RADIATION SAFETY MANUAL

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY

Index Page No

Scope

This manual is applicable to all activities involving the use and handling of radioactive isotopes in the Institute laboratories. This manual deals only with ionising radiation safety.

Introduction

Radiation is a form of energy in transit which occurs naturally and artificially. We are exposed to radiation from radioactive elements present in the earth crust and cosmic radiation from outer space.

Nuclear reactors, X ray equipments, etc., are examples of manmade sources of radiation.

Effects of exposure to high radiation doses can be visible within few hours whereas the effects of low radiation doses may appear after several years.

Exposure to radiation in excess of permissible limits can result in serious biological damage which can be passed on to future generations. This calls for utmost care and adoption of safe work practices while working with radioactive isotopes.

Radioactive Emission

- Emission of radiation from an isotope is in the form of photons or energetic particles.

- All matter is made up of atoms. The nucleus of an atom consists of positively charged protons and electrically neutral neutrons. The negatively charged electrons spin around the nucleus in shells.

- A radioactive nucleus has an imbalance in the proton to neutron ratio, with an excess number of neutrons in the nucleus.

- The nucleus tries to reach a stable state by changing its components in the following ways

    - A neutron will change itself into a proton by emitting an electron, which is called a beta particle.

    - A proton can change into a neutron by emitting a positive electron (positron). The positron gets annihilated when it comes in contact with a negative electron.

- Ionising radiation can knock out orbital electrons from atoms. The atom becomes a positive ion due to excess positive charge and the expelled electron becomes a negative ion. Ionisation involves transfer of energy.

Types of Ionising Radiation

Alpha particles

- Alpha emitting radionuclides have massive nuclei. Almost all alpha emitters have atomic numbers greater than or equal to lead (^{82}Pb).

- It consists of two protons and two neutrons. They combine with electrons in the medium in which they are passing to form helium atoms.

- Alpha particles can travel short distance in air. They can be stopped by a thin sheet of paper or by the clothing worn.

- Alpha particles do not pose an external health hazard as they travel only a few microns into the tissue. They do not penetrate even the outer dead layer of the skin.

- They can cause serious damage if the source enters the body. Their disintegration causes tissue damage in the immediate vicinity where they are deposited. They can accumulate in bone and other body organs like liver, kidney etc.

Beta particles

- Beta particles are high energy electrons produced by disintegration of the nucleus. Their energies will vary depending upon the radioactive isotope concerned.

- Higher the energy the deeper will be the penetration. Beta particle with energy of 5 MeV will penetrate 5cms into tissue. Longer exposure to beta particles can result in skin burn.

- Beta particles are mainly an internal hazard, if they enter the body by means of ingestion or inhalation.

- When compared with the alpha particles, beta particles are more hazardous externally because of their high penetration power.

- When the beta particle is slowed down or stopped, secondary X radiation known as bremsstrahlung may be produced.

- Light metals like aluminium are preferred for shielding beta particles as they produce less bremsstrahlung radiation.

- Common beta radiations have ranges in air less than 9 m and depending upon their energy, they will be stopped by the walls of the room or by a sheet of aluminium which is at least 1.3cm thick.

Gamma radiation

- Gamma rays are very high energy electromagnetic radiation of short wavelength that are deep penetrating. They can travel many meters in air.

- Gamma rays are emitted when a nucleus undergoes a transition from a higher to a lower energy state.

- Gamma rays present an external exposure hazard because of their deep penetration.

- Thick shielding of lead or concrete is required for attenuating gamma radiation.

Ionising radiation and injury

The hazards that are usually encountered in using radioisotopes arise from:

External exposure

- External exposure results when the person gets exposed to radiation emitted from external sources of radiation.

- The resulting damage will depend upon the type of the radiation emitted, energy of the source and duration to which the person is exposed.

- In this situation the person can be seriously injured, but is not radioactive.

Contamination

- Contamination can be external or internal.

- External contamination results when radioactive source in the form of solid, liquid or gas comes in contact with the body of the person.

- Radioactive sources can also enter inside the body through inhalation, ingestion or wounds on the skin resulting in internal contamination.

Incorporation

- Incorporation results following an internal contamination when the radioactive material gets deposited in the target organ.

