

# Radiation Safety Guide - Analytical X-Ray

**Radiation Safety Office**  
[www.dal.ca/safety](http://www.dal.ca/safety)

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Safety Code 32 - "***Safety Requirements and Guidance for Analytical X-Ray Equipment***"

## Radiation Safety Guide - Analytical X-Ray

### Introduction:

The teaching and research activities at Dalhousie University employ numerous and varied sources of radiation in the form of nuclear substances and radiation emitting devices. The policies and procedures described in this guide are designed to provide a reasonable and practical standard of safety for the use of radiation emitting devices in the university and to assist in compliance with all applicable regulations and codes as well as the **ALARA** principle (*as low as reasonably achievable*).

Providing a safe and healthy environment in the University's research and teaching laboratories is a shared responsibility of all those involved, including the University, departmental chairs, laboratory supervisors, staff and students.

No set of rules can cover all possible eventualities, hence, workers must exercise sound judgement in all of their work.

### Regulations:

In Canada there are several bodies which have jurisdiction over all aspects of the use of ionizing radiation. Under the **Nuclear Safety and Control Act**, the **Canadian Nuclear Safety Commission** licences the acquisition and use of all nuclear substances and certain radiation emitting equipment such as nuclear reactors and accelerators. The **Health Protection Branch of Health and Welfare Canada** and in particular the **Radiation Protection Bureau** formulate regulations relating to the standard of functioning of new radiation equipment under the aegis of the **Radiation Emitting Devices Act**. This group also prepare "Safety Codes" to provide for some national guidelines. Many provinces also have their own regulations regarding the use of radiation emitting equipment. In general the recommendations of the **International Commission on Radiological Protection (ICRP)** are used to formulate the rules and conditions under which radiation-emitting devices or nuclear substances are used.

### Administration:

The policies, regulations and procedures of the Radiation Safety program shall apply to all activities involving the use, storage, transportation and disposal of nuclear substances in the buildings and on the grounds of Dalhousie University.

The organizations to administer the Radiation Safety Program include the following:

1. Radiation Safety Committee
2. Radiation Safety Officer
3. Director of Environmental Health & Safety
4. Project Directors ( Principal Investigators )
5. Radiation Users

## **Radiation Safety Committee**

The Radiation Safety Committee is appointed by the President. It has general authority from the President to develop and administer the Radiation Safety Program for the university, embracing all areas of concern in radiation safety in addition to those involving nuclear substances. Its terms of reference and responsibilities include:

1. Assist with the preparation of and submission to the CNSC applications for the use of nuclear substances at Dalhousie University,
2. establish procedures and policies for the safe use and control of nuclear substances and radiation-emitting devices throughout the university,
3. review details of all proposed uses of nuclear substances and radiation emitting devices at Dalhousie University and to ensure that the methods of use will comply with the requirements of the CNSC, its advisors, and those of other regulatory bodies, as well as those of the university,
4. issue permits for the use of nuclear substances at Dalhousie University under the authority of the CNSC,
5. determine the suitability of space and facilities to be used for projects involving nuclear substances or radiation emitting devices, and to arrange assistance in the design or re-design of such space or facilities in accordance with the CNSC's regulatory guide **R-52, "Design Guide for Basic and Intermediate Level Radioisotope Laboratories"**,
6. receive reports of routine radiation monitoring programs it may establish
7. advise on the management of radioactive waste, when necessary,
8. receive reports of any incidents or accidents involving sources of radiation, arrange for investigations where warranted, and submit findings and recommendations to the appropriate bodies,
9. monitor necessary action on any recommendations or directives from health and regulatory agencies,
10. arrange for the dissemination of information on radiological health and safety matters for use in the university community, and to institute training programs when necessary,
11. order appropriate disciplinary measures when warranted by breach of regulations or hazardous practices in accordance with Dalhousie University's **Compliance Enforcement Policy**.

At least three committee members shall be drawn from those engaged in work

involving the use of nuclear substances or radiation emitting devices. In addition, the following **shall** be members:

Radiation Safety Officer ( Secretary )  
Director of Environmental Health & Safety  
Medical Physicist, Queen Elizabeth II Health Sciences Centre

The Radiation Safety Committee normally reports through the Vice-President (Academic & Research) but in unusual circumstances has direct access to the President and may act with the authority of the President's Office. Dalhousie University's, Environmental Health & Safety Committee is routinely advised of its proceedings, and in turn may refer matters to the Radiation Safety Committee for consideration or action. The Radiation Safety Committee also provides copies of documents it issues, as well as an annual report, to the CNSC which may likewise refer items for Committee attention.

The Radiation Safety Committee **shall** meet four times annually and special meetings may be called at any time.

### **Radiation Safety Officer**

The Radiation Safety Officer (RSO) is a technically qualified officer of the university experienced in the nature and use of radiation. The RSO is responsible for the daily operations of the Radiation Safety Office . This office performs the executive functions of the Radiation Safety Committee and carries out the following responsibilities:

1. Over-all administration of the university Radiation Safety Program,
2. Implementation of approved policies and procedures forming part of the universities Radiation Safety Program, including training and dispersal of information,
3. Maintenance of current awareness of developments in the field of radiation protection in order to make appropriate recommendations for modification of the Radiation Safety Program for the university,
4. Liaison with the municipal, provincial, and federal authorities concerned with radiation safety, and with RSO's at other institutions,
5. Review all applications for permits to use nuclear substances and other radiation sources prior to submission to the Radiation Safety Committee,
6. Arrange periodic surveys of laboratories, facilities and work places for radiation levels and contamination. **The RSO has the authority to suspend operations which are considered unsafe,**

8. Maintain records, including inventories, permits, reports on personal exposures, purchases and disposition of nuclear substances and radiation emitting devices, an up to date list of all rooms where nuclear substances are used or stored, an inventory of all sealed sources, an inventory of all portable monitoring devices and a list of all personnel using/handling nuclear substances or radiation emitting devices,
9. advise and consult with members of the university community in matters of radiation safety when required,
10. any other function assigned by the Radiation Safety Committee, the VP-Academic & Research, or the President.

### **Director of Environmental Health & Safety (EH&S)**

The Director of EH&S has a general responsibility for safety related matters on campus. The specific responsibility for radiation safety, however, rests with the RSO, who may call on the Director of EH&S for assistance, as is often the case when potential radiation hazards occur in combination with other hazards such as biological or chemical hazards. The RSO will inform the Director of EH&S of any incident or emergency involving radiation and may request assistance with its management.

### **Project Director**

Project Directors are responsible to the University for the safe use of radiation emitting devices by all persons under their supervision and for ensuring that these persons under their supervision receive adequate instruction in radiation safety. The Project Director is responsible for:

1. Providing the Radiation Safety Office with an X-Ray Registration form for each piece of equipment.
2. The safe operation of all operations carried out with the equipment.
3. Ensuring that all staff and/or students under their supervision have read and signed a copy of this guide.
4. Ensuring that all relevant regulations with respect to the operation of the unit are met.
5. Ensuring that only authorized persons will enter the restricted area.
6. Ensuring that all staff/students have been issued and use both a whole body TLD as well as a ring dosimeter. Staff and/or students must be registered with the National Dose Registry.
7. Ensuring that female staff/students are advised of the University ***Prenatal Exposure Policy***.

8. Ensuring that functional survey instrumentation is available to monitor for exposure and that this unit has been calibrated on an annual basis.
9. Maintaining a log book of use.
10. Reporting all incidents with the potential for staff/student over exposure to the Radiation Safety Office.
11. Ensuring that a responsible designated alternate, approved by the RSO, is available to oversee operations during absences.

### **Radiation Users**

Radiation users are all persons whose work involves the use of radiation emitting devices, whether or not they are project directors. They are responsible for:

1. Becoming familiar with and complying with the University's and any other required safety regulations,
2. following the three basic radiation safety principles - **Time, Distance, Shielding**.
3. practicing **ALARA**,
4. reporting to the supervisor any incident involving a known or suspected radiation exposure exceeding permissible limits,
5. wearing the assigned personal TLD and ring badge,
6. declaring pregnancy as soon as the female staff/student becomes aware of it.

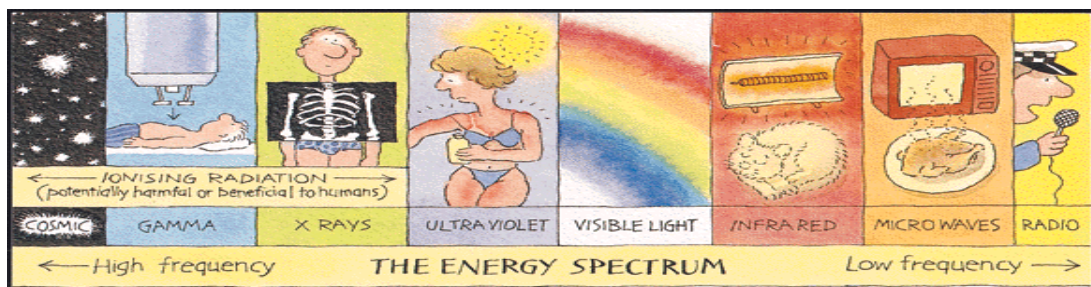


## Properties of Radiation:

### What is radiation ?

Radiation is the transfer of energy in the form of particles or waves. To illustrate toss a pebble into a pond. From the point where the pebble hits the water, ripples radiate in rings. The ripples represent the movement of energy imparted when the pebble hit the water.

