Slide 1 - Analytical/Cabinet X-Ray Safety Training

Slide 2 - Preface

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Overview

This program provides the training material for web based training relating to the safe use of x-ray equipment. The rules and regulations presented are meant to ensure the safe operation of x-ray equipment at Virginia Tech. The objectives are to acquaint the worker with the following:

- the fundamental physical phenomena associated with radiation
- the basic principles and operations of x-ray equipment
- personnel and area monitoring devices
- the biological effects and the risks associated with ionizing radiation
- methods to reduce x-ray exposure
- the rules and regulations governing the use of x-ray equipment at Virginia Tech
- your responsibilities as a radiation worker

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Slide 3 - Training Manuals

Slide 4 - Outcomes

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Outcomes

Virginia Tech EHS has the following objectives for this training:

1. Explain the physical fundamentals associated with radiation,
2. Review the biological effects and risks associated with ionizing radiation,
3. Detail the basic principles of x-ray equipment operation,
4. Note the regulations/rules governing the use of x-ray equipment at Virginia Tech,
5. Discuss methods to reduce exposure,
6. Explain your responsibilities as a worker/user of x-ray instrumentation.

For more information:

Virginia Tech EHS Web Site

VT EHS Radiation Safety Program

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Slide 5 - Preface continued

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The most important goal of this training is to encourage radiation workers to limit unnecessary radiation exposure to themselves and others. In order to accomplish this, it is important that the worker understand the material presented here. An exam will be administered at the end of the training session to test the worker's comprehension of the material presented. