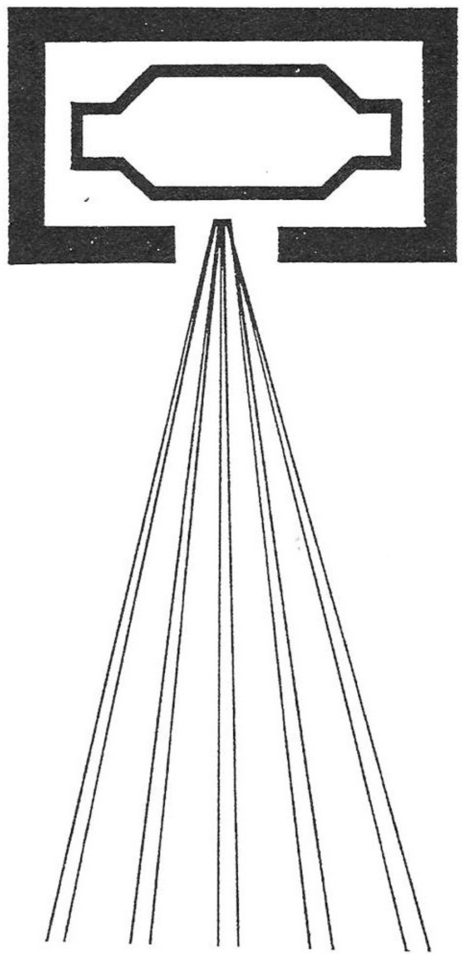
BASIC X-RAY SAFETY COURSE

FOR USERS OF X-RAY EQUIPMENT IN ACADEMIC RESEARCH



A Short Course offered by:

The Radiation Safety Office
University Of South Carolina
306 Benson School
Columbia, SC 29208

Phone: 777-5269
Fax: 777-5275
Email: Radsafe@mailbox.sc.edu

Lesson 1: Basic X-ray Physics

How X-rays Were Discovered
For many years before the discovery of x-rays, physicists had been observing high voltage discharges in vacuum tubes. In 1895, Wilhelm Konrad Roentgen was studying these high voltage discharges in a Crooke's tube when he noticed that a barium platinocyanide screen lying several feet away was glowing. He realized that this fluorescence was caused by some unknown radiation. He experimented with this radiation and discovered that the rays could pass completely through some solids such as paper and wood, but denser materials such as lead, completely stopped them.

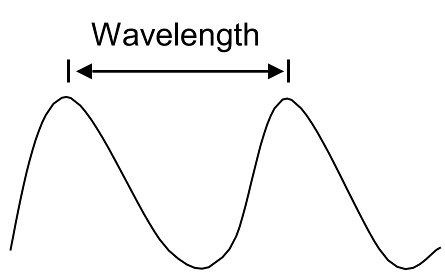
When he placed his hand between the tube and a piece of cardboard coated with barium platinocyanide, he realized the new radiation held great promise for medicine. He had taken the first x-ray of the hand.

As "X" represents the unknown in mathematics, Roentgen gave the new rays the name x-rays. It did not take but a few months before he knew most of their properties.

The discovery of x-rays changed not only the course of medicine but of science and industry as well.

What Are X-rays?
X-rays are classified as a type of electromagnetic (EM) radiation. EM radiation consists of electrical energy and magnetic energy that travel together through space as waves. Other types of electromagnetic energy include radio waves, visible and invisible light, and gamma rays. All EM radiation has the same general form and travels at the speed of light- (186,000 miles per second in a vacuum). They all differ in wavelength. The wavelength is the distance between two successive peaks in a wave (Fig. 1-1).

FIG. 1-1



The number of peaks or cycles per second is the frequency of the wave and is measured in hertz (Hz). Frequency is inversely proportional to the wavelength and directly proportional to energy. Increases in wavelength decrease the frequency and energy (FIG. 1-1).

Compared with other types of EM radiation, x-rays have extremely short wavelengths and high frequencies; therefore, they are extremely energetic (FIG. 1-2).

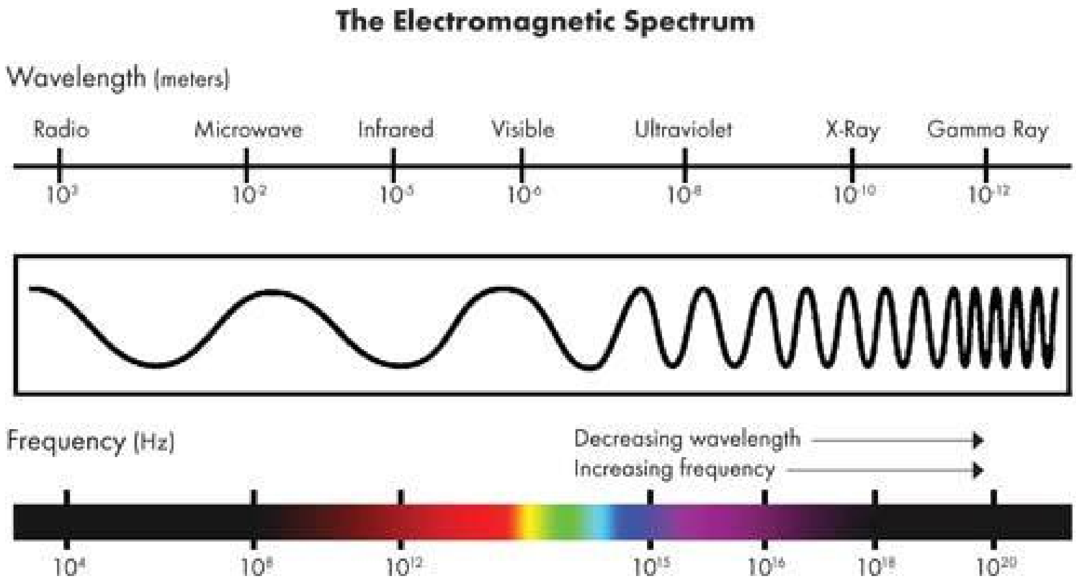


FIG. 1-2

How Are X-rays Produced?

X-rays are produced when a stream of fast moving electrons (e-) undergoes sudden deceleration. While this occurs frequently in nature when gamma rays are emitted from the nuclei of radionuclides, the rapid deceleration of e- can be artificially produced in an x-ray tube.

Elements of An X-ray Tube

The first x-ray tubes were cold cathode gas tubes. They consisted of a glass tube in which a partial vacuum had been produced, leaving a small amount of gas. Two electrodes were sealed inside. One was negative, the cathode; the other was positive, the anode. The cathode was not heated. A high voltage was applied across the terminals causing ionization of the gas in the tube. A stream of e- was released and upon striking the anode, x-rays were produced. This tube is now obsolete due to its inefficiency. The kilovolt peak or kVp (intensity) and mA or milliamps, (number) of the x-rays, could not be independently controlled; therefore, x-ray quantity and quality were difficult to control.

In 1913, W.D. Coolidge of the General Electric Company, invented a new type of x-ray tube, the hot cathode diode tube. It made it possible to independently select the ma and kVp and by doing so revolutionized radiographic technique.

This x-ray tube consists of 4 features (FIG. 1-3).

Evacuated glass tube
Air is removed not only from the interior of the tube but also from the glass and metal parts. This is done through prolonged baking of the tube before it is sealed. The process is called ***degassing*** and the vacuum is necessary for 2 reasons.

- To prevent collisions of high speed e- with molecules of air, which could cause significant slowing of the e-.
-To prevent oxidation and burning out of the filament.

Hot Filament
The filament is supplied with a separate low voltage heating current that allows the separation of some of the filament's outer orbital electrons. This filament acts as the cathode (negative electrode) when the high voltage is applied.

Target
The target serves as the anode (positive electrode) when the high voltage is applied. The target material must have a very high melting point to withstand the extremely high temperatures to which it is subjected. The high temperatures are due to the inefficient conversion of electrons to x-rays when the electrons collide with the tungsten atoms.

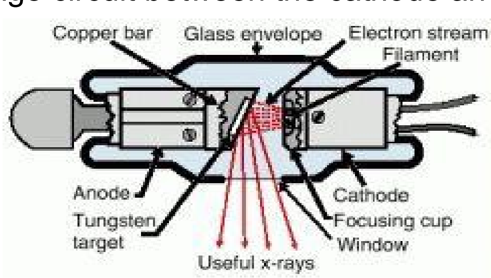
The target material must also have a high atomic number. This causes the characteristic radiation to have high energy and be more penetrating. The radiation is characteristic of the target element and the atomic shells involved. The high atomic number also increases the production of Bremstrauhlung radiation.

A common material used for the target is tungsten.
(Characteristic and Brems radiation will be discussed later in detail).

High Voltage
A high voltage is applied across the electrodes, charging the filament negatively and the target positively.

There are actually two circuits in an x-ray tube. One is a low voltage heating circuit through the cathode that heats the filament so electrons can be "boiled" off. The high voltage circuit between the cathode and anode is used to drive the e-.

FIG. 1-3



http://medical-dictionary.thefreedictionary.com/x-ray+tube

<u>Conditions Necessary for X-ray Production</u>

When fast moving electrons undergo rapid deceleration or when electrons drop from an outer shell to an inner atomic shell, x-rays are produced.

Four conditions are required for the production of x-rays in a hot cathode tube.

Separation of Electrons
The tungsten atoms in the filament have orbital electrons circling around a central nucleus. The current supplying the filament causes it to become glowing hot. This results in the separation of the outer orbital electrons. The electrons escaping from the filament form a cloud or space charge. The electrons are called ***thermions*** and the process of liberation through the heating of a conductor by an electric current is called ***thermionic emission***.

Production of High Speed Electrons
If a high potential difference (kV) is applied across the tube giving the filament a very high negative charge (cathode) and the target a very high positive charge (anode), the resulting strong electric field causes the space charge electrons (thermions) to move at a very high speed through the tube from the cathode to the anode. This electron stream constitutes the cathode rays or tube current. The speed of these electrons approaches one half the speed of light and sometimes more.

Focusing of Electrons
The electron stream in the tube is confined to a very narrow beam and is concentrated on a small spot on the anode face, the ***focus***, by a negatively charged ***focusing cup***. The narrower the electron beam, the smaller the focus is and the sharper the x-ray image.

Stopping of High Speed Electrons
When the electrons enter the target of the x-ray tube, their kinetic energy changes to other forms. Only a very small fraction of the kinetic energy is converted to X-rays. Over 99%of the energy appears as heat.

Electron Interactions With The Target

When the fast electron stream enters the target, the electrons interact with the target atoms producing x-rays by the following processes:

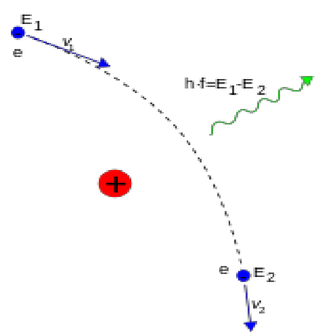
Bremsstrahlung radiation

When the negatively charged high-speed electron approaches the positively charged nuclear field of the target atom, it is deviated from the original path because of the attraction between the opposite charges. As the electron is slowed down, it loses some of its kinetic energy. The lost kinetic energy is in the form of an x-ray. The energy of the x-ray is equivalent to the loss of kinetic energy. This process is given the name ***Bremsstrahlung*** or braking radiation (FIG. 1-4). Brems radiation is polyenergetic or non-uniform in energy and wavelength because the amount of deceleration varies among electrons according to their speed and how closely they approach the nucleus.

Electrons also interact with and are repelled by the electrons swarming around the target nuclei. Heat is transferred in this process. This heat production far exceeds

X-ray production.

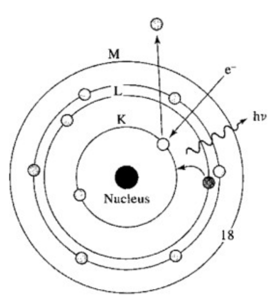
FIG. 1-4



Characteristic radiation

An electron with a minimum kinetic energy may interact with an inner orbital electron of the target atom. The target electron is ejected from its orbit. The atom is now ionized or unstable because there is a vacancy in one of the shells. This vacancy is immediately filled by electron transition from one of the outer shells. Since energy was put into the atom to remove the electron, an equal amount of energy must be given off when an electron from the higher energy level enters to fill the hole. The energy is emitted as a ***characteristic x-ray*** (FIG. 1-5). It is characteristic of the target element and the involved shells. In the diagram below, there is a series of characteristic x-rays because as each vacancy in a lower shell is filled, another opening in an outer shell is created.

FIG. 1-5



http://what-when-how.com/electronic-properties-of-materials/applications-optical-properties-of-materials-part-9/

Brems radiation and characteristic radiation compose ***"primary"*** radiation, or the x-rays that emerge from the tube. Brems radiation makes up approximately 90% of the x-rays emitted from the tube and characteristic radiation composes approximately 10% of the emitted rays.

Properties of X-rays

Highly penetrating, invisible rays which behave as both waves and particles.

Electrically neutral; cannot be deflected by electric or magnetic fields.