There is one particular characteristic of all radiation that helps to identify and describe it. That is wavelength, the distance from the crest of one "wave" to the crest of the next "wave". Waves in water are one form of radiation. There is another class that we call **electromagnetic radiation**. This is the type of radiation that the University Radiation Safety Program is concerned with.



Some types of radiation include:

Non-ionizing electromagnetic radiation

- \* radio
- \* microwave
- \* infrared (heat)
- \* visible light
- \* ultra-violet

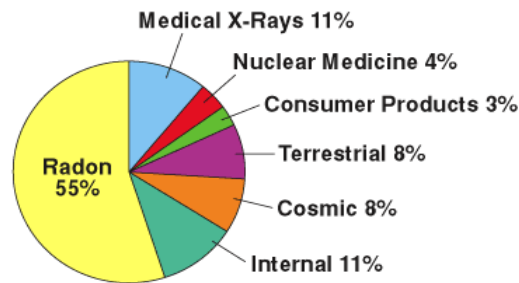
Ionizing electromagnetic radiation

- \* X-Rays
- \* Gamma rays
- \* Cosmic rays

Ionizing atomic particle radiation

- \* alpha particles
- \* beta particles
- \* neutrons

## Where does radiation come from ?



### Natural Radioactivity

**Cosmic radiation** comes from the earth's atmosphere, some from the sun and energy sources inside or outside our galaxy. Those from the sun are more intense during solar flares. The density is affected by the earth's magnetic field, which makes it greater nearer the poles and the equator. Cosmic radiation dose increases with altitude. The earth's atmosphere is a partial shield to the radiation. As one goes higher there is a lower shielding effect.

**The earth's crust** is made up of materials that are naturally radioactive. Uranium is dispersed throughout rocks and soil, as are thorium and Potassium-40. They all emit gamma rays which irradiate the whole body uniformly. Since some building materials are extracted from the earth, they are slightly radioactive.

**Radon** is a naturally occurring radioactive gas that comes from the uranium in the earth's crust. It is emitted from rocks or soil at the earth's surface and disperses in the atmosphere unless it enters a building or enclosed space where the concentration may build up.

Since radioactive materials occur everywhere in nature, it is inevitable that they make their way into drinking **water** and **food**. Potassium-40, in particular, is a major source of internal irradiation.

### Man-made Radiation

Persons in many occupations may encounter **radiation in the workplace** above normal background levels. Some of these occupations include doctors, nurses, technologists, researchers, astronauts, dental hygienists, pharmacists, welders and flight crews.

**Medical uses of radiation** are broken down into diagnostic and therapeutic. Radiation therapy is primarily used for tumor killing, but in the past it has been used for other types of treatment. Most of the dose received is to a small well described area of the body. Diagnosis runs from routine x-rays and blood tests to the injection of radioactive material for imaging purposes. The physician who prescribes the treatment must weigh the risk of the exposure with the benefit of the treatment.

The **nuclear power industry** releases a minuscule amount of radiation at each stage of the nuclear fuel cycle. Releases are continuously monitored by the industry and by government agencies.

**Non-nuclear industries**, including the processing of ores containing radioactive materials as well as the element for which the ore is processed, and the generation of electricity by coal-fired power stations, results in the release of naturally occurring radioactive material from coal.

Minute radiation doses are received from the radioactivity in some **consumer goods** such as smoke detectors, luminous watches, cigarettes and gas mantles.

### **What are the risks of radiation exposure ?**

Radiation is all around us. Humans have been exposed to radiation from natural sources since the dawn of time. This radiation cannot be avoided. For those workers who must be occupationally exposed to radiation we strive to maintain exposures as low as reasonably achievable (**ALARA**). Occupationally exposed workers receive **no benefit** from this exposure. Alternatively patients undergoing x-ray to diagnose disease or broken bones do derive **benefit** from their **risk** taken from being exposed. Personnel exposure limits are reported in millisievert (mSv) units. All workers at Dalhousie University are considered members of the general public for which a 1 mSv annual exposure limit is set. The average dose to occupationally exposed workers at Dalhousie normally does not exceed 0.5 mSv per year.

Radiation causes ionizations in the molecules of living cells. These ionizations result in the removal of electrons from the atoms, forming ions or charged atoms. The ions formed then go on to react with the other atoms in the cell, causing damage. An example would be if a gamma ray passes through a cell, the water molecules of DNA might be ionized and the ions might react with the DNA causing a break.

At low doses, such as what we receive from background radiation, the cells repair the damage rapidly. At higher doses (>1 Sv), the cells might not be able to repair the damage, and the cells may either be changed permanently or die. Most cells that die are of little consequence, the body replaces them.

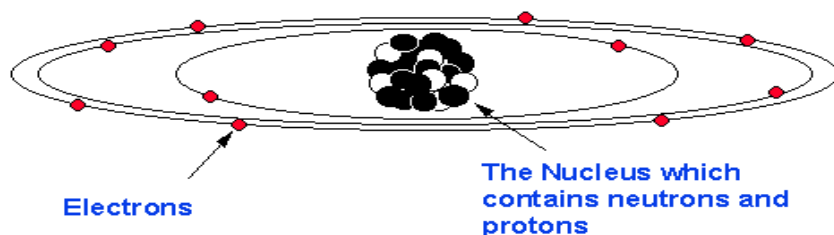
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# The Atom

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Example - Neon-20



A typical model of the atom is called the Bohr Model, in honor of Niels Bohr who proposed the structure in 1913. The Bohr atom consists of a central nucleus composed of neutrons and protons, which is surrounded by electrons which "orbit" around the nucleus.

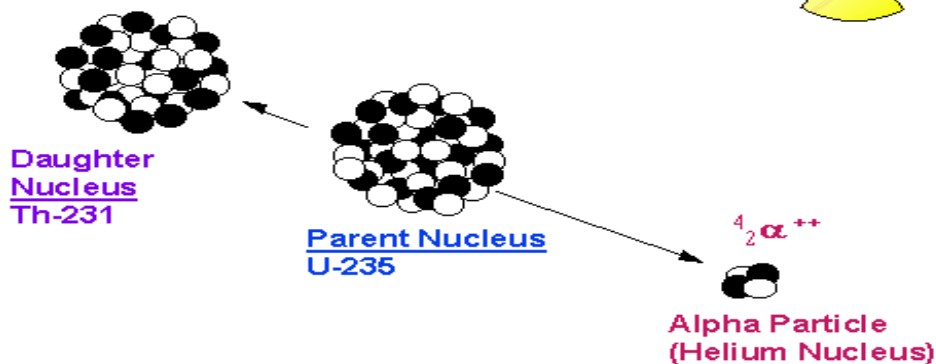
Protons carry a positive charge of one and have a mass of about 1 atomic mass unit (amu). Neutrons are electrically neutral and also have a mass of about 1 amu. In contrast electrons carry a negative charge and have a mass of only 0.00055 amu. The number of protons in a nucleus determines the element of the atom. For example, the number of protons in uranium is 92 and the number in neon is 10. The proton number is often referred to as **Z**.

Atoms with different numbers of protons are called elements, and are arranged in the periodic table with an increasing Z.

Atoms in nature are electrically neutral so the number of electrons orbiting the nucleus equals the number of protons in the nucleus.

Neutrons make up the remaining mass of the nucleus and provide a means to "glue" the protons in place. Without neutrons, the nucleus would split apart because the positive protons would repel each other. Elements can have nuclei with different numbers of neutrons in them. For example hydrogen, which normally only has one proton in the nucleus, can have a neutron added to its nucleus to form deuterium, or have two neutrons added to create tritium, which is radioactive. Atoms of the same element which vary in neutron number are called isotopes.

# Alpha Particle Radiation

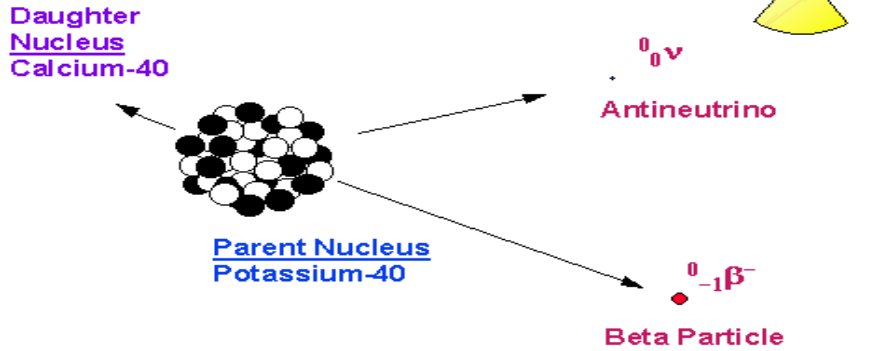


Alpha decay is a radioactive process in which a particle with two neutrons and two protons is ejected from the nucleus of a radioactive atom. The particle is identical to the nucleus of a helium atom.

Alpha decay only occurs in very heavy elements such as uranium, thorium and radium. The nuclei of these atoms are very neutron rich ( i.e. have a lot more neutrons in their nucleus than they do protons ). Thus, when uranium-238 ( which has a Z of 92 ) decays by alpha emission, thorium-234 is created ( which has a Z of 90 ).

Because alpha particles contain two protons, they have a positive charge of two. Further, alpha particles are very heavy and very energetic compared to other common types of radiation. These characteristics allow alpha particles to interact readily with materials they encounter, including air, causing many ionizations in a very short distance. Typical alpha particles will travel no more than a few centimetres in air and are stopped by a sheet of paper.

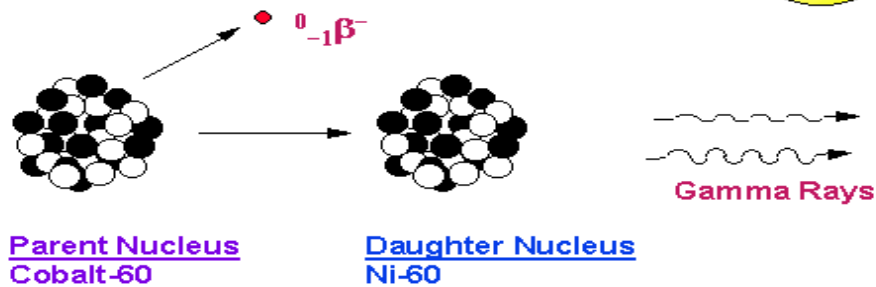
# Beta Particle Radiation



Beta decay is a radioactive process in which an electron is emitted from the nucleus of a radioactive atom, along with an unusual particle called an antineutrino. The neutrino is an almost massless particle that carries away some of the energy from the decay process. Because this electron is from the nucleus of the atom, it is called a beta particle to distinguish it from the electrons which orbit the atom.

Like alpha decay, beta decay occurs in isotopes which are "neutron rich". Atoms which undergo beta decay are located below the line of stable elements on the chart of nuclides, and are typically produced in nuclear reactors. When a nucleus ejects a beta particle, one of the neutrons in the nucleus is transformed into a proton. Since the number of protons in the nucleus has changed, a new daughter is formed which has one less neutron but one more proton than the parent. For example rhenium-187 (  $Z=75$  ) decays by beta decay, osmium-187 (  $Z=76$  ) is created. Beta particles have a single negative charge and weigh only a fraction of a neutron or proton. As a result, beta particles interact less readily with material than alpha particles. Depending on the beta particle energy, beta particles will travel up to several metres in air, and are stopped by thin layers of metal or plastic.

## Gamma-Ray Radiation

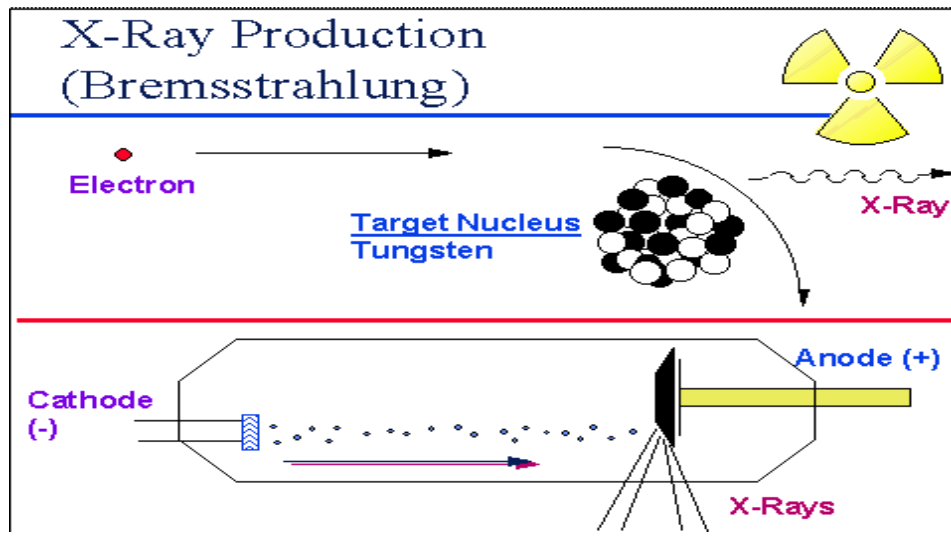


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After a decay reaction, the nucleus is often in an “excited” state. This means that the decay has resulted in producing a nucleus which still has excess energy to get rid of. Rather than emitting another beta or alpha particle, this energy is lost through the emission of a pulse of electromagnetic radiation called a gamma ray. The gamma ray is identical in nature to light or microwaves, but of very high energy.

Like all forms of electromagnetic radiation, the gamma ray has no mass and no charge. Gamma rays interact with material by colliding with the electrons in the shells of atoms. They lose their energy slowly in material, being able to travel significant distances before stopping.

It is important to note that most alpha and beta emitters also emit gamma rays as part of their decay process. However, there is no such thing as a “pure” gamma emitter. Important gamma emitters including technetium-99m which is used in nuclear medicine, and cesium-137 which is used for calibration of nuclear instruments.



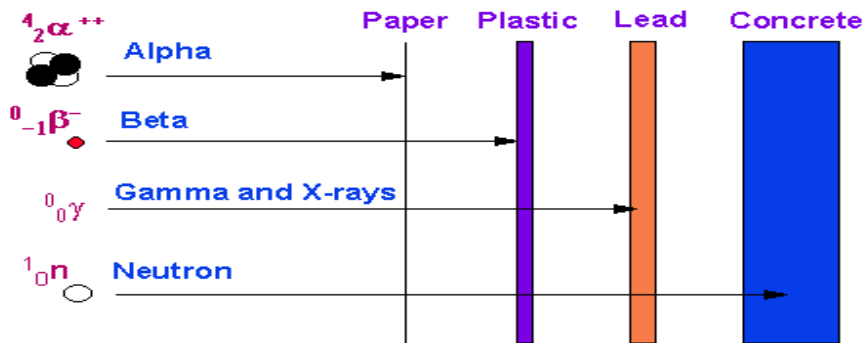
Over a century ago, in 1895, Roentgen discovered the first example of ionizing radiation, x-rays. The key to Roentgen's discovery was a device called a Crooke's tube, which was a glass envelope under high vacuum, with a wire element at one end forming the cathode, and a heavy copper target at the other end forming the anode. When a high voltage was applied to the electrodes, electrons formed at the cathode would be pulled towards the anode and strike the copper at very high energy. Roentgen discovered that very penetrating radiations were produced from the anode, which he called x-rays.

X-ray production occurs whenever electrons of high energy strike a heavy metal target, like tungsten or copper. When electrons hit this material, some of the electrons will approach the nucleus of the metal atoms where they are deflected because of their opposite charges ( electrons are negative and the nucleus is positive ). This deflection causes the energy of the electron to decrease, and this decrease in energy then results in forming an x-ray.

Medical x-ray machines in hospitals use the same principle as the Crooke's tube to produce x-rays. The most common x-ray machines use tungsten as their cathode, and have very precise electronics so that the amount and energy of the x-ray produced is optimum for making images of bones and tissues in the body



## Penetrating Distances

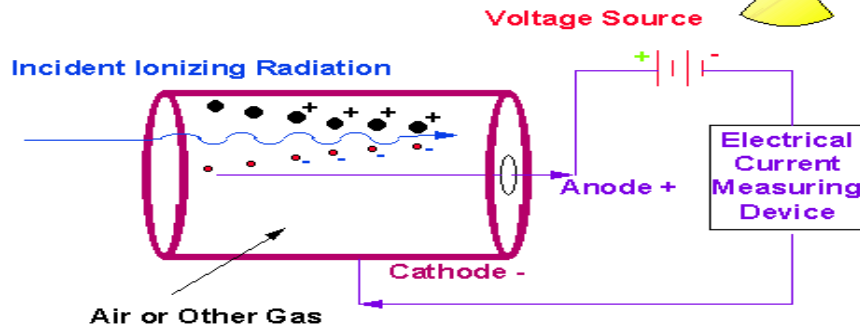


The most common types of radiation include alpha particles ( $\alpha$ ) beta ( $\beta$ ) and positron particles, gamma ( $\gamma$ ) and x-rays and neutrons. Alpha particles are heavy and doubly charged which cause them to lose their energy very quickly in matter. They can be shielded by a sheet of paper or the surface layer of your skin. Alpha particles are only considered hazardous to a person's health if an alpha emitting particle is inhaled or ingested. Beta and positron particles are much smaller and only have one charge, which cause them to interact more slowly with material. They are effectively shielded by thin layers of metal or plastic and are again only considered hazardous if a beta emitter is ingested or inhaled (P-32 excepted).