- Ionising radiation transfers energy to any material that comes in contact with it. This results in disruption of chemical bonds in cells resulting in permanent damage. The extent of damage will be based on the amount of energy received.

- Once the radionuclides are inside the body, they get metabolised and distributed in the organs according to their chemical properties.

Biological Effects of Radiation

A human body can tolerate a certain amount of exposure to ionizing radiation without having any adverse health effects. The degree of injury depends on the total dose, the rate at which the dose is received, the kind of radiation, and the body part receiving it.

The biological effects of radiation resulting from acute or chronic exposure can be classified as

Somatic – those affecting the cells responsible for the maintenance of body functions**.**

Genetic – those affecting the germ cells which are responsible for the propagation of genetic characteristics.

Chronic exposures

- Long term exposures to low levels of radioactive emission must be prevented.

- Special attention is required in preventing exposure as well as contamination through ingestion or skin contact.

- Chronic exposures have been found to have resulted in increasing incidence of leukemia. It can also cause cataract of eyes, induction of bone tumors etc.

- Radiation strips electrons from atoms and breaks their chemical bonds.

- The effect of ionizing radiation in living tissue is due to the ionization process which destroys the capacity of reproduction or can also cause mutation.

- The human body has the capability to repair damaged cell. But cell damage must be within the body's repair capabilities.

- Parts of eye, brain and most muscular tissues are unable to produce new tissue to replace the damaged cell.

- Tissues such as bone marrow, which contains blood forming cells, the lining of digestive tract and some cells of the skin are more sensitive to radiation.

- Single exposure to relatively small dose may have no effect, but may produce abnormalities if continued long enough.

- The time between the exposure and the first sign of radiation damage is called "latent period". Larger the dose, shorter the latent period.

- Radiation damage to human reproductive materials can be transmitted to succeeding generations.

- Ionising radiation can alter or destroy either chromosomes or genes or both. This will result in mutation and the cells produced after cell divisions are different from the parent cell.

- If any damage has been caused to germ cells, the offspring may develop abnormality. Mutational changes are irreversible.

Radiation protection

There are three effective means of protection from ionizing radiation, these are time, distance and shielding.

Time

- Limiting the time of exposure helps to limit the exposure dose.

- It is important to plan the activities such that the time spent in the radiation area is as less as possible.

- There is a direct relationship between the exposure dose and the duration of exposure; reducing the exposure time by one half will reduce the dose received by one half.

Distance

- Maintaining maximum distance from the source helps to limit exposure.

- If the distance between the source and the person is doubled then the exposure will be reduced to a quarter of the original value. The reduction of the exposure is exponential.

- Maintaining distance from the source will help to reduce the number of photons (e.g., gamma rays) per unit time encountered to an acceptable level.

Shielding

- Shielding consists of placing a barrier or shield, between the radiation and the person handling the radioactive isotope to protect against radioactive exposures.

- The greater the mass placed between a source and a person, the lesser the radiation the person receives.
- The denser the material, lesser the barrier thickness required.
- Shielding can be in any of the following forms:
  - Cladding on radioactive material.
  - Containers with heavy walls and covers for radioactive sources.
  - Thick concrete walls.

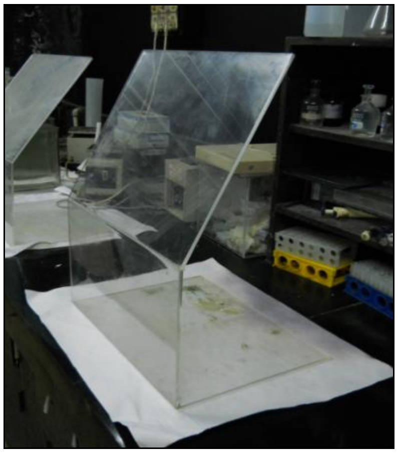
Shielding for various radiations

Alpha

A thin sheet of paper can offer protection from alpha particles. Clothes worn by person will help to block alpha particles.

Beta

Beta particles require light materials such as aluminium or thick plastic.



Materials of low atomic number are chosen to shield against beta particles to minimize the production of bremsstrahlung radiation.

Gamma

Gamma radiation is an electromagnetic radiation unlike particulate radiation, it cannot be completely stopped, it can only be attenuated. However, shielding will help to attenuate the radiation to very low levels.

This can be done by lead shields or thick concrete walls.

Determination of radiation exposure

Radiation monitoring techniques can be classified as

- Personnel monitoring and
- Area monitoring

Personnel Monitoring.

- Personnel monitoring involves measuring the radiation exposure by monitoring device worn by the person.

- Doses received are checked with appropriate instruments to ensure that maximum permissible doses are not exceeded and to make it possible to keep individual cumulative dose records.

- Internal contamination monitoring is done by the use of suitable equipments by analyzing body samples to determine the presence and quantity of radioactive material within the body.

- Such tests are performed where radioisotopes may enter the body through ingestion, inhalation, skin or through skin punctures and open wounds.

Types of personnel dosimeters.

Film badges

- Film badges are worn on outer clothing; the film consists of a photographic emulsion mounted in plastic.

- It also contains metallic filters usually copper, cadmium and aluminium to help distinguish among high energy photons.

- When the film is exposed to radiation it alters the silver halide grains that comprise the film emulsion.

- The darkening of film is compared with films exposed to known amounts of radiation of the same energy.

- Film badges provide a permanent record of each individual's accumulated exposure.

- Badge must not be exposed to sunlight or other source of heat, as heat affects the film.

Thermo luminescence detectors (TLD)

- These can be worn on a person's body as badges or finger rings.

- The electrons in a thermo luminescent crystal, on absorption of energy, move into a higher energy conduction band.

- They get trapped in an excited state until they are heated to a specific temperature, at which they return to original state by radiating the extra energy in the form of visible light photons.

- Lithium fluoride and lithium tetraborate are two commonly used crystals.

- A TLD readout instrument is used for measuring the light emitted from the chip. The amount of light released is related to absorbed radiation dose.

- TLDs can be reused. They are used to measure external individual doses from X, gamma and beta rays.

Pocket dosimeter

- The pocket dosimeter is a direct reading portable unit shaped like a pen with a pocket clip. It is generally used to measure X ray and gamma radiation.

- A dosimeter consists of a quartz fiber, a scale, a lens to observe the movement of the fiber across the scale, and an ionization chamber.

- The fiber is charged electrostatically until it reaches 0 on the scale. Then as the fiber is exposed to radiation, some of the atoms in the chamber become ionised.

- This allows the static electricity charge to leak from the quartz fiber in direct relationship to the amount of radiation present.

- As the charge leaks away, the fiber deflects to a new position on the scale that indicates the amount of radiation exposure.

- The main advantage of the pocket dosimeter is that it allows the individual to determine his radiation dose while he is working with radiation, rather than waiting until after periodic processing of a film badge or TLD.

Area Monitoring

- To prevent exposure to personnel working with radioactive isotopes it is important to monitor the radiation levels to ensure that the permissible limits are not exceeded.

- All locations around the radioactive source where personnel are exposed to radiation must be monitored.

- Monitoring must be done before starting a task, after any significant modifications in the research activities and at the completion of the job.

- Portable ionization chambers, GM-counters, scintillation counters are examples of devices used for area monitoring.

Ionisation chambers

- Radiation can be measured conveniently and accurately by measuring the ionization in a small volume of air.

- The ionization chamber consists of two plates or electrodes with an electrical potential between them placed in a container filled with air.

- If ionization chamber is exposed to a beam of radiation, a current will flow in the circuit because the electrons that are knocked out of the atoms by the radiation will be attracted by positive electrode.

- The ionization chamber measures can be used to measure alpha, beta and gamma radiations.

Geiger- Mueller Counters

- They are extremely useful for monitoring weak sources of beta and gamma radiations.

- Because of their high sensitivity they are used for measuring contamination and lost radiation sources.

- It uses an ionization chamber but it is filled with a special gas and has a greater voltage supplied between its electrodes.

- Electrons are freed by the initial ionization process and they acquire enough extra energy by the applied voltage to create more ions.

- Surface contamination may be checked up by taking swipe samples of the loose contamination with filter papers and counting the activity in an end window Geiger – Muller Counter.