Polyenergetic or have many different energies.

Travel at the speed of light in a vacuum.

Ordinarily travel in a straight line.

Ionize gases indirectly because of ability to remove orbital electrons.

Produce chemical and biological changes by ionization and excitation.

Produce secondary and scattered radiation

Interactions of Ionizing Radiation and Matter

When an x-ray beam passes through matter, it is attenuated or loses energy. Attenuation occurs by:

-Absorption of part of the energy by various interactions with the atoms of the body in the path of the beam.

-Emission of scattered and secondary radiations. Scattered radiation results when photons change direction upon interacting with atoms. Secondary radiation comprises characteristic radiation emitted by atoms after having absorbed x-ray photons.

Some x-rays do not interact with atoms at all because:

- X-rays are electrically neutral so there are no attractive forces.

- Atoms contain mainly empty space.

Lesson 2
Dose Units and Biological Effects

Radiation Dose/Exposure Terms

There are a few terms related to radiation exposure and radiation dose.

The first term is the **Roentgen (R)** which was named after William Conrad Roentgen who discovered x-rays in 1895. A roentgen is a measure of radiation exposure in air for energies less than 3 MeV. It specifically refers to x-rays or gamma rays but is often used to quantify other types of radiation, as well. It is defined in terms of the charge (dQ) due to ionization formed within a volume of air of a certain mass (dm):

Exposure= dQ/dm

1 R = 2.58×10^{-4} Coulombs/kg air

The roentgen unit does not correlate directly with the amount of dose that a human can receive from a radiation source and therefore, cannot assess biological damage. The energy absorbed per roentgen of exposure varies with the kind of material being irradiated and the energy of the irradiating beam.

Another unit was developed called the **radiation absorbed dose** or the **RAD**. The energy of the radiation and the density of the material that absorbs the radiation are two important factors in determining dose. Radiation energy is directly correlated with the degree of penetration in a human body. More energetic radiations are more penetrating. The denser tissues of the body will absorb more radiation.

The RAD is a unit of absorbed dose, considers the energy of the radiation and the density of the absorbing material. 1RAD = absorbed dose when 100 ergs of energy per gram is transferred to the absorbing material.

Roentgen units can be converted to RAD units using the following proportionality constants. Notice that the constant varies with energy and density in the table.

Radiation Absorbed Dose (RAD) – Proportionality Constants

		constant (RAD/R)			
kv	Filter mm of Al	air	water	muscle	Bone
100	5.5	0.87	0.91	0.94	3.10
250	3	0.87	0.96	0.96	1.42
400	nil	0.87	0.97	0.97	1.11

If you could measure the radiation quantity at the surface of the body in roentgens, you could then determine the amount of absorbed dose in RADS using the proportionality constants in this table. The very far left column lists the energy of the radiation in kv (kilovolts) from 100 to 400 kv. Now as you move from left to right in the table you seen columns for increasing material densities from air (least dense) to bone (most dense). In summary, you can take the number for skin entrance exposure and multiply it by the appropriate proportionality constant to obtain a value for absorbed dose in RADS.

Another term associated with dose is the **roentgen equivalent man** or the **REM**. A rem is a measure of radiation dose equivalent. In determining the biological effect of a particular type of ionizing radiation, it is not sufficient to consider only the total energy transferred to the living system. The distribution of energy along the path of the radiation (i.e. How or how little energy is deposited along the path) is also critical. For example, the biological damage incurred by one Rad of X-rays is not the same as the damage done by one Rad of alpha particles. Alpha particles cause about 20 times as much damage per unit of living tissue.
We can say that the alpha particle has a higher biological effectiveness than does the X-ray.

The REM is determined by applying a quality factor to the RAD unit. The following quality factors are applied to convert the dose in RADs to Dose Equivalent REMs.

Radiation Type	**Quality Factor**
X-rays or gamma rays	1
Beta Particles	1
Neutrons	10
Alpha Particles	20

NEW INTERNATIONAL UNITS

In 1975, the International Commission on Radiological Units (ICRU) adopted new units applicable to radiation protection that are consistent with the International System of Units (SI System). The Gray (Gy) has replaced the RAD. One gray is equal to 100 RAD's. And the Seivert (Sv) has replaced the REM. One seivert is equal to 100 REM. Most countries of the world have adopted the new units. However, they are still not widely used in the United States and Russia, but there is much movement to adopt these units. So, it is important to know both sets of terms. If you look at the scientific literature, you will find the Gray and Seivert used. If you visit most countries, you will find the new units used in discussions about radiation dose.

Gray (Gy) replaces RAD	Seivert (Sv) replaces REM
1 Gy = 1 joule/kg = 100 RAD	1 Sv = 100 REM

Dose Limits

Everyone is exposed to a certain amount of radiation from the environment (cosmic, radon, terrestrial…) which is called the background radiation dose. In SC, the average background radiation level is between 100- 500 mrem per year.

S.C. Regulation 61-63 states that the dose limits an individual **worker** can receive must be the sum of the dose from external exposures (called the ***deep dose equivalent- DDE***) and the dose from internally deposited radioactive material (called the ***committed effective dose- CEDE*** equivalent). The sum of these two values is called the ***total effective dose equivalent (TEDE)***. The annual limits for adults are:

1. 5 rem (.05 Sv) total effective dose equivalent
2. 50 rem (.5 Sv) total organ dose equivalent to any single organ or tissue other than the lens of the eye which has a limit of 15 rem (.15 Sv) per year.

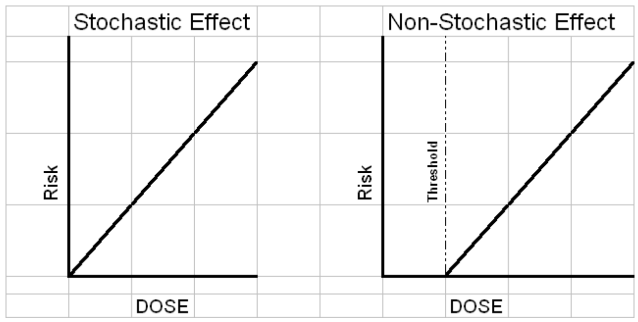
It should be pointed out that these limits do not imply a "safe" level. The actual biological effects from low levels of radiation are difficult to ascertain. As a result, regulatory agencies have required that licensees take a very conservative approach to this matter and recommend that radiation doses to individual employees be kept **A**s **L**ow **A**s **R**easonably **A**chievable (ALARA). Even though the yearly regulatory limit for total effective dose equivalent is 5,000 mrem (50 mSv), licensees must strive to eliminate any unnecessary doses from radiation in the workplace. USC is required to have an ALARA program that instructs employees on ways to reduce their radiation dose. Any unusual doses, no matter how small, must be investigated by the radiation safety officer.

