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Radiation Safety

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Overview

Radiation has various negative connotations, yet it has been shown to be extremely promising in both scientific and medical fields. This calls for the development and implementation of proper safety measures involving the usage of radiation. Radiation exposure poses significant health risks. The health risks associated with exposure to radiation are well-known and various safety measures are available to ensure limited exposure to radiation in the laboratory setting.[1] In-depth studies of radiation in both the laboratory and among human population continues to be of prime importance since the early 20th century. Extensive use of radioactive materials and sources in industry, medicine, and education demands a need for the users to be trained in their safe use and operation. Understanding the risks helps to establish dosage limits and regulations that can the keep exposure at an acceptable risk level.

Principles

In physics, radiation is defined as the emission or transmission of energy in the form of waves or particles through a medium.[1] Radiation can be of various types—electromagnetic radiation (radio waves, visible light, x-rays, and gamma radiation), particle radiation (alpha radiation, beta radiation, and neutron radiation), acoustic radiation (ultrasound and seismic waves) and gravitational radiation (gravitational waves). Radiation is generally categorized as ionizing and non-ionizing depending on the energy of the radiated particles.

Ionizing radiation is caused by unstable atoms which have sufficient energy to produce ions in matter at a molecular level. Ionizing radiation includes shorter wavelength radiation of the electromagnetic spectrum—ultraviolet, X-rays, and gamma wave radiation. This kind of radiation poses a greater health risk since it can change the basic makeup of atoms in cells, and more specifically the DNA contained inside of cells. Non-ionizing radiation comprises of the portion of the electromagnetic spectrum that consists of electromagnetic waves that are not energetic enough to dissociate electrons from a given atom. It can only change the rotational, vibrational, or electronic valence configurations of molecules and atoms. This type of radiation includes radio waves and microwave energy and is considered less harmful compared to ionizing radiation. It can only cause harm to the extent of the amount of heat it transfers.

There are four forms of ionizing radiation—alpha particles, beta particles, gamma rays, and, neutrons.[2]

An **alpha particle** consists of two protons and two neutrons, the equivalent of the nucleus of a helium atom. Alpha particles readily ionize materials and transfer energy to that material's electrons. An alpha particle can travel several millimeters in air, but in general its range decreases with increasing density of the medium. For example, alpha particles do not penetrate the outer layer of human skin, but if inhaled, alpha particles can damage lung tissue.

A **beta particle** is an electron or a positron and is much lighter than an alpha particle. Beta particles travel longer distances than alpha particles before losing energy. A medium-energy beta particle travels about one meter in air and one millimeter in body tissue.

Gamma rays are a form of electromagnetic radiation. A radioactive element may emit gamma rays (as **photons**) if the nucleus remaining after alpha or beta decay is in an excited state. Gamma rays can penetrate much more deeply than alpha or beta particles; a high-energy gamma ray photon may pass through a person without interacting with tissue at all. When gamma rays interact with tissue, they ionize atoms.

Neutrons are neutral particles that have no charge. Unlike alpha and beta particles, they do not interact with electrons or cause ionization directly. Neutrons can, however, ionize indirectly in a variety of ways: elastic collisions, inelastic scattering, non-elastic scattering, capture reactions, or spallation processes. These processes result in the emission of gamma rays, beta radiation, and, in the case of spallation, additional neutrons.

Two different systems are used for measuring radiation. The conventional system of units (including the Curie, Rad and Rem) was developed over the past 100 years. This system is still used by regulatory agencies in the United States as required by federal law. More recently, the System Internationale (SI) (including the Becquerel, Sievert and Gray) evolved as part of the metric system and is used to measure radiation by all other governments and scientists in the international community.[3]

Depending on what aspect of radiation is being measured, different terms are applied:

- For the amount of radiation being given off by a radioactive material: the conventional unit is *curie* (Ci) and the SI unit *becquerel* (Bq).
- For radiation absorbed by a person: the conventional unit is *rad* and the SI unit*gray* (Gy).
- For biological risk of exposure to radiation: the conventional unit is *rem* and the SI unit *sievert* (Sv).

