of 5 years	1 mSv in a year
Annual Equivalent dose limits		
Lens of the eye	150 mSv/year	15 mSv/year
Skin (averaged over 1 cm^2)	500 mSv/year	50 mSv/year
Hands and Feet	500 mSv/year	---------
Pregnant women, remainder of pregnancy	1 mSv to the embryo / fetus till child birth	---------

Table 1. The dose limits (ICRP 2007)

The limits on effective dose apply to the sum of doses due to external exposures and committed doses from internal exposures due to intakes of radionuclides. Dose limits do not apply in emergency exposure situations where an informed, exposed individual is engaged in volunteered life-saving actions or is attempting to prevent a catastrophic situation. For informed individuals of the general public involved in caring and comforting patients released from a hospital following therapy with unsealed radionuclides, the normal dose restrictions may be relaxed and such individuals should in general not be subjected to the public dose limits. The dose constraints in different radiological exposure situations are given in the table 2.

Type of exposure	**ICRP-2007 recommendations**
Public Exposure	
General	Below 1 mSv/y according to the situations
Radioactive waste disposal	$\leq$ 0.30 mSv/y
Long-lived radioactive waste disposal	$\leq$ 0.30 mSv/y
Prolonged exposure	$<$ 1 mSv/y
Prolonged component of long-lived	$\leq$ 0.10 mSv/y

nuclides	
Medical Exposure Volunteers for biomedical research, if benefit to the society Minor Intermediate Moderate Substantial Comforters and carers	 < 0.1 mSv 0.1-1.0 mSv 1-10 mSv > 10 mSv 5 mSv per episode
Emergency Exposure Situations ***Occupational Exposure*** Life-saving (informed volunteers) Other urgent rescue operations Other rescue operations ***Public Exposure*** All countermeasures combined in an overall protection strategy **Existing Exposure Situations** Radon-222 At Home At Work Natural background radiation	 No dose restrictions if benefit to others outweighs rescuer's risk 1000 or 500 mSv (Effective dose below 1000 mSv should avoid serious deterministic effects; below 500 mSv should avoid other deterministic effects ≤ 100 mSv Planning typically between 20 and 100 mSv/y according to the situation **Reference Levels** < 10 mSv/year (< 600 Bq/m^3) < 10 mSv/year (< 1500 Bq/m^3) Between 1 and 20 mSv/year according to the situation

Table 2. Dose constraints in different radiological exposure situations

Similar to hazardous chemical substances, limits for radionuclides in various consumables have been stipulated. The radioactivity limits for drinking water are expressed as Maximum Contaminant Levels (MCLs). The current MCL for radium-226 and radium-228 combined is 5 pCi/L, and the MCL for gross alpha particle activity (including radium-226, but excluding radon and uranium) is 15 pCi/L. For manmade beta particle and photon emitting radionuclides (except tritium and strontium-90), individually or in combination, the MCL is set at an annual dose limit of 4 mrem to the total body or any internal organ. For tritium and strontium-90, the MCLs are 20,000 pCi/L and 8 pCi/L, respectively.

8. Radiation protection gadgets:

The radiation safety equipments / devices routinely used in hospital or institutions for handling radiation sources are given in Fig.5. For implementing radiological safety in

compliance with the national / international competent authority regulations, the hospitals / institutions must be facilitated with the essential radiation safety gadgets. The radiation warning symbols for different radiation safety purposes are given in Fig. (6-8). All radiation installation should be highlighted with radiation warning symbols as shown in Fig. 7. The radioactive transport package should be property packaged and labeled with radiation symbol with details of category of package, UN class number, type of package and transport index as shown in Fig. 6. IAEA has recently issued a new radiation warning symbols for awareness of the radiation worker and not meant for public as Fig. 8. This warning symbol should be displayed only inside the radiation facilities installation, not in the public domain. This symbol has potential to create unnecessary panic among the general public who are not aware much about the radiation.