Biological Effects

Radiation can have deleterious effects on living systems. The biological effects of ionizing radiation were noticed very shortly after the discovery of radioactivity by Becquerel and x-rays by Roentgen at the end of the 19th century. These effects have been studied extensively over the past century. From these studies, dose-response relationships have been developed. Two of the more common dose-response relationships used to explain radiation bio-effects are (1). **deterministic effects** (also known as non-stochastic effects) and (2).**stochastic effects**.

In deterministic effects, the severity to the individual depends on the radiation dose. For deterministic effects, there is a threshold below which, there is no measurable effect. Examples of deterministic effects are cataracts, skin damage, and depression of red blood cell counts.

For stochastic effects, such as cancer induction, a certain fraction of the exposed population will actually develop cancer. The severity of the cancer does not depend on the radiation dose. In addition, there is no way to predict which individuals will develop cancer. Exposure of an individual to radiation dose increases the probability that the effect will occur.



In the above figure, for a stochastic effect, the risk to the population is proportional to the dose. For a deterministic effect, the severity of the response to the individual is proportional to the dose above a certain threshold.

Dose Rate

The faster the dose is delivered, the greater will be the effect. For example, a whole body dose of 1000 RAD (penetrating radiation) delivered at once to a man is lethal. However, if the same dose is delivered over a longer period of time, the dose is not lethal.

Area of Exposure

The greater the area of bodily exposure, the greater will be the effect. For example, 1000 RAD (10 Gy) of a highly penetrating radiation to the whole body is lethal; however, 1000 RAD (10 Gy) to the finger is not lethal.

Sensitivity of the Individual

There is a definite variation of sensitivity of the individual from radiation exposure. Statistically, the LD_{50} dose is used. LD_{50} refers to the dose needed to kill 50% of a population. For humans, the LD_{50} dose is 450 RAD (4.5 Gy) delivered at one time to the whole body from highly penetrating radiation.

Cell Sensitivity

Actively dividing cells (mitotic) are more radiosensitive than cells that are not dividing. In 1906, Bergonie & Tribondeau noted that the radiosensitivity of cells is directly proportional to cell reproductive activity and inversely proportional to cell differentiation. In general, the more actively dividing cells are more radiosensitive.

CLASSIFICATION OF CELLS BY DECREASING RADIOSENSITIVITY

SENSITIVITY	EXAMPLES
HIGHLY RADIOSENSITIVE	mature lymphocytes erythroblasts some spermatagonia
RELATIVELY RADIOSENSITIVE	granulosa cells myeloblasts intestinal crypt cells basal epidermal cells
INTERMEDIATE SENSITIVITY	endothelial cells gastric gland cells osteoblasts chondrocytes spermatocytes
RELATIVELY RADIORESISTANT	granulocytes osteocytes spermatozoa erythrocytes
HIGHLY RADIORESISTANT	fibrocytes chondrocytes muscles cells nerve cells

Dose vs. Effect
Radiation doses can be **acute** (100 RAD or 1 Gy delivered at once) or they can be **chronic** (100 RAD or 1 Gy delivered over a lifetime). Acute doses result in an immediate (within hours to days) biological response such as radiation sickness where the individual experiences nausea, vomiting, diarrhea, loss of hair. Chronic doses have long term effects in that the biological response does not occur immediately but may appear after many years. This delay is referred to as a latency period.

Short Term Effects from Acute Levels of Radiation

Organ systems involved:

<u>hematopoietic system</u> – infections, hemorrhages, loss of white blood cells and platelets due to killing of progenitor cells in the bone marrow

<u>gastrointestinal system</u> - abdominal pain, vomiting, diarrhea, fluid & electrolyte imbalance from damage to the epithelial lining of the small intestine

<u>hair</u> – epilation or loss of hair; this is usually a reversible condition

<u>skin</u> – the skin can receive a significant dose from a major radiation event such as a criticality accident. The dose originates from the non-penetrating component of the radiation spectrum and can result in skin “burns”

<u>general systemic effects</u> – “radiation sickness”, loss of appetite, nausea, vomiting, fatigue

<u>central nervous system failure</u> (and cardiovascular collapse) – occurs after very high doses are received

Dose-effect relationship for acute whole body irradiation

Dose (REM)	nature of effect
5-23	minimal dose detectable by chromosome analysis
25-125	slight blood changes
75-125	minimum acute dose likely to produce vomiting in 10% of exposed people
150-200	temporary disability, blood changes
200-400	mild to moderately severe form of acute radiation syndrome
400-800	serious illness & death; severe complications of hematopoietic malfunction & some evidence of gastrointestinal damage
800-2000	accelerated version of acute radiation syndrome & death within 2 weeks
2000-10000	CNS impairment & cardiovascular collapse & death within 1-2 days

Chronic Effects
Long term effects usually occur many years after acute or chronic radiation exposure. These effects occur at much lower doses and at dose rates that are insufficient to cause acute somatic effects. The effects are probably related to irreversible alterations in the genetic material of cells which are capable of continued cell division.

mutations – changes in the genetic characteristics of a cell (somatic) or a change in an organism that is perpetuated in subsequent generations (genetic). Large amounts of radiation are not needed to induce mutations. Mutations are not unique to radiation and they do not result in gross malformations.

carcinogenesis – radiation is a carcinogenic agent to a wide variety of tissues in both experimental animals and humans.

in utero effects – radiation is considered a teratogenic agent which causes developmental abnormalities in fetuses. Two factors controlling teratogenic effects are the dose to the embryo/fetus and the stage of development at the time of the exposure.

Lesson 3
RADIATION PROTECTION MEASURES

Basic Protection Measures
When working in a radiation field, there are a number of measures you can employ to reduce your radiation dose. By skillfully employing the concepts of time, distance and shielding, you can work safely in just about any radiation field.

Time
For a source of given strength, the absorbed dose is proportional to the duration of the exposure. Therefore, the less time you spend near a radiation source, the less will be your dose.

Distance
The exposure rate from a point source of radiation is inversely proportional to the square of the distance. In other words, increasing the distance by a factor of 2 will decrease the exposure by a factor of 4. This concept can be summarized using the inverse square law.

$$I_1 D_1^2 = I_2 D_2^2$$

I = radiation dose rate
D = distance

Example: If the exposure rate is10 mR/hr at one foot from a radiation source, what is the exposure rate at 2 feet?

$$I_1 D_1^2 = I_2 D_2^2$$

$$(10\text{mR/hr}) \times (1 \text{ foot})^2 = (?) \times (2 \text{ feet})^2$$

$$10 = 4x$$
$$x = 2.5 \text{ mR/hr}$$

Shielding
Material placed between yourself and the radiation source to attenuate (absorb or scatter) the radiation field.

X-rays – shields are usually composed of high atomic number materials such as lead which are very effective for attenuating electromagnetic radiation. Shields should have staggered joints to avoid direct leakage paths. When a shield is erected, care should be taken to assure that excessive radiation from the top, bottom and back of the shield is controlled.

NOTE: the thickness of the shielding needed for a particular application depends on the energy of the radiation as well as the amount of radioactivity used. The Radiation Safety Office will advise investigators on the amount of shielding needed for a particular application.

Radiation Detectors
Since our senses can't directly perceive the presence of radiation, we must rely on instrumentation to identify and measure the strength of the radiation fields. If you need an instrument in the laboratory, you will use a Geiger counter.

The Geiger counter is a portable radiation detecting instrument that will allow you to measure the strength of radiation fields. The Geiger counter is actually a gas ionization detector. The detecting chamber is filled with a gas that will become ionized when exposed to radiation. When using this type of instrument for detecting the strength or boundaries of a radiation field, move the detector around until you see a response on the detector. There is also a device on the instrument that produces an auditory response in the presence of radiation. There are usually 3 or 4 scales that can be used depending on the strength of the radiation field. Initially, you would set the instrument at the most sensitive scale (x 0.1) and if the field is too strong, then move up to the next scale. The scales are denoted with a multiplier that you use in conjunction with the displacement of the needle on the face of the instrument.

If you are using the instrument to conduct a survey around the machine to check for stray scatter or leakage radiation, remember to start with the most sensitive scale.

The Geiger counter used in most of our laboratories has a flat probe that resembles a pancake. It can detect just about any type of radiation except hydrogen-3. The detecting window on the probe has a very thin Mylar window and caution should be taken to not tear the window. This will result in the destruction of the probe (125 bucks to replace!!).

Radiation Monitoring Programs

Monitoring for external sources of radiation

An individual working in a radiation area who is likely to receive 10% of the annual regulatory limits must be monitored for external radiation exposure. External radiation exposure is defined as radiation coming from a source such as a vial of phosphorus-32 or an x-ray machine that can impart a dose to a living system. The method for monitoring for external radiation exposure is a personnel dosimeter worn by the individual. There are two types of badges issued to USC personnel – the whole body badge, which measures dose to the head, neck, trunk, upper arms and legs, and the ring badge, which measures dose to the fingers from high energy beta particles such as phosphorus-32 and x-ray machines. USC uses a whole body dosimeter consisting of a thin layer of aluminum oxide that when exposed to radiation, can alter the layer. The aluminum oxide badge is more sensitive than other types such as film or thermo luminescent dosimeters (TLD) and can detect the presence of 1 mrem of dose. The ring badge uses a TLD chip to detect radiation.

NOTE: Most personnel in laboratories using analytical x-ray equipment do not require personnel monitoring.

The Radiation Safety Office issues personnel dosimeters to employees. An application must be completed and sent to the Radiation Safety Office.

The following practices must be observed when wearing a personnel monitoring device:

1. Always wear your badge when working in a restricted area.

2. Whole body badges should be worn on the trunk of the body nearest to the source of radiation (collar, belt, pocket, etc.)

3. A ring badge should be worn on a finger that would be nearest to the radiation source.

4. Do not take your badge home. Leave it at the workplace in a safe area away from any radiation sources.

5. Never intentionally expose your badge to ionizing radiation. This could result in the suspension of your privileges.

6. Do not wear your badge while being exposed to an x-ray or fluoroscope for medical diagnostic purposes. This badge is only for monitoring your occupational dose.

7. Do not tamper with the dosimeter packet (except during periodic changes). Accidental exposure of the device could result or the dosimeter filters could become dislodged and result in an erroneous reading.

8. Protect your badge from moisture (rain, washing machines, etc.). Moisture damaged badges can't be properly read.

9. Notify the Radiation Safety Office of any changes in your employment status such as termination, leave of absence, maternity leave, name change or transfer to another laboratory.

Dose to the embryo/fetus

Since the developing embryo/fetus is considered to be relatively radiosensitive, all employees/students who have the potential of becoming pregnant must be aware of the potential risks associated with occupational exposure of the embryo/fetus to ionizing radiation. They must also be aware of the proper controls to be employed to limit the risk.

Title VII of the Civil Rights Acts of 1964, as amended by the Pregnancy Discrimination Act, forbids sex-specific fetal protection policies. In order to properly monitor the external and internal dose to the employee/student and the embryo/fetus, it is strongly recommended that the pregnant employee declare her condition, in writing, to the radiation safety officer as soon as possible. However, it is the responsibility of the pregnant worker to decide when or whether she wishes to formally declare her condition.

South Carolina Regulation 61-63, RHB 3.8.1. states that the dose to an embryo/fetus during the entire pregnancy, due to occupational exposure of a declared pregnant employee/student must not exceed 0.5 rem (.005 Sv). The dose to the embryo/fetus is determined by the sum of the deep-dose equivalent (external dose) to the declared pregnant employee and the internal dose (committed dose equivalent) from x-rays in the embryo/fetus and the declared pregnant employee.

External dose to the embryo/fetus will be monitored with a whole body dosimeter (if appropriate) that will be placed in the abdominal region.

The radiation safety officer and the supervisor of the declared pregnant employee/student will review the specific procedures used by the employee in handling x-rays and will determine if additional precautions and/or engineering controls are necessary to reduce exposure to ionizing radiation.

Any employee/student may alter work routines to further reduce radiation exposure if the proposed alterations are approved by the principal investigator. Accidental exposures to a declared pregnant employee/student that are deemed to be potentially significant by the employee and/or her supervisor will be immediately evaluated by the Radiation Safety Office.

Lesson 4
Academic X-ray Equipment:
Related Hazards and Safety Controls

In providing a radiation safety program, equipment, procedural and administrative controls must be used. **Equipment controls** include: warning lights (x-ray on-off, shutter open-closed), buzzers and interlock switches. **Administrative controls** include safety training as well as a safety program, inspection program, and posting signs and personnel notices. **Procedural controls** entail written operating, alignment and emergency procedures. These procedural controls must be developed by the user and must allow for flexibility in equipment configurations. They must be designed so all operators, including non-experts, can use the equipment and they must be posted at the control so they can be referred to when problems arise.

There are many types of x-ray equipment used for a variety of different purposes. Analytical x-ray equipment, including that used for x-ray diffraction and x-ray fluorescence spectroscopy, is used extensively in colleges, universities and other research laboratories.