- All instruments used for monitoring should be calibrated and checked regularly.

Monitoring of contamination on surfaces of rooms and equipment.

- Everything used for work with radioactive materials may be subjected to widespread contamination.

- This includes work benches, equipments, glassware, clothing, floor or walls of working rooms, etc. This can be a serious health hazard to personnel working inside the laboratories.

- A systematic monitoring of all areas that has been in contact with radioactive materials must be performed. Such monitoring must be performed at least when the work is over and also during the work.

- Thin windowed GM counters are suitable for examining the smear samples taken.

Monitoring of skin and clothing.

- Monitoring of hands, shoes, and clothing must always be carried out when working with containers of unsealed sources.

- No person must leave the laboratory without checking for contamination.

- Monitoring for contamination of the skin and clothing can be done with a GM counter.

Types of radioactive sources

The radiation sources in use can be classified as sealed and unsealed/open sources.

Sealed Sources

These sources are sealed in a container or in a manner to protect it from mechanical disruption. Sealed sources do not contribute to contamination.

Co-60 and Cs-137 are some of the more commonly used sources. These are sealed in capsules to prevent the escape of the radioactive material and due care must be taken against breakage.

The main hazard involved in the use of sealed source is external exposure.

The following points have to be kept in mind while the work is being carried out.

- The energy of the emitted radiation must not be greater than that required for performing the task.
- Inventory of the radioactive sources must be maintained.
- Warning signs must be displayed in front of the areas handling radioactive isotopes.
- Sources must not be touched by hands. Long handled forceps with firm grip or other suitable devices to be used.
- Work must be planned in advance so that minimum time is spent in the radiation area.
- The sealed sources must be periodically checked for leakage and contamination. This can be done by, scrubbing the dry container with a dry filter paper and counting the activity.
- In case of mechanical damage, the source must be placed in a sealed container.
- While working with any sealed radiation source, adequate shielding must be provided and the adequacy must always be tested by direct measurements.

Open/Unsealed sources- mean any radioactive material that is not sealed and which are used for secondary preparations through dilutions, etc.

They are potential sources of contamination and require more care in handling when compared with that of sealed sources.

There are chances of entry into the body as a result of ingestion and inhalation of air-borne particles and skin absorption through contact with contaminated surfaces.

Working with unsealed sources

- Equipment, tools or glassware used in radioactive areas must be marked/identified and must not be taken out of the radioactive laboratory.

- Similarly, equipment must not be brought from outside into radioactive room unnecessarily.

- Hazards related with handling unsealed sources depend on factors such as the
    - types of compounds in which the isotopes appear,
    - volatility,
    - procedures involved in the experiment and
    - relative doses of radiation to the critical organs and tissues.

- The source must be handled in secondary containers to contain spills.

- Work surfaces must be covered with absorbent material to soak up minor spills. Same must be considered as radioactive waste after use.

- Shielding must be provided as near to the container of radioactive substances as possible.

- Equipment like pipettes and other tools used must not be placed directly on the bench, but in trays and pans with absorbent disposable paper.

- The working methods and procedures adopted must be such as to minimize the formation of aerosols, gases, vapours or dusts.

- Wet operations must be used instead of dry ones.

- Frequent transfers must be avoided.

- The quantity of radioactive substances necessary for a specific purpose must always be chosen as small as possible.

- Open radioactive sources must not be manipulated with unprotected hands.

- Laboratory coat, hand gloves and safety glasses must be used while working with unsealed radioactive substances.

- Open toed footwear must not be used in the laboratory.

- Care must be taken not to contaminate objects needlessly, in particular, light switches, taps, door knobs, etc. The gloves should be either taken off or a piece of non-contaminated material (tissue paper) should be used for the same.

- The gloves must be worn and removed in a manner without contaminating the inner side and the hands.

- Mouth pipetting must not be done in the laboratories.

- Precautions must be taken to avoid puntures or cuts while handling/manipulating radioactive isotopes.

- Any person who has a wound or abrasion below the wrist must not handle radioactive isotopes.

- Glassware or containers with sharp edges must not be used in radioisotope laboratories.

- The following items must not be introduced into laboratories.

    - Food or drinks
    - Books/note pads
    - Handkerchiefs

- Disposable paper towels and paper handkerchiefs must be used in the laboratory.