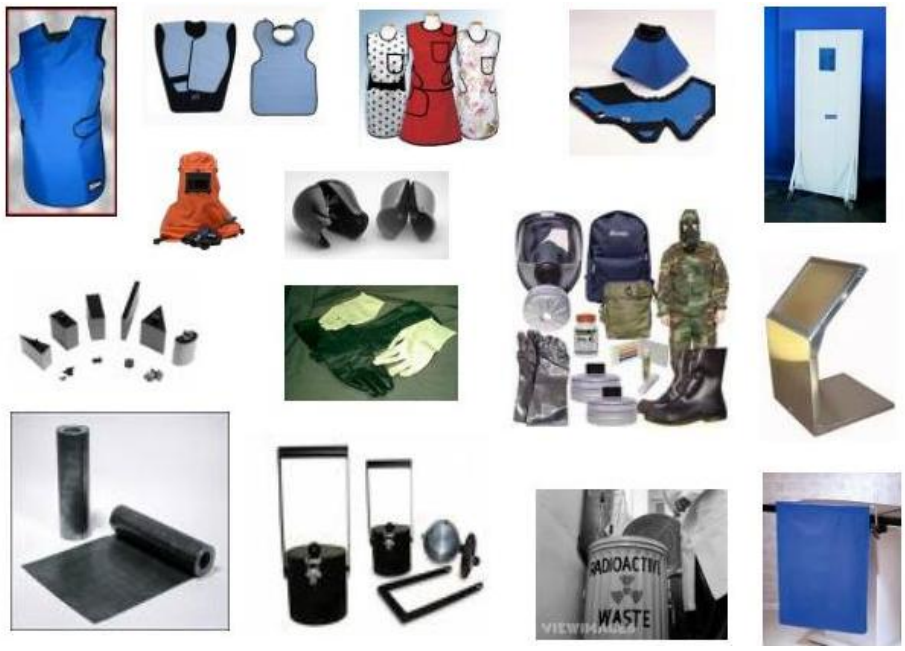

Fig.5: Radiation safety equipments/devices

Fig.6: Radiation Symbol for Radioactive packages

Fig.7: Radiation Warning sign to put on the radiation installation

Fig.8: Recent Radiation warning sign issued by IAEA for radiation workers awareness not for the public display

9. Responsibilities of the Radiological Safety Officer (RSO):

- The RSO is responsible for advising and assisting the Head of the institution/hospital on safety aspects aimed at ensuring that the provisions of radiation safety rules are implemented.
- The RSO has to carry out routine measurements and analysis on radiation and radioactivity levels in the controlled area, supervised area of the radiation installation and maintain records of the results thereof.
- The RSO should investigate any situation that could lead to potential exposures.
- The RSO liable provide advisory services to the head of the institution/hospital regarding –
  - The necessary steps aimed at ensuring that the regulatory constraints and the terms and conditions of the license are adhered to the safe storage and movement of radioactive material within the radiation installation.
  - Initiation of suitable remedial measures in respect of any situation that could lead to potential exposures.
  - Routine measurements and analysis on radiation and radioactivity levels in the off-site environment of the radiation installation and record of the results thereof.
  - The modifications in working condition of the pregnant worker.
  - The safety and security of radioactive sources.
  - The periodic reports on safety status of the radiation installation for forwarding to the competent authority.
- The RSO has to ensure that –
  - Reports on all hazardous situations along with details of any immediate remedial actions taken are made available to the head of institution for reporting to the competent authority and a copy endorsed to the competent authority.
  - Quality assurance tests of structures, systems, components and sources, as applicable are conducted; and monitoring instruments are calibrated periodically.
  - The radioactive sources are safely stored, used and maintained in the institution.
  - Safety audits are carried periodically for all radiation facilities of the institution.

10. Responsibilities of radiation worker:

Every radiation worker should observe the safety requirements and follow the safety procedures and instructions and refrain from any willful act that could be detrimental to self, co-workers, the radiation installation and public. *The worker should:*

- Provide information about his previous occupations including radiation work, if any to the head of the institution through RSO.

- Make proper use of protective equipments, radiation monitors and personnel monitoring devices as provided.
- Inform the Radiological Safety Officer, of any accident or potentially hazardous situation that may come to his/her notice.
- In case of female worker, on becoming aware that she is pregnant, she should inform to the head of the institution through Radiological Safety Officer in order to modify her working conditions, if necessary.

11. Guidelines for medical practitioners:

In the practice of medicine, a judgment is made concerning the benefit / risk ratio in a particular diagnostic or therapeutic medical procedure. When radiation is used for medical purposes, this requires knowledge not only of medicine but also of the radiation risks. ICRP-2001 has issued guidelines for the medical practitioners who use radiation for diagnostic as well for therapeutic purposes. The summary of the different radiobiological deterministic effects as per radiation doses which may help the medical professionals in optimizing the radiation practices are given in the table 3.

Organ/tissue	Effect	Threshold absorbed dose (mGy)	
		Short term exposure (single dose)	(Yearly doses, repeated for many years)
Testicles	Temporary sterility	150	400
	Permanent sterility	3500-6000	2000
Ovaries	Sterility	2500-6000	> 200
Ocular lens	Detectable opacities	500-2000	> 100
	Visual impairment (cataract)	5000	> 150
Bone marrow	Haemopoiesis impairment	500	> 400
Skin	Erythema (dry desquamation)	2000	----
	Moist desquamation	18000	----
	Epidermal and deep skin necrosis	25000	----
	Skin atrophy with complications and telangiectasia	10000-12000	1000
Whole body	Acute radiation sickness (mild)	1000	----

Table 3. Deterministic effects after whole body and localized irradiation by x and gamma rays

Various diagnostic radiology and nuclear medicine procedures cover wide dose range depending upon the procedure. Doses can be expressed either as absorbed dose to a single tissue, or as effective dose to the entire body, which facilitates comparison of doses to other radiation sources (such as natural background of radiation). One should also be aware that even for a given procedure, there might be a wide variation in the dose given for that same procedure on a specific individual when performed at different facilities. This variation may be up to a factor of ten and is often due to differences in technical factors for the procedures such as film/screen speed, film processing and voltage. Typical values of effective dose for some procedures are presented in the table 4.

Diagnostic Procedure	Effective dose (mSv) centered around a value of:	Equivalent period of natural background radiation	Life time additional risk of cancer per examination
Chest X-ray, Teeth X-ray, Arms and legs x-ray Hands and feet x-ray	0.01	A few days	Negligible risk
Skull X-ray Head X-ray Neck X-ray	0.10	A few weeks	Minimal risk 1 in 1,000,000 to 1 in 100,000
Breast X-ray (mammography) Hip, Spine, abdomen, Pelvic X-ray, CT head, Lung nuclear medicine isotope scan, Kidney isotope scan	1.00	A few months to a year	Very low risk 1 in 100,000 to 1 in 10,000
Kidney and bladder x-ray (IVU), Stomach x-ray (barium meal), Colon x-ray (barium enema), CT of abdomen, Bone Isotope Scan	10	A few years	Low risk 1 in 10,000 to 1 in 1,000

Table 4. Typical effective doses from diagnostic medical examinations using x-rays or isotope scans (NCRP 1990)

12. Recent recommendations of ICRP-2007 (Report No. 103):

The summary of the recent ICRP recommendation issued for implementing radiological safety in the working environment is given herewith. A worker is defined by ICRP as any person who is employed whether full time, part time, or temporarily, by an employer and who has recognized rights and duties in relation to occupational radiological protection. A member of public is defined as any individual who receives an exposure that is neither occupational nor medical. A large range of different natural and man-made sources contributes to the exposure

of members of the public. At radiation doses below 100 mSv in a year, the increase in the incidence of stochastic effects is assumed by the commission to occur with a small probability and in the proportion to the increase in radiation dose over the background dose. The application of LNT (Linear-No-Threshold) model is recommended to be the best possible practical approach to managing risk from radiation exposure. The commission considers that the LNT model remains a prudent basis for radiological protection at low doses and low dose rates. The probabilistic nature of stochastic effects and properties of the LNT model make it impossible to derive a clear cut distinction limit between 'safe' and 'dangerous' exposure and this creates some difficulties in explaining the control of radiation risk. The major policy implication of the LNT model is that some finite risk, however small, must be assumed and a level of protection established based on what is deemed acceptable. This leads to the commission's system of protection with its three fundamental principles of radiological protection:

- **Justification:** Any decision that alters the radiation exposure situation should do more good than harm. This means that, by introducing a new radiation source, by reducing existing exposure, or by reducing the risk of potential exposure, one should achieve sufficient individual or social benefit to offset the detriment it causes.
- **Optimization of protection:** 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, taking into account economic and societal factors.
- **Application of dose limits:** The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the ICRP.