The typical x-ray instrument includes an x-ray source, specimen support and detector. The x-ray sources are similar in all types of equipment; variations occur in the detector and specimen support, depending on the application. These can be purchased as a complete system enclosed in one unit or as three separate components, assembled by the user.

Generally, x-ray fluorescence is commercially manufactured and used by technical, not scientific personnel. X-ray diffraction equipment is usually purchased as separate components.

X-ray Diffraction
When a beam of monochromatic x-rays strikes a crystalline sample of matter, the x-rays are scattered in all directions from each atom in the sample. They scatter in a pattern that is characteristic of the lattice type of the crystal. The scatter patterns can be used to identify the material or can be used for complete crystal structure analysis including: phase transformation, orientation, and other structure related properties of materials.

X-ray Fluorescence
Fluorescence is used for determining the elemental composition of a sample. The sample is irradiated with an x-ray beam that excites the characteristic x-ray spectrum of each atom in the sample. The x-ray spectrum is then analyzed.

Hazards Associated With X-ray Equipment

The radiation from x-ray machines is extremely dangerous and such danger should not be minimized. Operation of these units should pose no hazards as long as proper training has been received. This training should include basic radiation safety as well as complete instructions on the use of the particular equipment and function of all safety devices. Although many safety devices may be provided, the best is common sense.

The wavelengths most commonly used in x-ray diffraction and fluorescent x-ray spectroscopy fall into the ***"soft"*** range and are very readily absorbed into the skin. It does not require much shielding to protect from these x-rays but it is this quality that makes them very dangerous. Because they are so readily absorbed, the direct and diffracted beams can cause serious burns to exposed areas of the skin and eyes.

The principle sources of hazardous radiation from x-ray diffraction and fluorescent x-ray spectroscopic equipment include.

Primary and diffracted beams

The primary and diffracted beams associated with the x-ray diffraction equipment are small and well collimated. This increases the possibility of receiving severe burns on very localized areas of the body. Exposure rates for primary beams may be as great as 400,000 R/min and diffracted beams may reach 80R/hr.

Leakage of radiation through cracks in shielding

Leakage radiation through cracks in shielding or faulty shutters may also give rise to small but intense beams that may go undetected unless periodic radiation surveys are performed.

Penetration of primary beam through shutters

Primary beam radiation may penetrate shutters if shutters have been damaged or do not close properly.

Scattered radiation from sample or shielding material

Improperly designed shielding may be excited to fluorescence and pose a hazard if the radiation is allowed to scatter.

Radiation generated from rectifiers in controls

The rectifiers in the high voltage supply may generate hazardous radiation. When the rectifiers become gassy, they function like x-ray tubes. Due to the high voltages across them, they can produce x-rays. Adequate shielding must be applied around the power supply to prevent radiation from scattering into the room.

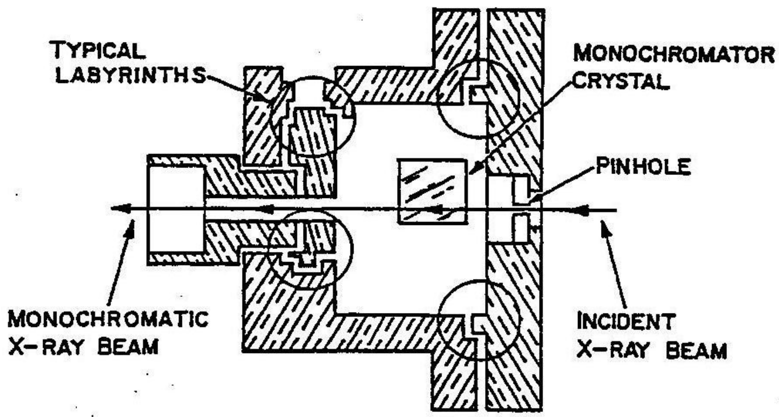
Safety Devices For Analytical X-ray Equipment

Because x-ray fluorescence equipment generally poses more hazards, it is usually completely enclosed; however, these safety devices are found on both the diffraction and fluorescence equipment.

Leak Proof Joints

If two flat surfaces are brought together, the tiny gap that exists between them is often sufficient to allow a measurable amount of radiation to pass through. Overlapping joints and labyrinths are often used to eliminate any straight paths where x-rays may escape (FIG. 4-1).

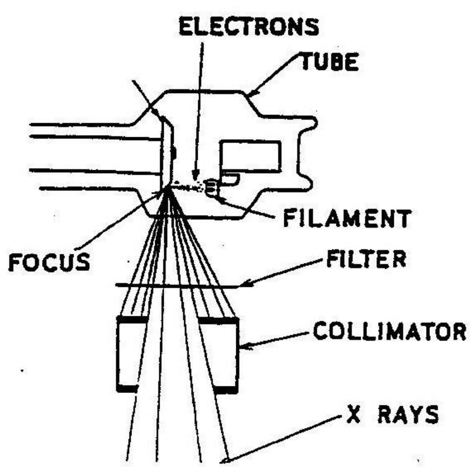
FIG. 4-1



X-ray Collimators

The ideal collimator permits entry of only x-rays that are designed to strike the sample inside the diffraction apparatus. It should give a well-defined beam (FIG.4-2).

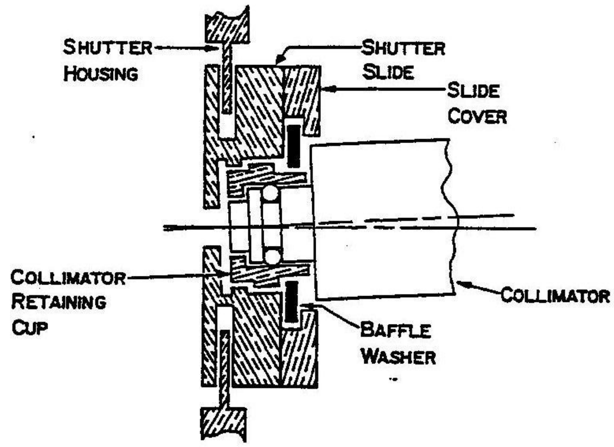
FIG. 4-2



Collimator Couplings

The link connecting the x-ray tube to the collimator is referred to as the collimator coupling. It should be designed to prevent radiation leakage (FIG. 4-3).