Gamma emitters are associated with alpha, beta and positron decay. X-rays are produced either when electrons change orbits within an atom, or electrons from an external source are deflected around the nucleus of an atom. Both are forms of high electromagnetic radiation which interact lightly with matter. X-rays and gamma rays are best shielded by thick layers of lead or other dense material and are hazardous to people when they are external to the body.

Neutrons are neutral particles with approximately the same mass as a proton.

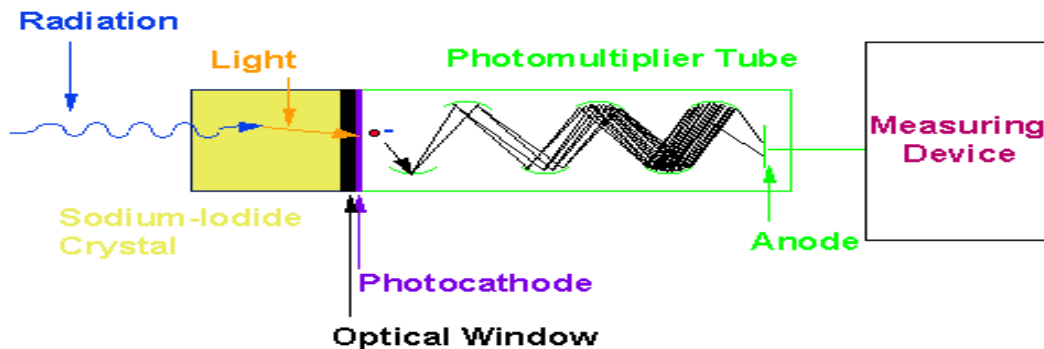
## Radiation Detection Gas Filled Detectors



The most common type of instrument is a gas filled radiation detector. This instrument works on the principle that as radiation passes through air or a specific gas, ionization of the molecules in air occur. When a high voltage is placed between two areas of the gas filled space, the positive ions will be attracted to the negative side of the detector ( cathode ) and the free electrons will travel to the positive side ( anode ). These charges are collected by the anode which then form a very small current in the wires going to the detector. By placing a very sensitive current in the wires from the cathode and anode, the small current measured and displayed as a signal. The more radiation which enters the chamber, the more current displayed by the instrument.

Many types of gas filled detectors exist, but the two most common are the ion chamber used for measuring large amounts of radiation and the Geiger-Mueller or GM detector used to measure very small amounts of radiation.

## Radiation Detection Scintillation Detectors



The second most common type of radiation detection instrument is the scintillation detector. The basic principle behind this instrument is the use of a special material which glows or "scintillates" when radiation interacts with it. The most common type of material is a type of salt called sodium iodide ( NaI ). The light produced from the scintillation process is reflected through a clear window where it interacts with a device called a photomultiplier tube.

The first part of the tube is made of another material called a photocathode. The photocathode has the unique characteristic of producing electrons when light strikes the surface. These electrons are then pulled towards a series of plates called dynodes through the application of a positive high voltage. When electrons from the photocathode hit the first dynode, several electrons are produced for each initial electron hitting its surface. This "bunch" of electrons is then towards the next dynode, where more electron "multiplication" occurs. The sequence continues until the last dynode is reached, where the electron pulse is now millions of times larger than it was at the beginning of the tube. At this point the electrons are collected by an anode at the end of the tube forming an electronic pulse. The pulse is then detected and displayed by a special instrument.

Scintillation detectors are very sensitive radiation instruments and are used for special environmental surveys and as laboratory instruments.

# Production of X-Rays

## Electromagnetic Radiation

X-rays are a type of electromagnetic radiation. Other types of electromagnetic radiation include:

- \* radio waves
- \* microwaves
- \* infrared
- \* visible light
- \* ultraviolet
- \* gamma rays

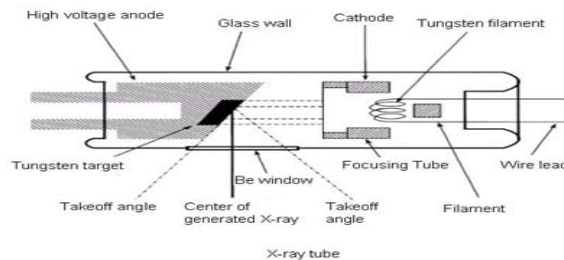
The types of radiation are distinguished by the amount of energy carried by the individual photons. All electromagnetic radiation consists of photons. The energy carried by individual photons, which is measured in electron volts (eV) is related to the frequency of the radiation.

## Electromagnetic Radiation

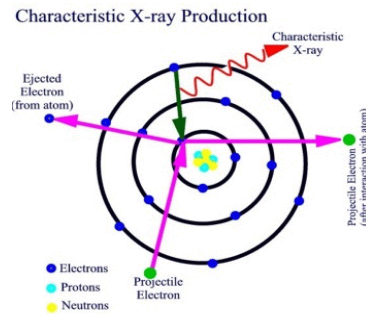
Type of Radiation	Typical Photon Energy
radio wave	1 $\mu\text{eV}$
microwave	1 meV
infrared	1 eV
red light	2 eV
violet light	3 eV
ultraviolet	4 eV
x-ray	100 keV
gamma ray	1 MeV

## X-Ray Production

X-rays are produced when charged particles, usually electrons, are accelerated by an electrical voltage. Whenever a high voltage, a vacuum and a source of electrons are present x-rays can be produced. This is why many devices that use high voltages produce incidental x-rays. Televisions, computer monitors and scanning electron microscopes can produce incidental x-rays.



Most x-ray devices emit electrons from a cathode, accelerate them with a voltage within a vacuum, and allow them to hit an anode which emits x-ray photons.



## Bremsstrahlung

When high speed electrons from a cathode bombard an anode target material, some of the negatively charged electrons are able to get through the target atom's electron cloud due to their high velocity and interact with the positively charged nucleus. This proximity causes the electrons to undergo a change in momentum due to the strongly attractive force of the target nuclei. The electrons that are able to penetrate the target material are "braked", or decelerated, to varying degrees depending on how closely they approach the target nuclei. The Coulomb force field of the target nuclei causes up to 100% of the kinetic energy of the bombarding electrons to be converted to x-ray photon energy. X-ray photons are thus produced by many individual energies over a wide energy spectrum depending on the degree of braking that the original bombarding electrons experienced in the Coulomb force field of the target nuclei. Bremsstrahlung is most effectively produced when small charged particles bombard atoms of high Z number such as tungsten.

## Characteristic X-Rays

High speed electrons travelling in a vacuum may impinge upon a target material such that the negatively charged high velocity electrons liberate electrons from the target atom. The target atom electron vacancy thus created is filled by other electrons within the atom moving to fill the vacancy. The transition of electrons between energy states results in the emission of x-rays that are "characteristic" of the target atom identity and whose energy corresponds to the difference between the initial and final electron state.

# BIOLOGICAL EFFECTS OF RADIATION

## How Radiation Affects Biological Organisms

Radiation induced injuries begin with molecular damage. Charged particles ( such as  $\alpha$  and  $\gamma$  particles ) transfer their energy via ionization and excitation interactions. Massless and chargeless gamma or x-rays must first interact with some atom in the cell. In these processes the gamma or x-ray transfer energy to an electron which then causes ionizations and excitations within the materials surrounding them.

Since most of the human body is comprised of water, a majority of these interactions will occur in water molecules. The splitting apart, or radiolysis, of water is brought about by the transfer of energy from alphas, betas, or electrons to the water molecule.

Free radicals are neutral atoms or molecules with unpaired electrons. They are extremely reactive. If several solutes are available the free radical will react with molecules of the largest size, number, and chemical reactivity, in that order.

Direct "hits" on solute molecules most likely occur, but this is a very small portion versus the indirect effects from free radicals. Large molecules in biological systems are often sensitive to radiation induced structural changes; these include degradation and intermolecular and intramolecular cross linking. The presence of oxygen during irradiation enhances the chemical and biological effects by increasing the number of harmful radicals and or by blocking the repair of damaged molecules.

The multi-target, multi-hit theory describes the phenomenon of more complex biological systems that are irradiated. This theory states that many targets exist which require multiple hits before an effect is realized. Cell death thus depends on factors such as the type of cell and the linear energy transfer ( LET ) of the particular radiation. LET is the rate that energy is imparted to a medium over a specified distance. A high LET radiation, such as an  $\alpha$  particle, may deposit enough hits to a cell while the number of hits to deeper cells would be very limited. On the other hand, a low LET  $\gamma$  emitter might only cause one hit over many cells but effect cells that are far deeper into the tissue.

In 1906, two French radio-biologists, ( **Bergonie & Tribondeau** ) recognized that different types of cells differ in their radio-sensitivity. They stated cells have increased radio-sensitivity if:

- \* their mitotic rate is high
- \* they have a long mitotic future
- \* they are of a primitive cell type ( not specialized )

The ability of a cell to repair damage done by a given amount of absorbed radiation can be highly variable and dependent on many factors. Some of these are:

1. cellular repair capability
2. linear energy transfer ( LET ) for the particular radiation
3. synergistic effects from other metabolic processes
4. delivery rate of the dose

Alterations in the three dimensional structure of a cell membrane can be altered. For example, a nerve cell may lose the ability to conduct electrical impulses.

The damage produced by low doses of radiation can be repaired by cells. This is demonstrated by dividing a dose into two or more fractions and noting that the cellular mortality is less for the single dose of the same total amount. Experiments show the cells receiving fractionated doses have higher survival rates, with repairs starting immediately after irradiation.

The radiosensitivity of tissues within an organism under the action of ionizing radiation is also highly variable. Tissue radiosensitivity in mammals, from the most radiosensitive to the least are as follows:

1. embryonic tissue
2. hematopoietic organs
3. gonads
4. epidermis
5. intestinal mucous membrane
6. connective tissue
7. muscle tissue
8. nervous tissue

## Categorizing Effects

It is known that **high** levels of exposure can cause biological effects that are harmful to the exposed organisms. These effects are classified into three categories:

1. **Somatic effects:** effects occurring in the exposed individual that may be divided into two classes.
  - i) Prompt effects - observable soon after a large dose , >1 Sv to the whole body
  - ii) Delayed effects - may occur years after an exposure
2. **Genetic effects:** abnormalities passed on to future generations as a result of a parents exposure
3. **Teratogenic effects:** effects that may be observed in children who were exposed during fetal and embryonic stages of development. These can be in the form of **deterministic** or **stochastic** effects.

Additionally, effects are also referred to as deterministic ( non-stochastic ) and stochastic. Deterministic effects are those in which the severity of the effect increases with dose above an apparent threshold. Some examples of deterministic effects are erythema and cataracts. Stochastic effects are those in which the probability of an effect, rather than its severity, is assumed to increase linearly with a linear increase in dose. An example of stochastic effects would be cancer induction.

## Radiation Syndromes in Adults from Whole Body Exposures

Acute radiation syndrome takes place within 30 days following a high dose of radiation received to the whole body. The LD 50 ( 30 ) value is used for expressing lethality dose to 50% of the exposed organisms.

There are four recognized radiation syndromes which are named by the clinical symptoms that arise from each range of acute radiation dose.

1. **Molecular Death Syndrome** - results from doses of 1000 Gy or more. Death is immediate, associated with the inactivation of critical molecules ( DNA, RNA )
2. **Central Nervous System Syndrome** - results from doses of 100 to 1000 Gy. Death occurs one or two days after exposure, associated with incoordination, respiratory failure, and intermittent stupor
3. **Gastrointestinal Syndrome** - results from doses of 9 to 100 Gy. Death occurs from 3 - 5 days after exposure, associated with morphological changes in the GI tract



4. **Hematopoietic Syndrome** - results from doses between 3 to 9 Gy. If death occurs, it is generally 10 - 15 days after exposure, resulting from changes in the blood cells.

Whole body doses of >50 mGy or more produces symptoms of radiation sickness. The symptoms include:

1. headache
2. dizziness
3. nausea
4. diarrhea
5. insomnia
6. decrease in white blood cells & platelets

Treatment is generally given after clinical conditions exist; such as, large doses of antibiotics after an infection is contracted.

#### **Non-Lethal Deleterious Effects Of Radiation.**

Other effects, that are often a concern to individual workers, and their threshold ranges are listed below.

<b>Effect</b>	<b>Threshold Range</b>
Hair loss ( epilation )	5 Gy ( temporary loss ) 25 Gy ( permanent loss )
Reduced sterility	♀ ( 2 Gy to the ovaries ) ♂ ( 0.5 Gy to the testis )
Permanent sterility ( ♀ & ♂ )	8 Gy ( acute ) 15 Gy ( fractionated )
Cataracts	2 Gy ( acute ) 14 Gy ( fractionated ) to lens of eye

## Radiation Exposure Limits

Occupationally exposed workers at Dalhousie University are normally considered to be persons working in controlled areas for whom effective dose limits apply as they do for **"A person who is not a nuclear energy worker"**. The majority of occupationally exposed workers at Dalhousie receive effective doses far below these limits, as set out in the following table. The limits given are for radiation doses due to **occupational** exposure only and do not include doses received as a result of medical or dental procedures performed by a qualified practitioner. In special circumstances, the RSO may designate individual workers as **Nuclear Energy Workers** as defined by the **Nuclear Safety & Control Act**.

It should be noted that the setting of a dose limit is equivalent to specifying a maximum acceptable level of risk. Nevertheless, it is not acceptable to be exposed to the full extent of the limit if a lower dose can be reasonably achieved (**ALARA**).

### Effective Dose Limits

Item	Person/ Organ or Tissue	Period	Effective Dose ( mSv)
1	Nuclear energy worker including pregnant nuclear energy worker	One year dosimetry period Five year dosimetry period	50 100
2	Pregnant nuclear energy worker	Balance of pregnancy	4 (CNSC limit) 2 (NS provincial limit)
4.	<b>A person who is not a nuclear energy worker</b>	<b>One calendar year</b>	<b>1</b>
5.	Lens of the eye: Nuclear energy worker <b>Any other person</b>	One year dosimetry period <b>One calendar year</b>	150 15
5	Skin: Nuclear energy worker <b>Any other person</b>	One year dosimetry period <b>One calendar year</b>	500 50
6.	Hands & feet: Nuclear energy worker <b>Any other person</b>	One year dosimetry period <b>One calendar year</b>	500 50

## Exposure To Personnel

### Personal Dosimeters

Personal monitoring devices are worn to record cumulative doses received as a result of occupational exposures to external radiation. Most applications are to obtain an approximation of whole body dose, but dosimeter units are available to measure localized areas ( e.g. fingers ). Information obtained when the dosimeters are read is useful for evaluating the effectiveness of protective measures and the necessity of appropriate action ( especially if overexposure is indicated ). The most common device is the thermoluminescent dosimeter (TLD).

TLD's have inherent limitations which must be recognized. Most apparent is that they must be processed in order to obtain a reading of accumulated dose. The use of direct reading dosimeters (DRD's) may be warranted if immediate indication of exposure is required. Personal monitoring devices are **insensitive to weak beta radiation** such as that from  $^3\text{H}$ ,  $^{14}\text{C}$ ,  $^{35}\text{S}$  and  $^{33}\text{P}$ . Information and advice concerning the choice of dosimeters and readout services are the responsibility of the user or the users department. In any work for which dosimeters are required by the permit they are considered part of the personal safety equipment and must be worn at all times when working with radiation.

Dosimeter services are available at nominal costs from various vendors. These services include the supply of dosimeters and standardized readout of exposures at regular intervals. For information on various vendors approved by the CNSC, contact the Radiation Safety Office.

Reports of personnel exposures from the vendor are sent first to the Radiation Safety Office for review and then forwarded to the department or lab.

The RSO will investigate any **unusual exposure** and advise corrective action where indicated for the health and safety of personnel. The RSO is **required** to investigate and report to the CNSC on the circumstances of any exposure report exceeding maximum permissible dose limits as stipulated in the **Nuclear Safety & Control Regulations**.

## Required Radiation Warning Signs & Postings

The purpose of posting warning signs is to inform staff and students of the area's radiological conditions. Areas in which radiation emitting devices are present or in which a person could receive a dose of ionizing radiation in excess of 2.5  $\mu\text{Sv}/\text{hour}$ , **shall** have posted at each entrance to the lab a Dalhousie University **Hazard Identification** sign posted with the radiation trefoil and the words X-Ray.

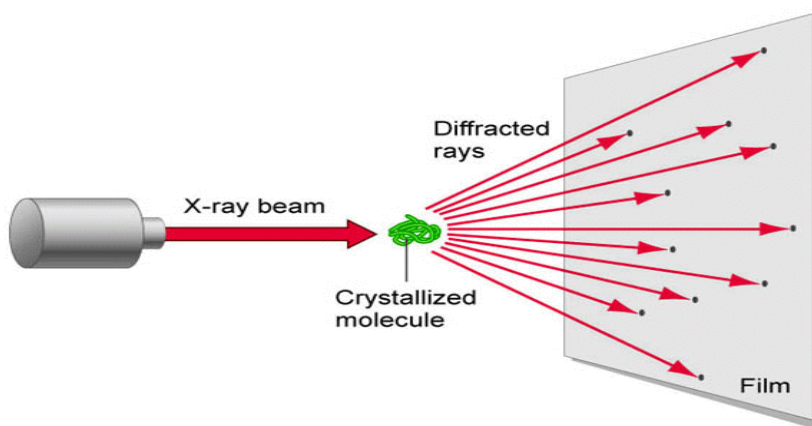
The unit must also be labelled with a sign carrying the words **Caution - This Equipment Produces X-Rays When Energized**". These signs are available from the Radiation Safety Office.

Warning lights interlocked to the main power supply or the shutter should be provided at the on-off switch and near the tube housing to remind the operator that the x-ray beam is on. In addition, a light or other device should be provided to warn the operator when the shutter is open. Warning lights should be of a fail-safe design so that the generator will turn off or the shutter closes if the light fails.

## Analytical X-Ray Equipment

### X-Ray Diffraction

When a beam of monochromatic x-rays strikes matter x-rays are scattered in all directions. In crystalline materials atoms are organized in an orderly manner with sets of parallel planes arranged in a lattice structure. Irradiating a crystal with monochromatic x-rays will result in x-rays emanating from the sample in an orderly pattern that is dependent on the position and intensity of each reflected beam. This directional dependence of the diffracted beam is called the diffraction pattern. It can be used to identify compounds, study phase transformations, determine crystalline size, measure stress or strain and other similar structure related properties of materials.



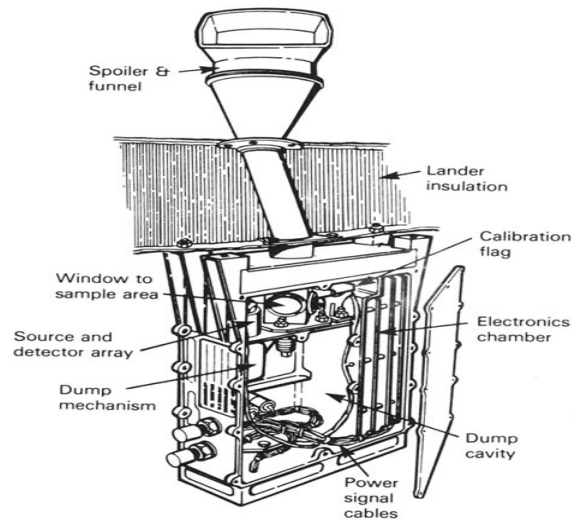
In a typical unit, the primary beam passes from the tube through a shutter in the x-ray tube housing. A filter is often inserted close to the shutter to filter out the continuous x-ray spectrum allowing a high percentage of the characteristic x-rays through. The energy of the characteristic radiation is dependent on the target material and beam energy.

The beam passes through a collimator which limits the cross section of the beam to approximately 1 sq. mm. and strikes the sample creating a characteristic diffraction pattern. The diffracted x-rays are recorded on film or by a Geiger, proportional or scintillation counter for further study. The detection device travels through a circular path on a device known as a goniometer. Only a small fraction of the primary beam impinges on the sample. The beam then strikes a beam trap which absorbs the remaining x-rays.

The unit is designed for continuous operation in contrast to diagnostic x-ray tubes which typically stay on for a fraction to a few seconds. Consequently, all connections in the unit must be tight to prevent the leakage of scattered radiation.

## X-Ray Fluorescence Spectrometers

Fluorescence x-ray spectroscopy is an analytical method for determining the elemental composition of a substance. The sample is irradiated with high intensity x-rays generated from a tungsten target. Characteristic x-rays are emitted and the spectrum is analysed in an x-ray spectrometer. The elements present can be identified by their characteristic wavelengths. The relative proportion of the elements can be estimated by the respective intensities of the lines.



High intensity beams of fairly penetrating radiation are utilized in this method. The instruments are usually completely enclosed to minimize scattered radiation and to prevent access to the primary beam.

To prevent accidental exposure to the x-ray beam, sample chamber doors are provided with safety interlocks. The sample is usually placed very close to the x-ray port. Serious burns have been received as a result of the insertion of the finger into the sample chamber while the unit is operating.

## Radiation Hazards Associated With Analytical X-Ray Equipment

Hazardous radiation from x-ray diffraction and fluorescence equipment may result from exposure to:

- \* the primary beam
- \* scattered radiation
- \* diffracted beam
- \* high voltage power supply unit

The primary uncollimated beam close to the tube housing is the most hazardous because of extremely high dose rates. Accidental exposure of only a few seconds can cause burns to the fingers, hands, arms or eyes. Accidents of this type can occur from insertion of the fingers into sample chambers and by dismantling shutters when the beam is on.

Primary beam radiation can also leak through small cracks around loose fittings or through pin-hole openings in the shielding or tube housing. The primary beam can also penetrate through shutters that do not close properly. Exposure to the primary beam may also occur as it exits from the collimator.

Diffraction beams from the sample have high exposure rates and small cross sections. These beams can be directed from the sample at almost any angle and expose workers to unnecessary radiation.

Another potential source of radiation exposure comes from exposure to high voltage power supply units. Rectifier tubes in these units may become gassy and emit very penetrating radiation.

## **Radiation Protection Measures For Analytical X-Ray Equipment**

### **Shielding**

Shielding must be adequate enough to ensure that dose levels in the room do not exceed 2.5  $\mu\text{Sv}/\text{hour}$ . Because x-ray energies are relatively low adequate shielding is easy to provide.

The most important concern is to protect staff and students from exposure to the primary beam which can cause serious injury within a few seconds. The main protection from exposure to the primary beam is the x-ray tube housing. An x-ray tube must never be turned on without the housing in place. The thickness of the shielding as supplied by the manufacturer is usually sufficient. Leaks can occur at higher voltage if the shield is defective or too thin.

Lead shielding is typically used for absorption of the primary beam. Shielding around the port and shutter assembly should be designed with labyrinth-type joints to avoid any straight paths. Care should also be taken to avoid cracks or small openings in the shielding material. All joints and shielding should be checked to ensure that they fit tight.

### **Ports**

In diffraction units the housing may contain up to four ports to allow the primary beam to exit from the tube. Unused ports must be effectively closed to prevent the beam from emerging and accidentally exposing the worker. Ports must be secured in such a manner that tools are required to open the ports. Shielding around the ports must be properly constructed of leak-proof joints to ensure that high intensity scattered radiation does not escape from the tube.

### **Shutters**

The shutter is located immediately in front of the port and behind the collimator coupling. The purpose of the shutter is to place a piece of highly absorbent material such as lead in front of the port to block the emergence of the primary beam. The shutter gate is contained inside a leak-proof compartment with appropriate

labyrinth joints to prevent escape of radiation.

Ports that are in use must be properly fitted with a safety shutter that cannot be opened unless a collimator or a coupling has been connected to the port. Removal of the collimator will cause the shutter to automatically close. The shutter should be connected to a warning light or other device to warn the operator that the shutter is open.

### **Collimators**

Collimators are connected to the shutter to limit the size of the x-ray beam and reduce the amount of scatter. The collimator must be electrically or mechanically interlocked with the shutter.

Care must be taken to ensure that the coupling between the tube and the collimator is tight. Intense beams of scattered radiation can be produced when the primary beam strikes the collimator. Shielding must be of adequate thickness, connections must overlap, and straight paths from the tube to the outside must be avoided.

### **Sample Chamber**

All fluorescence units and some x-ray diffraction units may include a chamber that contains the sample being analysed. To prevent serious burns, sample chamber covers must be interlocked to the main power supply or shutter to prevent insertion of fingers into the chamber while x-rays are being produced.

### **Interlocks**

Interlocks are used to prevent access to the primary beam by either cutting off the high voltage supply or closing the shutter. Interlocks are commonly found on the shutter-collimator assembly, sample changer and/or the safety enclosure.

Interlocks must be reliable and not subject to accidental over-riding. Deliberately over-riding an interlock is forbidden.

Interlocks are strictly a safety device and should not be used to turn equipment off or close shutters.

### **Beam Trap**

Only a small portion of the primary beam is absorbed or diffracted by the sample. The x-rays that pass through the sample are absorbed by a beam trap. The beam trap consists of a hollow cylinder with a bottom covered by a highly absorbent material. Approximately 2 mm of lead is typically used.



## **Safety Barriers**

Whenever possible, a safety barrier should be installed to prevent the operator's hands from accidentally being placed in the x-ray beam. This device should be interlocked to the shutter or main power supply. The safety barrier also functions to reduce scattered radiation in the room.

Because of the low energy of the x-rays, safety barriers are typically made from plexiglass. Holes can be cut into the plastic so that tools can be inserted without risk of exposure.

Open beam equipment with a safety barrier should be used in a separate room. Access to the room must be restricted while the equipment is operating. A warning light connected to the main power supply should be placed at the door. Signs should be posted to warn personnel of open beam systems.

# **APPENDIX**

## USE LOG FOR ANALYTICAL X-RAY EQUIPMENT

X-Ray Unit: \_\_\_\_\_ Principal Investigator: \_\_\_\_\_

User Name (print)	Date	Shutter Check	Time In	Time Out

## Analytical X-Ray - Self-Audit Checklist

**Principal Investigator:** \_\_\_\_\_

**Location:** \_\_\_\_\_ **Date:** \_\_\_\_\_

**Audited By:** \_\_\_\_\_

### General Requirements

	Yes	No	N/A
Annual survey & inspection performed			
Standard Operating Procedure available			
List of undergraduate students submitted to RSO			
Shutter inspection performed prior to each use			
Operating log maintained			
Maintenance log maintained			
Machine secure against unauthorized use			
Copy of Health Canada's Safety Code 32 available			
New users have read and signed off on safety guide			
Unit is registered with the Radiation Safety Office			

### Postings, Signs and Warning Lights

	Yes	No	N/A
Dalhousie University Hazard Identification sign posted			
Clearly visible label with the words " <b><i>This equipment produces x-rays when energized. To be operated only by authorized personnel.</i></b> "			
A clearly visible warning light with fail-safe characteristics, located near the tube housing, indicating when the x-ray tube is producing x-rays or the shutter is open.			