The unit used globally for measuring radiation dose is the Sievert. The conversions between Sievert and Rem are as follows:

1 microSievert (μSv) = 0.1 mrem

1 milliSievert (mSv) = 100 mrem

1 centiSievert (cSv) = 1 rem (1000 millirem)

1 Sievert (Sv) = 100 rem

The international unit "Gray" is used to measure absorbed radiation dose. The following conversion illustrates how the "Gray" translates into Rems:

1 Gray (Gy) = 100 Rads = 1 Sievert (Sv) = 100 Rem

As a measure of levels of radioactivity, United States uses the unit "Curie." Other countries use the unit "Becquerel". By definition, a Curie is an amount of radioactivity equivalent to a radioactive decay rate of 37 billion disintegrations per second. A Becquerel represents the amount of radioactivity equivalent to a decay rate of one disintegration per second.

Conversion factors between the two units are as follows:

1 Ci = 3.7×10^{10} Bq (37 billion Becquerels)

1 Ci = 37 GBq (37 GigaBecquerels)

1 µCi = 37,000 Bq

1 Bq = 2.70×10-11 Ci (less than one ten billionth of a Curie)

1 Bq = 2.70×10-5 µCi

1 GBq = 0.0270 Ci

The use of ionizing radiation requires following a number of regulations set by the government and other appropriate administrative authorities, and demands the cooperation of many individuals. It is the duty of every supervisor to ensure that any individual working with radiation is adequately trained, the lab or work area is available for inspection at any work time, and the project is managed in accordance to the stipulated code. It is also the responsibility of every radiation worker to be thoroughly trained, adhere to regulations and procedures, have careful work habits, and respect the health and safety of fellow workers.

A detailed description of the proper procedures and steps that need to be taken for radiation safety are outlines in the subsequent sections.

Procedure

1. **Acquiring Radioactive Materials and Maintaining Inventory**

   1.1. Each laboratory using radioactive material should have authorization to use it.

   1.2. It is the responsibility of the supervisor to keep track of and control all radioactive materials acquired by users and it should never exceed the possession limits of radioactive materials under the license issued to the user.

   1.3. If any user plans to acquire radioactive material as a gift, loan, or transfer from a vendor, another institution, or company, he/she must contact Environmental Health &

Safety (EHS) before the material is shipped to the university. Failing to do so may cause the authorization of the lab to be suspended or revoked.

1.4. Packages of radioactive materials should not be directly delivered to the user placing the order. It should be delivered to a central radioisotope-receiving area. Only after the package is verified and entered into the institution's database by EHS should the user be granted access to the package.

1.5. Necessary precautions must be taken while opening packed radioactive materials. It must be opened in a fume hood and appropriate clothing must be worn.

1.6. Packaging material should be not discarded in regular trash cans. They should be marked and disposed only in separate cans marked for radioactive disposal.

1.7. A separate inventory should be maintained for radioactive substances and the record of all uses should be stored in a separate log book. In this log book, the amount of sample used should also be documented such that a mass balance of the radioactive material can be kept.

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1.8. Every lab must perform a quarterly physical inspection of the inventory of radioactive materials.

1.9. Standard operation procedures (SOP) should be maintained in the lab for the different radioactive materials being used.

1.10. If any radioactive material is missing or lost, it should be immediately reported to the appropriate authorities.

2. Safe Handling of Radioisotopes

2.1. Appropriate clothing is the foremost step in radiation safety since any laboratory accident may involve spills or splashes and can affect bare skin. The user must wear gloves, a full-length lab coat, close-toed shoes, and safety glasses.

2.2. No food or drink is allowed in the laboratory which has open sources of radioactive materials.

2.3. Radioactive solutions should never be mouth pipetted.

2.4. Radioactive stock materials should always be kept in sealed containers. No such material should be left unattended. Any visitors in such workplace should be supervised.

2.5. Labeling of all radioactive materials, container, and secondary containers is mandatory, and it is important to reduce cross contamination.

2.6. Working with radioactive material, especially volatile ones, should always be in a designated radioactive materials fume hood. Some materials also pose biological or chemical hazards in addition to radiation hazards. The user should be familiar with that and follow safety protocol accordingly.

2.7. It is important for the user to keep radiation exposure ALARA (As Low As Reasonably Achievable). All required efforts should be made to keep radiation exposure below regulatory dose limits.

2.8. Laboratory personnel are responsible for conducting work survey and personal survey of each individual at the end of each day when experiments with radioactive material are conducted in the laboratory. **Table 1** summarizes the instrumentation and method of choice for the isotopes most commonly used.

2.9. Each worker should be monitored for external or internal radiation exposure. The exposure to radiation for each user should not exceed the limits listed in **Table 2**.

3. Radioactive Waste Disposal

3.1. Labeling wastes for disposal:

All wastes consigned to the Radiation Safety Office for disposal must be labeled with a radioactive waste tag. Each container of radioactive waste must have a properly completed radioactive waste tag affixed to it. All information must be legible, in indelible ink, and include: the isotope, an accurate estimate of activity, the name of the authorized user, the date the waste is prepared for disposal and the type of waste.

3.2. Segregation of radioactive waste:

Segregation of wastes at the point of generation is essential in the safe handling and disposal of radioactive wastes. Radioactive wastes can be broken down into six broad categories, each with specific disposal requirements:

3.2.1. Dry Solid Waste: Contaminated paper, plastic, and glass associated with radioactive materials work, residual solid radioactive materials, contaminated building debris, etc.

3.2.2. Liquid Waste: Any non-hazardous liquid containing dissolved or suspended radioactive materials.

3.2.3. Scintillation Waste: Vials, plates or bulk liquid waste and other materials containing solutions used in liquid scintillation counting.

3.2.4. Biological Waste: Animal carcasses, blood, tissue samples, food wastes, solid or liquid excreta or other organic material not rendered resistant to decomposition.

3.2.5. Mixed Waste: Any waste, solid or liquid which possess inherent hazards in addition to being radioactive, including listed hazardous chemicals, infectious or biohazardous materials.

3.2.6. Sealed Sources: Radioactive materials encapsulated, plated or otherwise incorporated into a solid support media used in association with an instrument or device.

In addition to segregation by waste class all wastes must also be segregated by isotope. Whenever possible high activity wastes, such as stock vials, should not be mixed with regular dry wastes and should be packaged separately. This is necessary to facilitate shielding and minimize storage and/or disposal volumes.

3.3. Disposal

3.1.1. Most solid wastes that contain isotopes with half-lives not exceeding 120 days or are contaminated with such isotopes should be handled through the centralized Decay-in-Storage (DIS) Program for ultimate disposal as non-radioactive medical waste.

3.1.2. All liquid wastes should be disposed of by contracted radioactive waste disposal services.

3.1.3. Special wastes which can cause chemical or biological hazards should be disposed of by contacting the EHS for special arrangements.

3.1.4. The waste disposal services should be immediately contacted once a container is full and ready to go. No waste should be stored for long.

4. Use of Radiation-Emitting Machines

There are several instruments that produce radiation. Some instruments, such as X-ray diffraction spectrometers, electron microscopes, or medical X-ray equipment, are intended for producing radiation greater than 5 mrem/h, while some like high voltage rectifiers, discharge tubes, etc. are not specifically intended for, but do produce radiation higher than 5 mrem/h. Several precautions need to be taken to be safe while working with such instruments. The precautions are listed as follows.

4.1 Installation of any new radiation-producing instrument should be monitored and approved by the EHS.

4.2. Before turning on the instrument, the shielding and radiation detector should be checked for proper functioning.

4.3. The user should be well acquainted with the instrument before handling it on his/her own. If the user is not confident about its proper operation, he/she should be accompanied by the supervisor.