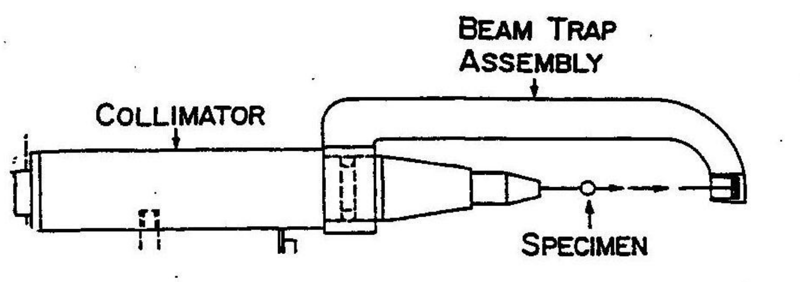
FIG. 4-3



Beam Trap

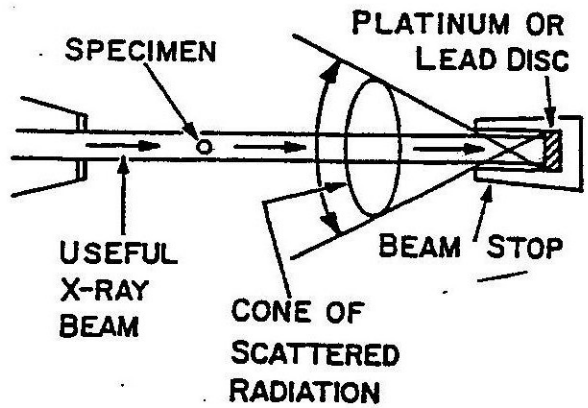
The beam trap causes x-rays that pass through the sample to be dissipated so secondary radiation does not interfere with the experiment (FIG. 4-4).

FIG. 4-4



Beam Stops
One of the biggest problems with x-ray diffraction occurs after sample irradiation and the x-rays pass to the beam stop. Beam stops are often not permanent fixtures, for experimental convenience, and they are sometimes improperly placed or missing completely. Most beam stops produce considerable backscatter. A properly devised beam trap is needed but seldom provided (FIG. 4-5).

FIG. 4-5



Safety Shutters and Warning Lights
Shutters consist of a highly absorbing, movable metal (lead) gate placed in front of the x-ray port to absorb radiation. It opens during periods of measurement and closes for other operations, such as changing samples. The most suitable location for a safety shutter is as close as possible to the x-ray source- immediately in front of the port and immediately behind the collimator coupling, inside a leak proof joint (FIG. 4-6).

Shutters may be automatic or manual but some indication must be made whether the x-rays are on or off and whether the shutter is opened or closed. Usually, warning lights are devised so that lamp failure turns the generator off or closes the shutter.

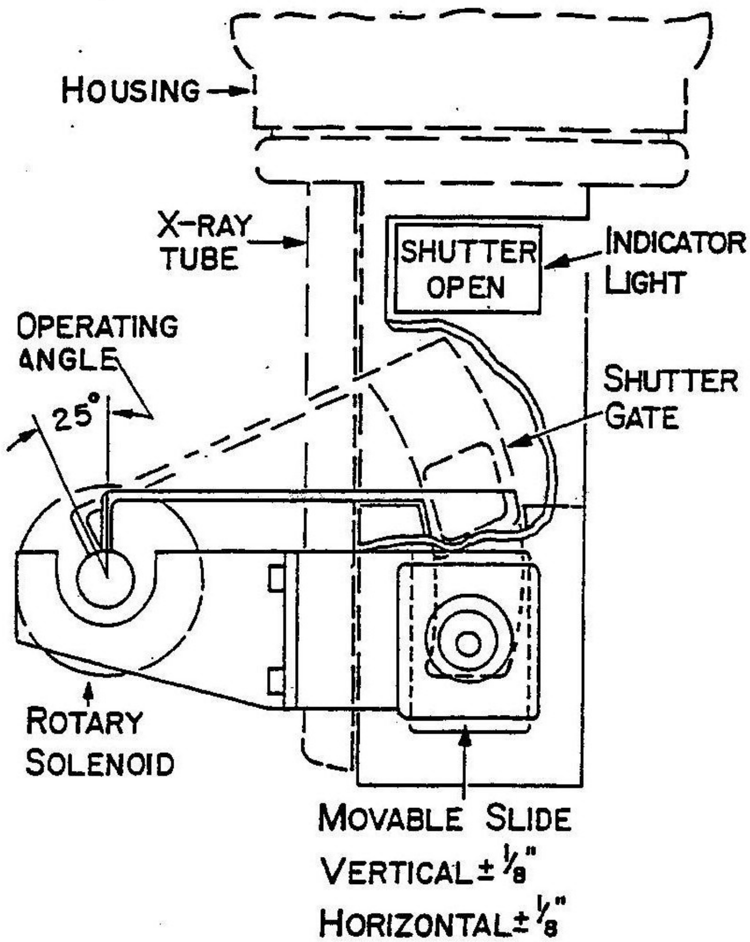
For manual shutter operation, the shutter should close through the action of gravity and not rely on springs. Since the gate can jam, leaving the shutter open, positive verification of shutter status is needed. Having a warning light turn on when the shutter is open can do this.

For automatic shutter operation, fully opened and fully closed indicators are necessary. Any intermediate shutter position (gate jam) should cause data collection to stop. A warning light should remain on unless the x-ray generator is off.

NOTE: No matter how well a safety shutter is designed, the best assurance against x-ray exposure is to be alert and properly trained. Warning lights are useful, but should never be trusted 100% when they are “off”.

The status indicators should be provided both at the on-off switch and near the tube head so the operator will be reminded whenever the x-ray beam is on. All indicators should be checked at routine intervals to ensure they are failsafe and functioning properly.

FIG. 4-6



Interlock Switches
Interlocks or other manual controls should be incorporated to prevent access to the beam when the shutter is open. All interlocks should be checked at routine intervals to ensure they are failsafe and functioning properly.

Temporary Shielding
Many times, sheet lead or foil is placed around parts of the equipment to shield off leaks occurring around the collimator couplings, tube shields, etc. In most cases, this is effective. Problems arise when the shielding has been removed and is not relocated in the proper position or not replaced at all. The potential for serious personnel exposure exists.

Precautionary Measures
Shielding
To be effective, shielding must prevent any stray radiation from escaping into areas where personnel may be exposed. Care should be taken to avoid cracks or small openings that may go unnoticed.

Radiation Monitoring
Radiation monitoring includes whole body and extremity badges. Typically, monitoring with these devices is unwarranted as all equipment on this campus is totally enclosed and interlocked. Provided standard operating procedures are followed, personnel monitoring is not required.

Alignment
If necessary to use an alignment tool such as a fluorescent strip, precautions must be taken to ensure exposure levels are kept to a minimum. The alignment must be performed with the operating voltage set as low as possible to reduce the hazard.