The ICRP considers that certain exposures should be deemed to be unjustified without further analysis, unless there are exceptional circumstances. These include the following:

- Increasing, by deliberate addition of radioactive substances or by activation, the activity of products such as food, beverages, cosmetics, toys and personal jewelry or adornments.
- Radiological examination for occupational, health insurance, or legal purposes undertaken without reference to clinical indications, unless the examination is expected to provide useful information on the health of the individual examined or in support of important criminal investigations. This almost always means that a clinical evaluation of the image acquired must be carried out; otherwise, the exposure is not justified.
- Medical screening of asymptomatic population groups involving radiation exposure, unless the exposed advantages for the individual examined or for the population as a whole are

sufficient to compensate for the economic and societal costs, including the radiation detriment.

Medical exposures are predominantly delivered to individuals (patients) undergoing diagnostic examinations, interventional procedures, or radiation therapy. Other individual caring for and comforting patients are also exposed to radiation. These individuals include parents and others, normally family or close friends, who hold children during diagnostic procedures or may come close to patients following the administration of radiopharmaceuticals or during brachytherapy. Exposures to members of the general public from released patients also occur, but this exposure is almost always very small. In addition volunteers in biomedical research often undergo medical procedures involving radiation exposure that are similar procedures performed on patients. In applying the principle of optimization of protection of the patient, the benefits and detriments are received by the same individual, the patient, and the dose to the patients are determined principally by the medical needs. Dose constraints for patients are therefore inappropriate in occupational and public exposure. The limitation of the dose to the individual patient is not recommended by ICRP because it may by reducing the effectiveness of the patient's diagnosis or treatment, do more harm than good. The physician and other health professionals involved in the procedures that irradiate patients should always be trained in the principle of radiological protection, including the basic principle of physics and biology. The final responsibility for the medical exposure of patient lies with the physician, who therefore should be aware of the risk and benefits of the procedures involved.

The medical use of radiation should be justified, although that justification lies with the medical profession rather than with the government or regulatory authorities. The principal aim of the medical exposures is to do more good than harm to the patient, subsidiary account being taken of the radiation detriment from the exposure of the radiological staff and of other individuals. The responsibility of the justification of the use of a particular procedure falls on the relevant medical practitioners. The principle of justification applies at three levels in the use of radiation in medicine.

- At the first level, the use of radiation in medicine is accepted as doing more good than harm to the patient. The level of justification can now be taken for granted.
- At the second stage, a specified procedure with a specified objective is defined and justified (e.g., chest radiographs for patients showing relevant symptoms, or a group of individuals at risk to a condition that can be detected and treated). The aim of second level of justification is to judge whether the radiological procedure will usually improve the diagnosis or treatment or will provide necessary information about the exposed individuals. The justification of the radiological procedure is a matter for national and international

professional bodies, in conjunction with national health and radiological protection authorities and corresponding international organizations. The possibility of accidental or unintended exposures should also be considered. The decision should be reviewed from time to time, as more information becomes available about the risks and effectiveness of the existing procedure and about new procedure.

- At the third level, the application of procedure to an individual patient should be justified. Hence all individual medical exposures should be justified in advance, taking into account the specific objectives of the exposure and the characteristics of the individual involved. Justification of individual exposure should include checking that the required information is not already available and that the examination is the most suitable method of providing the clinical information required. For high-dose examinations, such as complex diagnostic and interventional procedures, individual justification is particularly important and should take account of all available information.

ICRP-2007 (103) has revised the radiation weighting factors (W_R) and Tissue Weighting factors (W_T) data as tabulated in table 5 & 6 as per need and demand of the recent radiation research.