- Hands must be washed thoroughly before leaving the laboratory with special attention to nails, in between fingers and outer edges of the hands.

- Hands, shoes and clothing worn must be monitored for contamination before leaving the lab.

- All radioactive sources must be stored in the radioactive room. The sources must not be stored in individual labs.

Radiation Units

Becquerel (Bq)

The strength of a radioactive source is measured in units of Becquerel (Bq). It is equivalent to one disintegration per second. This unit provides a measure of the rate of radioactive disintegration. There are 3.7 X 10^{10} Bq per curie of radioactivity.

Curie (Ci)

An older unit of measuring radioactivity is the curie (Ci). One curie corresponds to 3.7 x 10^{10} disintegrations per second.

1 Ci = 37000 MBq.

Becquerel (Bq) or Curie (Ci) is a measure of the rate of radiation emission from a source.

Half life

Radiation intensity from a radioactive isotope diminishes with time as more and more radioactive atoms decay and become stable.

Half life is the time after which the radiation intensity is reduced by half, as half of the radioactive atoms will be decayed in one half life period.

Half lives vary from a fraction of a second to millions of years.

Roentgen (R)

X ray and gamma ray exposure is often expressed in units of roentgen (R). Roentgen is the amount of radiation that produces ionization resulting in one electrostatic unit of charge in one cubic centimeter of dry air at standard conditions.

Measuring radiation dose

Absorbed dose

The amount of energy absorbed per unit weight of the organ or tissue is called absorbed dose. It is expressed in units of Gray (Gy).

One Gy is equal to one Joule of absorbed energy per kilogram of matter.

Rad is the older unit and
1 Gy = 100 rads

Equivalent dose

Equal doses of all types of ionising radiation will not have the same harmful effect. This difference is expressed as equivalent dose in units of Sievert (Sv).

The equivalent dose in Sv is equal to "absorbed dose" multiplied by a "radiation weighting factor". Equivalent dose is often referred to simply as “dose”. The old unit used for equivalent dose is rem.

The radiation weighting factor for x rays, gamma rays and beta particles are taken as 1. For alpha particles the radiation weighting factor is taken as 20.

1 Sv = 100 rem
1 R exposure is approximately equivalent to 10 mSv tissue dose

Effective dose

The effective dose is the sum of weighted equivalent doses in all the organs and tissues of the body. It indicates a combination of different doses to different tissues.

It is expressed in Sievert (Sv)

Effective dose = sum of [organ doses X tissue weighting factor]

Tissue weighting factors (TwFs) represent relative sensitivity of organs for developing cancer. For TWF for gonads-20, red bone marrow is 0.12, liver 0.05, skin-0.01, etc.

Radiation symbol or Warning sign:-

The radiation symbol or warning sign must be conspicuously and prominently displayed at all times

- On external surfaces of radiation equipment.
- Containers for storage of radioactive materials.
- Packages for radioactive materials.

- At the entrance to the room housing the radiation generating source.

Specifications for radiation symbol/warning sign (As per AERB)

- The trefoils and the circle shall be of magenta colour.
- The background of the above symbol shall be yellow.
- The symbol should be accompanied by appropriate legend in English, Hindi and local language indicating radiation hazard and restricted entry, e.g. CAUTION – RADIOACTIVITY.

Dose Limits

The occupational exposures of any worker shall be so controlled that the following limits are not exceeded:

- an effective dose of 20 mSv/yr averaged over five consecutive years
- an effective dose of 30 mSv in any year;
- an equivalent dose to the lens of the eye of 150 mSv in a year;
- an equivalent dose to the extremities (hands and feet) of 500 mSv in a year and
- an equivalent dose to the skin of 500 mSv in a year;
- Limits given above apply to female workers also. However, once pregnancy is declared the equivalent dose limit to embryo/fetus shall be 1 mSv for the remainder of the pregnancy.