Surveys
Periodic surveys around the tube and cabinet must be conducted to ensure the adequacy of the shielding. This is done with a G-M type detector yearly, during maintenance involving tube replacement or when equipment configuration changes.

Procedures
One of the most important precautionary measures is to develop written operating, alignment and emergency procedures. They should include the start up and shut down of the equipment and other special operations. They must be written clearly and precisely and should be easy for all operators to follow. They must be kept near the control in the red x-ray safety logbook. All operators must read the procedures prior to use of the equipment for the first time as part of the operator training. The procedures must be signed and dated by all operators indicating the procedures have been read and understood.
Please view the “Double Edged Sword”:
mms://ms3.deis.sc.edu/allaccess/THE_DOUBLE_EDGED_SWORD.wmv

Lesson 5
Regulatory Matters, General Laboratory Safety, Posting Requirements

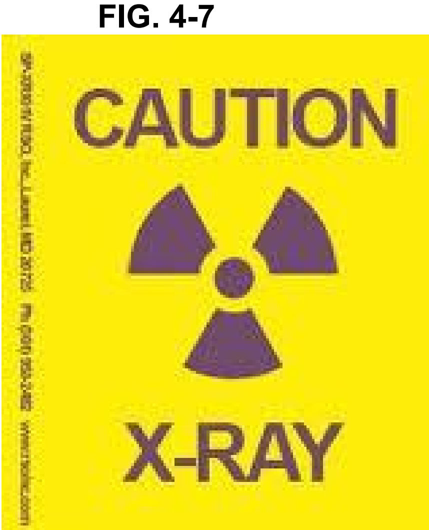
Regulatory requirements pertaining to the safe use of x-ray machines are mandated by the South Carolina Department of Health and Environmental Control (SCDHEC) and found in South Carolina Rules and Regulations for Radiation Control, Regulation R61-64 – also known as “Tile B.” A copy of the pertinent regulations is found at https://live-sc-dhec.pantheonsite.io/sites/default/files/media/document/R.61-64.pdf

If issued a personnel monitoring device, it must be worn at all times when using the x-ray equipment.

In addition to having an operating procedure for each unit, an emergency procedure is required, as well. A label is required that states that should the equipment be moved or modified, radiation safety must be contacted to perform a radiation safety survey to verify there is no scatter radiation or leakage emanating from the unit. Radiation surveys will be conducted yearly or any time changes are made in experimental set-ups when the x-ray tube is involved or at anytime laboratory personnel feel one is warranted.

All areas housing x-ray equipment will be posted with a sign bearing the radiation symbol and the words ***“CAUTION- X-RAY****” and “****CAUTION- HIGH INTENSITY X-RAY BEAM****” must be posted on the tube housing.* (FIG. 4-7)

FIG. 4-7



Required signage for tube housing

All areas must be posted with the Occupational Safety and Health Association (OSHA) form RHA-20, ***"Notice to Employees."*** This form provides information on your rights as a radiation worker. It states that if you are monitored for exposure you have the right to see the exposure results and you must be advised annually of your exposure to radiation.

Form SC-RHA-20

D H E C

PROMOTE PROTECT PROSPER

South Carolina Department of Health and Environmental Control

NOTICE TO EMPLOYEES

STANDARDS FOR PROTECTION AGAINST RADIATION IN SOUTH CAROLINA REGULATIONS FOR CONTROL OF RADIATION SOUTH CAROLINA DEPARTMENT OF HEALTH & ENVIRONMENTAL CONTROL HAS ESTABLISHED STANDARDS FOR YOUR PROTECTION AGAINST RADIATION HAZARDS

YOUR EMPLOYER'S RESPONSIBILITY

Your employer is required to:

1. Apply these regulations to work involving sources of radiation.
2. Post or otherwise make available to you a copy of the South Carolina Department of Health & Environmental Control regulations, licenses, and operating procedures which apply to the work you are engaged in, and explain their provisions to you.

YOUR RESPONSIBILITY AS A WORKER

You should familiarize yourself with those provisions of the South Carolina Department of Health & Environmental Control regulations, and the operating procedures which apply to the work you are engaged in. You should observe their provisions for your own protection and the protection of your co-workers.

WHAT IS COVERED BY THESE REGULATIONS

1. Limits on exposure to radiation and radioactive material in restricted and unrestricted areas;
2. Measures to be taken after accidental exposure;
3. Personnel monitoring, surveys and equipment;
4. Caution signs, labels, and safety interlock equipment;
5. Exposure records and reports; and,
6. Related matters.

POSTING REQUIREMENTS

COPIES OF THIS NOTICE MUST BE POSTED IN A SUFFICIENT NUMBER OF PLACES IN EVERY ESTABLISHMENT WHERE EMPLOYEES ARE EMPLOYED IN ACTIVITIES LICENSED OR REGISTERED, PURSUANT TO TITLES A, B, AND C, BY THE SOUTH CAROLINA DEPARTMENT OF HEALTH AND ENVIRONMENTAL CONTROL TO PERMIT EMPLOYEES WORKING IN OR FREQUENTING ANY PORTION OF A RESTRICTED AREA TO OBSERVE A COPY ON THE WAY TO OR FROM THEIR PLACE OF EMPLOYMENT.

REPORTS ON YOUR RADIATION EXPOSURE HISTORY

1. The South Carolina Department of Health & Environmental Control regulations require that your employer give you a written report if you receive an exposure in excess of any applicable limit as set forth in the regulations or in the license. The basic limits for exposure to employees are set forth in the regulations or in the license. The basic limits for exposure to employees are set forth in Sections RHA 3.5 and RHB 3.4 and 3.6, RHC 2.2 and 2.3 of the regulations. These sections specify limits on exposure to radiation and exposure to concentrations of radioactive material in air and water.
2. If you work where personnel monitoring is required, and if you request information on your radiation exposure:

   (a) Your employer must give you a written report, upon termination of your employment, of your radiation exposures, and

   (b) Your employer must advise you annually of your exposure to radiation.

INSPECTIONS

All licensed or registered activities are subject to inspections by representatives of the South Carolina Department of Health & Environmental Control.

INQUIRIES

Inquiries dealing with the matters outlined above can be sent to:

South Carolina Department of Health & Environmental Control
Bureau of Radiological Health
2600 Bull Street
Columbia, South Carolina 29201
(803) 545-4400

3A-17 (8/93)

<u>**Emergency phone numbers are located on each control. Contact campus police at 911 in the event of an emergency.**</u> Then, contact the radiation safety office at 7-5269 and your principle investigator.

Please call 777-5269 to make an appointment to take the examination. A certificate will be mailed to you after you have passed the exam.