Radiation Type	Radiation Weighting Factor (W_R)
Photons	1
Electrons and Muons	1
Protons and Charged Pions	2
Alpha particles, Fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy $2.5 + 18.2 \exp[-\{\ln(E_n)\}^2/6]$, $E_n < 1$ MeV $5.0 + 17.0 \exp[-\{\ln(2E_n)\}^2/6]$, $1 \text{ MeV} \leq E_n \leq 50$ MeV $2.5 + 3.25 \exp[-\{\ln(0.04E_n)\}^2/6]$, $E_n > 50$ MeV

Table 5. Radiation Weighting Factors (W_R), ICRP-103

Tissue	W_T	$\sum W_T$
Bone marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues {Adrenals, Extra-thoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscles, Oral mucosa, Pancreas, Prostate, Small intestine, Spleen, Thymus, Uterus/cervix}	0.12	0.72

Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary Glands, Skin	0.01	0.04
Total		1.00

Table 6. Tissue Weighting Factors (W_T), ICRP-103

For the purpose of controlling occupational exposure, there is no distinction between the two sexes (male/ female). However, a female worker once declared that she is pregnant, additional controls have to be considered to protect the embryo / fetus. The working conditions of a pregnant worker, after declaration of pregnancy, should be such as to ensure that the additional dose to the embryo/fetus would not exceed about 1 mSv during the remainder of the pregnancy. In publication ICRP-60, the commission recommends that exposures to cosmic radiation be a part of occupational exposure in the operation of commercial jet aircraft and space flight. It is again clarified in ICRP-75, indicating that it is not necessary to treat the exposure of frequent-flier passengers as occupationally exposed for the purpose of control. Thus, only the exposure of aircrew can be considered as occupational exposure as per recommendation of ICRP-103.

Major changes from earlier recommendations: The following summary statements related largely to health effects attributed to radiation in the dose range upto around 100 mSv (as single or annual doses) for the purposes of radiological protection.

- For the induction of cancer and heritable disease at low dose and low dose rates, the use of a simple proportionate relationship between increments of dose and increased risk is scientifically plausible assumption; uncertainties on this judgment are recognized.
- A dose and dose rate effectiveness factor (DDREF) of ICRP-60 recommendations is retained for radiological protection purposes; the effect of introducing the possibility of a low-dose threshold for cancer risk is judged to be equivalent to that of an uncertain increase in the value of DDREF.
- The changes in the radiation weighting factors (W_R) of protons and neutrons have been proposed.
- New radiation detriment values and tissue weighting factors (W_T) have been proposed; the most significant changes from ICRP-60 related to breast, gonads, and the remainder

tissues. The W_T changes in question are: breast (0.12 from 0.05); gonads (0.08 from 0.20); remainder tissues (0.12 from 0.05 using a new additive system).

- Based on cancer incidence data, detriment adjusted risk coefficients have been changed from 6.0 x 10^{-2} Sv^{-1} to 5.5 x 10^{-2} Sv^{-1} for whole population and from 4.8 x 10^{-2} Sv^{-1} to 4.1 x 10^{-2} Sv^{-1} for adult workers.
- Detriment adjusted probability coefficients for heritable disease upto the second generation are changed from 1.3 x 10^{-2} Sv^{-1} to 0.2 x 10^{-2} Sv^{-1} for whole population and from 0.80 x 10^{-2} Sv^{-1} to 0.10 x 10^{-2} Sv^{-1} for adult workers.
- Cancer induction to the children following in-utero exposure is judged to be no greater than that following exposure in early childhood.
- Genetic susceptibility to radiation-induced cancer involving strongly expressed genes is judged to be too rare to appreciably distort estimates of population risk; the potential impact is common but weakly expressing genes remains uncertain.
- Dose responses for radiation-induced tissue reactions (deterministic effects) in adults and children are, in general, judged to have true dose threshold which result in the absence of risk at low doses; further consideration of the extent of the dose threshold for cataract induction (visual impairment) is recommended.
- Dose responses for in-utero radiation-induced tissue reaction, malformations and neurological effects are also judged to show the dose threshold above around 100 mSv; uncertainty remains on the induction of IQ deficits but at low doses the risk is judged to be no practical significance.
- Risks of non-cancer disease at low doses remain most uncertain and no specific judgment is possible.