	Yes	No	N/A
" <b>Caution, X-Ray Equipment</b> " sign posted on the area door			

### Additional Requirements For Open Beam Systems

	Yes	No	N/A
Suitable barrier or markings to delineate the boundary between the radiation area and the controlled area			
Suitable shielding to reduce dose rates to personnel to < 5 µSv/hour			
Beam shutter provided for each port of the x-ray tube housing			
Guard or interlock capable of preventing entry of any part of the body into the primary beam			
Each shutter interlocked to allow shutter opening only when the collimator or apparatus coupling is in place			
Shutters on unused ports secured			

### Additional Requirements For Enclosed Beam Systems

	Yes	No	N/A
Interlocks to prevent x-ray exposure while enclosure is open			
Fail-safe interlock on sample chamber closure			
Chambers enclosing the x-ray tube housing, sample, detector and analysing crystal to prevent entry of any part of the body during normal operation			

### Monitoring & Training Requirements

	Yes	No	N/A
Whole body badges (TLD's) provided for each user			
Ring badges provided for each user			
Each user has read the safety guide			
Each user has been trained by the P.I. in safe use of the unit			

## **ALARA STATEMENT**

**ALARA** an acronym for **As Low As Reasonably Achievable**, means making every reasonable effort to maintain exposures as far below the regulated dose limits as is practical consistent with the purpose for which the licence activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licence materials in the public interest.

The current system of radiological protection reflected in the International Commission on Radiological Protection (ICRP) Publication 60, "1990 Recommendations of the International Commission on Radiological Protection", and the National Council on Radiological Protection (NCRP) Publication 116, "Limitation of Exposure to Ionizing Radiation", is based on three general criteria:

- 1) **Justification**, the need to justify any activity which involves radiation exposure on the basis that the expected benefits to society exceed the overall societal detriments
- 2) **Optimization**, the need to ensure that the benefits of such justifiable activities or practices is maximized for the minimum associated societal detriment, economic and social factors being taken into account
- 3) **Dose and Risk Limitation**, the need to apply dose limits to ensure that individuals or groups of individuals do not exceed acceptable levels of risk.

Dalhousie University is committed to maintaining radiation exposures to staff, students, and the public, resulting from the use of nuclear substances and radiation emitting devices in diagnostic, therapeutic and research procedures, as low as is reasonably achievable, **ALARA**. The Radiation Safety Committee and the Radiation Safety Office will advise and assist in all matters of radiation safety. The Committee will recommend to University administration through the Radiation Safety Office, policies and procedures **to be required** for maintaining radiation exposures ALARA through the safe handling, storage, use, transport and disposal of radiation sources and will assist in the interpretation of the Nuclear Safety & Control Act, Regulations and Licence conditions.

Sources of radiation include materials or equipment which are capable of emitting ionizing radiation. Ionizing radiation sources include nuclear substances, nuclear reactors, particle accelerators, x-ray machines and electron microscopes. Policies and procedures for radiation safety are delineated in the Dalhousie University, Radiation Safety Manual.

# DALHOUSIE UNIVERSITY

## ALARA PROGRAM

### Introduction:

**ALARA** an acronym for **As Low As Reasonably Achievable**, means making every reasonable effort to maintain exposures as far below the regulated dose limits as practical consistent with the purpose for which the licenced activity is undertaken, taking into account the state of technology, the economics of improvements in relation to the state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licenced materials in the public interest.

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- I. **Justification** - the need to justify any activity which involves radiation exposure on the basis that the expected benefits to society exceed the overall societal detriments
- II. **Optimization** - the need to ensure that the benefits of such justifiable activities or practices is maximized for the minimum associated societal detriment, economic and social factors being taken into account
- III. **Dose and Risk Limitation** - the need to apply dose limits to ensure that individuals or groups of individuals do not exceed acceptable levels of risk

### Administration Commitment:

1. The administration of Dalhousie University is committed to the program described herein for keeping individual and collective doses as low as reasonably achievable. In accord with this commitment we hereby describe an administrative organization for radiation protection and will develop policies, procedures and instructions to foster the **ALARA** concept. The organization will be comprised of a Radiation Safety Committee and a Radiation Safety Officer (RSO).
2. An annual review of the radiation safety program will be performed. This review will include operating procedures, past personnel dose records, inspections, laboratory self-audits, training and consultation with the RSO.
3. Modifications to operating, maintenance, and experimental procedures as well as changes in equipment and facilities will be made if they will reduce exposures

unless the cost, in our judgement, is considered unjustified. If modifications have been recommended but not implemented, we will be prepared to justify the reasons for not implementing them.

4. The Radiation Safety Committee will meet quarterly to review the **ALARA** program with a formal written annual report submitted no later than one month after the end of the calendar year.

#### **Obligations of Licensees and those responsible for Radiation Emitting Devices**

1. Ensure the presence of a sufficient number of qualified workers to carry on the licensed activity safely and in accordance with the **Nuclear Safety and Control Act** (the Act), the regulations made under the Act and the **Nuclear Substances and Radiation Devices Licence**
2. Train workers to carry on the licensed activity in accordance with the Act and regulations
3. Take all reasonable precautions to protect the environment and the health and safety of persons and to maintain security
4. Provide the devices required by the Act and regulations and maintain them within the manufacturer's specifications
5. Require that every person at the site of the licensed activity uses equipment, devices, clothing and procedures in accordance with the Act and regulations
6. Take all reasonable precautions to control the release of radioactive nuclear substances or hazardous substances within the site of the licensed activity and into the environment as a result of the licensed activity
7. Implement measures for alerting the licensee to the illegal use or removal of a nuclear substance, prescribed equipment or prescribed information, or the illegal use of a nuclear facility
8. Implement measures for alerting the licensee to acts of sabotage or attempted sabotage anywhere at the site of the licensed activity
9. Instruct the workers on the physical security program at the site of the licensed activity and to their obligations under that program
10. Keep a copy of the Act and the regulations made under the Act that apply to the licensed activity readily available for consultation by the workers.

These obligations are tasked to the Radiation Safety Committee to be carried out by the Radiation Safety Officer.



### **Obligations of Workers:**

1. Use equipment, devices, facilities and clothing for protecting the environment or the health and safety of persons, or for determining doses of radiation, dose rates or concentrations of radioactive nuclear substances, in a responsible manner and in accordance with the Act, the regulations made under the Act and the Nuclear Substance User Permit (permit)
2. Comply with the measures established by the licensee to protect the environment and the health and safety of persons, maintain security, control the levels and doses of radiation, and control releases of radioactive nuclear substances and hazardous substances into the environment
3. Promptly inform the licensee or the worker's supervisor of any situation in which the worker believes there may be
  - a) A significant increase in the risk to the environment or the health and safety of persons
  - b) A threat to the maintenance of security or a incident with respect to security
  - c) A failure to comply with the Act, the regulations made under the Act or the permit
  - d) An act of sabotage , theft, loss or illegal use or possession of a nuclear substance, prescribed information, or
  - e) A release into the environment of a quantity of a radioactive nuclear substance or hazardous substance that has not been authorized by the licensee
4. Observe and obey all notices and warning signs posted by the licensee in accordance with the ***Radiation Protection Regulations***, and
5. Take all reasonable precautions to ensure the worker's own safety, the safety of the other persons at the site of the licensed activity, the protection of the environment, the protection of the public and the maintenance of security.

### **ALARA Procedures:**

The Radiation Safety Committee will delegate authority to the RSO for enforcement of these procedures. The Radiation Safety Committee will support the RSO when necessary in asserting his/her authority. If the Radiation Safety Committee overrules the RSO, it will record the basis for its action in the minutes of the quarterly meeting.

1. All occupationally exposed workers will be provided with a copy of the ALARA policy. It will be made available to each research group as part of the ***Radiation Safety Policies*** and will be available for review on the EH&S web site at <http://www.dal.ca/safety>

2. All new occupationally exposed workers will participate in the first available Radiation Safety Training course available after joining a research group, unless otherwise exempted by the RSO. The Radiation Safety Training course is held three times annually, typically in May, September and December.
3. The RSO will thoroughly review the qualifications of each principal investigator with respect to the types and quantities of nuclear substance requested, methods of use, suitability of laboratory space, availability of required shielding, dosimetry, and monitoring equipment.
4. The RSO will thoroughly review all planned laboratory construction and renovation prior to submission of plans to the Canadian Nuclear Safety Commission (CNSC) to ensure that the requirements of CNSC's Regulatory Document R-52 "**Design Guide for Basic and Intermediate Level Radioisotope Laboratories**" are met.
5. The RSO will review quarterly the occupational radiation exposures of all monitored workers. Dalhousie University does not have any Nuclear Energy Workers (NEW), therefore the limits set for "**a person who is not a nuclear energy worker**" apply. An action level of one third the maximum limit is set. If an action level is exceeded the RSO will conduct an investigation and decide if action is warranted. These limits apply to combined external and internal exposures.

Item	Person	Period	Effective Dose (mSv)	Action Level (mSv)
1	a person who is not a NEW	1 calendar year	1 mSv	0.3 mSv
2	a person who is not a NEW lens of an eye	1 calendar year	15 mSv	5 mSv
3	a person who is not a NEW skin	1 calendar year	50 mSv	16 mSv
4	a person who is not a NEW hands & feet	1 calendar year	50 mSv	16 mSv

6. Licence conditions require that removable contamination does not exceed radionuclide-specific limits on accessible surfaces in occupational and public areas. Radionuclides are assigned classifications as follows:

**Class A** - typically long lived and emit alpha radiation

**Class B** - typically long lived and emit beta or gamma radiation

**Class C** - typically short lived and emit beta and gamma radiation

At Dalhousie University Class B & C radionuclides are typically used. In keeping with an ALARA policy contamination limits are set below regulatory limits. In the case of Class A radionuclides regulatory limits apply. Contamination limits are based on activity per square centimeter.

<b>Class</b>	<b>Control Area Limit</b>	<b>PublicArea/ Decommissioning Limit</b>	<b>Dalhousie Limit</b>
A	3 Bq/cm <sup>2</sup>	0.3 Bq/cm <sup>2</sup>	0.3 Bq/cm <sup>2</sup>
B	30 Bq/cm <sup>2</sup>	3 Bq/cm <sup>2</sup>	0.5 Bq/cm <sup>2</sup>
C	300 Bq/cm <sup>2</sup>	30 Bq/cm <sup>2</sup>	0.5 Bq/cm <sup>2</sup>

7. Apply the **Compliance Enforcement Policy** as required
8. Each research group will be required to conduct a nuclear substance laboratory self-audit on a twice yearly basis, in May and November. These audits will be reviewed by the RSO and appropriate corrective action taken within one week of receipt of audit.

# **Prenatal Radiation Exposure Policy**

## **Introduction:**

Every pregnant woman and her developing fetus are exposed to some risks affecting their well being. These risks may be voluntary or involuntary and avoidable or unavoidable on the part of the mother. They include the ingestion of alcohol, tobacco smoke, prescription and non-prescription drugs, dietary and environmental agents and exposure to ionizing radiation from non-medical sources.

In utero radiation exposure of the embryo causes intense anxiety among parents and the public in general. Too often, pregnant women and their families are frightened by careless statements made with little or no regard of the actual facts.

Those of you who work in or visit areas where nuclear substances are used need to understand the biological risks radiation presents to your unborn child.

The fetus passes through three relatively clear cut phases. In each of which the type and magnitude of an effect, that can be produced by radiation will differ. They are:

### **Preimplantation**

This period begins with fertilization and ends with implantation in the uterus. this stage is complete at 10 days. There are few epidemiologic data available for this period of gestation. During preimplantation, irradiation of animals appears to lead to "all or none" effects. X-ray doses of 2 Gy in mice result in a high incidence of embryonic death; however, those that survive appear to be normal. It is possible that spontaneous abortions increase slightly during this early time period; however, this increase has been too small to quantitate accurately. The "normal" incidence of spontaneous abortion in humans may be as high as 30-50%.

### **Organogenesis**

The period of organogenesis is usually divided into early and late portions. The early organogenesis period is 15-28 days after conception, whereas late organogenesis refers to the time 29-50 days after conception. During early organogenesis, the embryo is sensitive to lethal, teratogenic and growth-retarding effects because of the criticality of cellular activities and the high proportion of radiosensitive cells. Irradiation at this time may lead to severe developmental defects. Effects in animals can be seen down to 100 mSv. Human embryos exposed to similar doses at Hiroshima and Nagasaki, however, did not exhibit any increase in frequency of developmental defects.

### **Fetal Stage**

Animal experiments suggest that irradiation is less likely to lead to developmental anomalies after the first two months of gestation. The only human data available are drawn from pregnant survivors of Hiroshima and

Nagasaki, where reduced head size and mental retardation were the developmental abnormalities noted after whole body exposures exceeding 500 mSv. There is also thought to be an increased risk of childhood cancer. The "natural" incidence of childhood cancer including leukemia, up to the age of ten years is 6 per 10,000. The added risk of cancer including leukemia from exposure during pregnancy is 2-6 per 10,000 per 10 mSv over the first ten years of life. The best estimate of risks associated with prenatal exposure to radiation suggests that the overall risk lies in the range of 0-1 cases per 1000 irradiated by 10 mSv in utero, which is at least 30 times lower than the natural level of occurrence of serious handicaps in average pregnancies.

**The vast majority of occupationally exposed radiation workers at Dalhousie University receive annual whole body exposures of less than 1 mSv.**

**Fetal Exposure and the *Nuclear Safety and Control Act*:**

The International Commission on Radiological Protection (ICRP) regularly reviews the biological evidence of the detrimental effects of ionizing radiation and publishes appropriate recommendations regarding acceptably safe practices for the exposure of occupational workers, patients undergoing treatment/diagnosis and for members of the public. In Canada these recommendations have been incorporated into law in the ***Nuclear Safety and Control Act***. The law is administered by the ***Canadian Nuclear Safety Commission*** and enforced locally by the Dalhousie University Radiation Safety Committee. The ***Nuclear Safety and Control Act*** requires that the dose to the pregnant Nuclear Energy Worker after the licensee is informed of the pregnancy of that worker shall not exceed 4 mSv. **The vast majority of occupationally exposed radiation workers at this institution receive annual whole body exposures of less than 1 mSv.** Thus a pregnant worker exposed to the levels of radiation which would normally be encountered at Dalhousie is well within the levels of radiation exposure as defined in the ***Nuclear Safety and Control Act*** and the probability of harm occurring to the fetus is considered to be extremely small in comparison to the incidence of "spontaneous" genetic and developmental abnormalities.

**RESPONSIBILITIES OF FEMALE RADIATION WORKERS:**

1. Where a pregnant nuclear energy worker becomes aware of her pregnancy, she shall immediately inform Dalhousie University in writing of her pregnancy.

**RESPONSIBILITIES OF DALHOUSIE RADIATION SAFETY COMMITTEE:**

1. An assessment of the work situation shall be done to ensure that radiation safety principles are being adhered to and that radiation dose limits are not exceeded and remain as low as reasonably achievable (ALARA).
2. Radiation exposures of pregnant Nuclear Energy workers shall be monitored to ensure that the dose limit of 4 mSv for the balance of the pregnancy is not exceeded in accordance with the Nuclear Safety and Control Act.

### DECLARATION OF PREGNANCY FORM

I declare that I am pregnant, for the purposes of lowering the dose received by me and/or my embryo/fetus. I understand and agree that additional monitoring may be required of me during the balance of my pregnancy to ensure that the dose limit of 4 mSv is not exceeded.

\_\_\_\_\_  
**Worker Name ( please print )**

\_\_\_\_\_  
**Telephone Number**

**Estimated Date of Birth** \_\_\_\_\_

\_\_\_\_\_  
**Signature of Worker**

\_\_\_\_\_  
**Date**

\_\_\_\_\_  
**Signature of Supervisor**

\_\_\_\_\_  
**Date**

\_\_\_\_\_  
**Signature of Radiation Safety Officer**

\_\_\_\_\_  
**Date**

## Glossary

### **Absorbed Dose**

The amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose is the Gray (Gy)

### **ALARA**

Acronym for As Low As Reasonably Achievable- making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account technology, the economics of improvements in relation to benefits to the public health and safety, and other socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

### **Background Radiation**

Ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays, and natural radioactivity is always present

### **Becquerel**

The international (SI) unit of radioactivity in which the number of disintegrations is equal to one disintegration per second

### **Bremsstrahlung**

Photon radiation produced by deceleration of charged particles (usually electrons) passing through matter

### **Dose Equivalent**

The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest.

### **Dose Rate**

The radiation dose delivered per unit of time

### **Dosimeter**

A portable instrument for measuring and registering the total accumulated exposure to ionizing radiation

**Efficiency (radiation detection instrument)**

A measure of the probability that a count will be recorded when radiation is incident on a detector.

**Electron Volt**

A unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt, abbreviated eV.

**Gray**

The international (SI) unit of absorbed dose in which the energy is equal to one Joule per kilogram.

**Ionization**

The process by which a neutral atom or molecule acquires a positive or negative charge.

**Ionizing Radiation**

Any radiation capable of displacing electrons from atoms or molecules, thus producing ions.

**Occupational Radiation Dose**

The dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.

**Photon**

A quantum of energy emitted in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.

**Quality Factor**

A modifying factor that is used to derive dose equivalent from absorbed dose. It corrects for varying risk potential due to the type of radiation.

**Sievert**

The international (SI) of dose equivalent.



## **Thermoluminescent Dosimeter (TLD)**

Crystalline materials that emit light if they are heated after they have been exposed to radiation.