Radionuclides classified according to relative radiotoxicity per unit activity (International Atomic Energy Agency)

Group I (Very High Toxicity)	^{210}Pb	^{230}U	^{241}Am	^{210}Po	^{226}Ra	^{227}Th	^{240}Pu
Group II (High Toxicity)	^{60}Co	^{22}Na	^{131}I	^{236}U	^{137}Cs	^{90}Sr	^{212} Pb
Group III (Moderate Toxicity)	^{14}C	^{32}P	^{35}S	^{31}Si	^{57}Co	^{42}K	^{203}Pb
Group IV (Low Toxicity)	^{3}H	^{85}Kr	^{87}Rb	^{232}Th	^{59}Ni	^{71}Ge	^{147}Sm

(This table contains details of only selected radioisotopes and is not a complete list)

Waste disposal

Wastes generated can be of the following types:

Solid waste

- Solid waste includes filter papers, contaminated glass, plastic tips, hand gloves, etc.

- The waste must be stored in a Perspex box. Based on the half life, after the level of radiation is reduced below permissible limits, same can be disposed off as normal waste.

- Wastes with a longer half life must be stored until they are handed over to statutory body.

Liquid waste

- If a solution contains low activity below the permissible level, it may be disposed off in drain followed by a large flushing of water. Statutory norms must be followed for the same.

- Active sources, active spills, etc., must be collected in polyethylene carboys for disposal.

- All containers used for storing radioactive waste must be properly labelled.

Decontamination

Types of contamination in research laboratories handling radioisotopes can be of the following

- Personal contamination
- Equipment contamination, and
- Work area contamination.

Inspite of due care taken during handling of radioisotopes, there are always chances of contamination, on which appropriate measures should be taken to decontaminate.

Personal decontamination

Measures to be taken in case of external contamination of personnel.

- Maintaining personal cleanliness is of utmost importance while handling radio isotopes.

- The immediate washing of contaminated areas with water and soap must be done for removing loose contamination.

- Washing must be done gently without causing any damage to the skin.

- After washing for a few minutes the skin must be dried and monitored.

- Washing may be repeated if necessary without causing skin damage.

- Use of organic solvents or alkaline solutions must be avoided.

- While washing hands special care must be taken to ensure proper cleaning of finger nails, inter-finger space, folds and the outer edges of the hands.

- While washing care must be taken to prevent contamination of uncontaminated parts or internal contamination.

- If there is a chance of spreading to other areas, the contamination can be removed locally by using an absorbent and also by covering the uncontaminated area.

- Open wounds on the skin must be protected.

- After each decontamination, the affected part must be dried with a fresh non-contaminated tissue and monitored. Same shall be treated as contaminated waste.

- While decontaminating face, care must be taken not to contaminate the eyes and lips.

- In case of contamination of eyes, the eyes must be flushed with copious amount of water.

- Medical attention must be sought.

- The scrubbing of the skin must be done carefully without causing any injury to the skin.

- In case of contaminated small open wounds, cuts or other injuries, the wound must be immediately washed and bleeding encouraged and medical attention must be sought.

- Same shall be brought to the notice of the Lab in charge/Radiation Safety Officer.

- The clothing which are contaminated must be discarded.

Measures to be taken in case of internal contamination.

- Internal contamination of personnel can occur through ingestion, inhalation or skin penetration.

- The incident must be immediately reported to Radiation Safety Officer.

- Internal contamination requires special medical advice and supervision.

- The purpose of treatment in case of an internal contamination will be to eliminate as fast as possible, much of the contaminant still remaining in the mouth, gastro-intestinal or respiratory tract as possible.

Decontamination of laboratory equipment and work areas

- All equipments used in research work must be treated as contaminated unless proved otherwise.

- The solutions used for cleaning must be disposed off as active waste.

- All metallic objects must be cleaned by washing with detergent solution or dilute nitric acid.

- Decontamination of equipment must be done at the earliest after its use. As this will cause the contamination getting fixed and will be difficult to deal with.

- Once the decontamination procedures are over, the equipment must be checked for residual contamination. If this is more than the permissible limit, it must not be reused; instead, it must be regarded as radioactive waste.

Conclusion

The damage done by the ionising radiation is not felt immediately except in case of exposure to high dose levels.

The adverse effects may appear several years after exposure or it can be passed on to the next generation.

This necessitates special features in design and construction of laboratories handling radioisotopes and adoption of work practices which prevent undue exposure to ionising radiation.

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