5. **Emergency Situations (Spills and Accidents)**

5.1. In case of any accidents, EHS should be notified immediately.

5.2. In the event of fire, explosion, or any other serious accidents, 911 should be dialed immediately.

5.3. For any kind of spill or contamination, the extent should be assessed first and acted upon accordingly.

5.4. In case of body or skin contamination, affected area should be washed with mild soap and water and decontamination should be applied. In case the contamination persists, further measures should be taken immediately.

Conclusion

In conclusion, safety measures are of absolute importance for proper use and handling of radioactive materials and radiation producing equipment. Several of the precautions and necessary steps required for safe usage of radiation have been highlighted in this article.

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Table 1. Survey Instrumentation Guide[4]

Radioisotope	Acceptable Survey Method	Comments
H-3	LSC	There are no other acceptable survey methods
C-14	G-M or LSC	LSC is most sensitive; G-M detects moderate to high levels of contamination; do not cover G-M with parafilm
P-32	G-M or LSC	G-M detects low levels of contamination
P-33	G-M or LSC	LSC is most sensitive; G-M detects moderate to high levels of contamination; do not cover G-M with parafilm
S-35	G-M or LSC	LSC is most sensitive; G-M detects moderate to high levels of contamination; do not cover G-M with parafilm.
Cr-51	NaI, g, or LSC	
Zn-65	G-M or g	
I-125	NaI, g, or LSC	
U-238	G-M or LSC	

G-M: Survey meter with a Geiger-Muller detector
LSC: Liquid scintillation counting
NaI: Survey meter with a thin crystal sodium iodide detector
g: Gamma counter

How to Perform a Meter Survey

1. The survey meter's battery should be checked by turning the meter knob to the battery test position. If the battery is adequately charged, the meter needle will swing to the battery test position on the meter face. The batteries should be replaced if low.

2. An operational check should be performed the first time you use the meter each day or when you suspect it may have been misused or damaged. The calibration sticker on the side of the meter shows the expected reading for the operational check source. The meter is turned on and the meter's multiplier switch is turned to a setting that will measure the check source and will provide a mid-scale reading but will not cause the needle to swing beyond full scale. For a Ludlum G-M survey meter the multiplier knob should generally be set to the X1 position. The probe is firmly placed against the check source on the side

of the meter and the meter response is noted. If the observed meter response differs from the expected response by more than 20%, the meter should be considered nonfunctional and should be taken out of service.

3. The meter is taken to an area away from sources of radiation and the meter background reading is noted. Typically, the background for a G-M meter with a pancake survey probe should be less than 100 counts per minute (cpm) while the background reading for a meter with a NaI scintillation crystal should be less than 300 cpm. If the meter's background reading is substantially greater than expected, it should be confirmed that there are no unexpected sources of radiation or radioactive materials in the vicinity, and then a contaminated meter should be reported to Environmental Health & Safety (EHS).

4. The probe surface should not be covered with parafilm or other protective covering. Parafilm and similar materials will shield the low energy betas from C-14, P-33 and S-35 and will prevent the meter from detecting contamination.

5. The probe slowly moved about 1 centimeter above the area of interest.

6. If an item or area with a sustained count rate more three times background is found, the item or area should be considered to be contaminated.

7. Such an area or item should be immediately labelled and promptly decontaminated. If an area cannot be decontaminated, the contaminated area should be marked and labeled to indicate the isotope, date and level of contamination.

8. Sometimes, especially in the presence of other radioactive materials, the meter survey may be equivocal. When the meter survey indicates that low level contamination may be present, a wipe survey should be performed to confirm or disprove the presence of contamination.

9. The survey results should be documented whenever contamination is discovered or if 250 µCi or more have been handled in the laboratory survey log.

How to Perform a Wipe Test

1. Wipe surveys must be performed when H-3 is used and is the survey method of choice to detect the presence of low levels of removable C-14, P-33 and S-35 contamination. Wipe surveys should also be performed to confirm the presence of contamination when a meter survey suggests that low level contamination may be present.