13. General radiation safety guidelines for radiation workers:

- Only trained and experienced persons in safe handling of radioisotopes should work with radioactive materials. Radiation sources should be issued through a logbook maintained in the institution/hospital.
- Eating, smoking and drinking in the room using unsealed radioisotopes are strictly prohibited.
- The chemical solution should not be pipetted by mouth in the room where unsealed radioisotopes are used.
- Radiation workers with wound and cuts in their body are not allowed to work with unsealed sources.

- All occupational workers should familiar with proper method of wearing and removing gloves, aprons and shielding equipments.
- At the end of the work with unsealed radioisotope and at the end of the day's work, monitoring and washing (decontamination if required) are essential.
- Uncontaminated and contaminated protecting clothing should be kept in separate bags at prescribed place.
- Unsealed or sealed radioisotopes should be stored suitably with proper radiation warning on the source container and storage room.
- Before handling radioactive material by an unfamiliar technique, dummy experiments (mockup drills) with inactive source should be performed and practiced.
- All table topes likely to be contaminated should be covered with a polythene sheet/ blotting paper etc, which should be frequently monitored and if found contaminated must be disposed off properly.
- All operations with unsealed active sources should be carried out inside trays lined with absorbent paper.
- Care must be taken to avoid contamination of general-purpose facilities such as; light switches, water taps, door latches, counting and monitoring instruments. Tissue papers can be used for these purposes.
- Separate sets of glassware should be used for each different isotope to minimize cross-contaminations.
- All operations likely to produce radioactive air contamination should be carried out in glove box of fume hood.
- Properly marked containers (foot operated bins for solid and plastic carboys for liquid) should be kept in the experiment room for collecting radioactive wastes.
- Different types of radioactive wastes (solid/liquid) should be segregated and stored in different bins and if possible disposed in consultation with RSO.
- All cases of contamination of equipment, floor, bench etc and spill shall be reported in written to RSO, who will take appropriate action to decontaminate.
- All radioactive material must be stored in secured area/storage room. Keys of radioactive material storage room should be in control of RSO of the institution/hospital.
- No radiation worker should approach radioactive facility without wearing a personnel-monitoring badge and without having working survey meter in "ON" condition.
- The RSO or health physicist should maintain logbook for each radiation instruments or sources.

- RSO/health physicist must maintain a source issue register. No source should be allowed to use without proper entry in the register.
- Follow time, distance and shielding principles, while handling radioactivity. Radiation cannot be seen, hence use calibrated radiation survey meter while approaching radioactivity. Use proper personnel monitoring device. Report unusual occurrences to RSO for his/her action.

14. Future perspectives:

It is a general belief that low doses of ionizing radiation produce detrimental effects proportional to the effects produced by high-level radiation. Over the past decades, however, some pioneer scientists have reported that low-dose ionizing radiation is not only a harmless agent but often has a beneficial or hormetic (the beneficial effect of small doses) effect. That is, low-level ionizing radiation may be essential trace energy for life, analogous to essential trace elements. It has been even suggested by some investigators that about one third of all cancer deaths are preventable by increasing our low dose radiation. Radiation hormesis implies stimulation by ionizing radiation. Although small doses of radiation can stimulate cell and cancer growth, the stimulation of different components of our complex immune system more than compensates for simple cellular effects. The net effect is decreased cancer mortality. The concept of radiation hormesis is usually applied to physiological benefits from low LET radiation in the range of 1-50 cGy total absorbed dose (Macklis 1991). One of the first studies in radiobiology (1898) found that X-irradiated algae grew faster than un-irradiated control groups. Stimulated growth was noted in trees (1908) and increased life span in invertebrates (1918) and insects (1919). X-Ray stimulated seedlings (1927), plant growth (1937), along with guinea pigs, rabbits and mice (1940's) had also been observed in past. Increased life span was the rule in low dose irradiated rats, dogs, and even house flies (1950's). After the atomic bomb explosions in Hiroshima and Nagasaki, studies concerning life span of atomic bomb survivors showed a linear relationship between cancer mortality and high doses of radiation (Pollycove, 1998). In an Indian study, it was observed that in areas with a high-background radiation level (Kerala coastal area), the incidence of cancer and also the mortality rate due to cancer was significantly less than similar areas with a low background radiation level (Nambi and Soman, 1987). In a very large-scale study in U.S.A, it was found that the mortality rate due to all malignancies was lower in states with higher annual radiation dose (Frigerio, 1976).

Our radiation protection policy is based on linear extrapolation from the dose-response data of high doses of ionizing radiation (LNT theory). According to the results of many worldwide

studies, this assumption is not compatible with observed health effects of low levels of radiation. Obviously LNT and current radiation protection regulations exaggerate the risk of low-level ionizing radiation (in the range of 1-50 cGy) and cause radio-phobia (Yalow RS 1990). It is concluded that according to new findings, the existence of radiation hormesis and adaptive response are not deniable and abandoning the LNT theory in low dose risk estimations will be a real necessity in the near future. It is widely believed that radiation biology in the future will be focused on bio-molecular and genetic implications, problems of damage and repair and connected problems such as radiation hormesis and radio-adaptive response. Medical communities have to look into the matter to get health benefit from the low level of ionizing radiation exposures.

Secondly, in the light of guidelines of Atomic Energy Regulatory Board, Mumbai, each institution should constitute a Radiological Emergency Response Committee (RERC) to handle radiological emergency within the institution. RERC has to keep ready in terms of infrastructures and manpower and be vigilant for any radiological emergency in its institution/hospital.

15. Conclusion:

Ionizing radiation has served the mankind many fold than any other scientific inventions in the form of medical, industrial, agriculture applications, and scientific solutions. Radiation is totally safe if, handled properly. Awareness, preparedness and detecting equipments are the main key factors while using radiation sources for peaceful purposes.

17. Recommended readings:

- Estimation of effective dose equivalent from tritiated water exposure using tritium concentration in urine. J. R. Johnson, Radiation Protection Dosimetry 2, 245,1982.
- Govt. of India Gazette Notification No.44, Part II, Section 3, Oct. 30, 1971, GSR-1601.
- IAEA Safety series No. 48, Manual of decontamination of surfaces, STI/PUB/483, 1979.
- Limits of intakes of radionuclide by workers. Annals of ICRP Part I, Vol. 7, 1-3, ICRP-30, 1982.
- Maximum permissible activities in radioactive consignments, Document RPG/TR-1, DRP/BARC, 1982 and code of safety in transport of radioactive material (AERB Code No. SC/TR-1), 1986.
- Radiation and your patient: A guide for medical practitioners, Annals of the ICRP, Supporting Guidance 2, Vol. 31, No. 4, (2001).
- Radiological Safety for the design and installation of land-based stationary Gamma Irradiators. AERB Standard Specification No. 6, AERB-SS-6 (1993)

- Radiological Safety in Neutron Generator Installations. RPG/R-1, DRP, BARC (1982).
- Radiological Safety in the design and manufacture of consumer products containing radioactive substances. AERB Standard Specification No.4, AERB-SS-4 (1991).
- Radiological safety in the design and manufacture of X-ray analysis equipments. AERB Standard Specification No.5, AERB-SS-5 (1992).
- Radiological Safety in the design, construction and use of industrial ionizing radiation gauging devices. AERB Standard specification No. 2, AERB/SS-2 (1990).
- Radiological Safety in the use of radioactive neutron sources in industrial and research establishments, RPG/IND-2, DRP, BARC (1982).
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- Recommendations of ICRP, Annals of ICRP Vol. 1 (3), ICRP Publication 26 (1997).
- Regulations for the safe transport of radioactive materials, Safety Series No.6, IAEA, (1979).
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- Techniques and practices for pretreatment of low level and intermediate level solid and liquid radioactive waste. Technical Series No. 272, IAEA, (1987).
- Testing and classification of sealed radioactive sources, AERB Standard Specification, AERB/SS-3, (1990).
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- Utility of excretion data for estimation of Pm-147 body burdens of dial painters. J. H. Dunlop, Health Physics 47 (2), 324-326, (1984).