2. Using a piece of filter paper (about 1" in diameter), Q-tip or other swab, the area being surveyed is wiped. If the area is very large, it is subdivided into smaller areas and several wipes are used to better pinpoint the location of contamination. For some surfaces, including skin and clothing, the wipe media should be moistened with water or other appropriate solvent.

3. The wipe samples are analyzed in a liquid scintillation counter for H-3 and other beta emitters and preferably in a gamma counter for Cr-51 and I-125.

4. Sample activity is determined by dividing the sample count by the counter's efficiency for the isotope in question.

5. EHS should be called with questions about liquid scintillation and gamma counter use.

Table 2. List of permissible dose limits for radiation workers[5]

Radiation Workers (Users)	**Maximum Permissible Dose (mrem)**	**10% CU Notification Limit (mrem)**	**25% CU ALARA Investigation (mrem)**
Whole body (WB) total effective dose equivalent (TEDE) from internal (CEDE) and external (DDE) sources	5,000/year	500/year	1,250/year
Total organ dose equivalent (TODE) from internal (CDE) and external (DDE) sources	50,000/year	5,000/year	12,500/year
Lens of the eye dose equivalent (LDE)	15,000/year	1.500/year	3,750/year
Skin, hands, forearms, elbows, knees, leg below the knee, feet, and ankles shallow dose equivalents (SDE)	50,000/year	5,000/year	12,500/year
Embryo/fetus	500/gestation period for a declared pregnancy	50/gestation period	125/gestation period
Non-radiation workers (non-users), including members of the public	100/year	100/year	100/year

ALARA: as low as reasonably achievable
mrem: milli roentgen equivalent in man (or mammal), CGS unit of equivalent dose

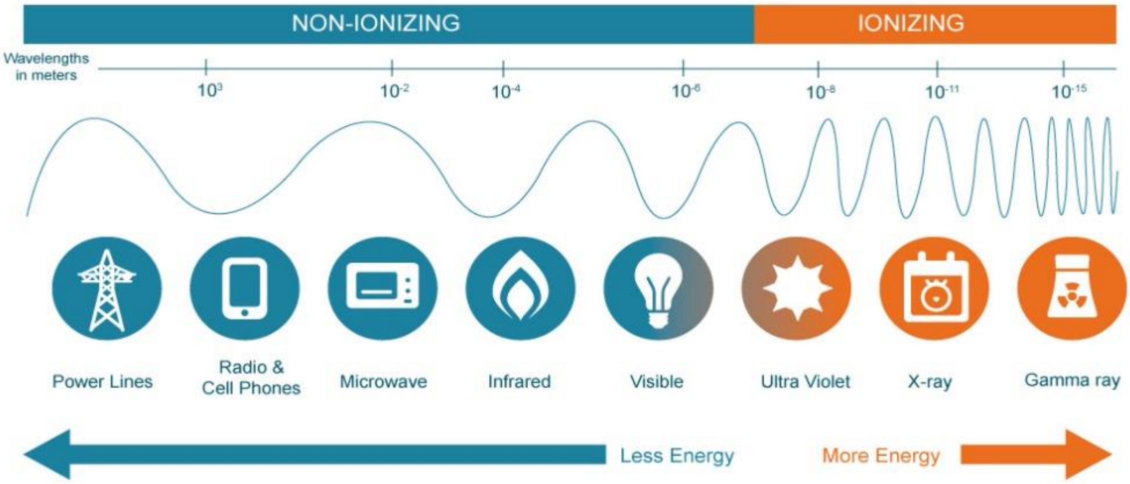
NON-IONIZING
IONIZING
Wavelengths in meters
10³
10⁻²
10⁻⁴
10⁻⁶
10⁻⁸
10⁻¹¹
10⁻¹⁵
Power Lines
Radio & Cell Phones
Microwave
Infrared
Visible
Ultra Violet
X-ray
Gamma ray
Less Energy
More Energy

Fig. 1.

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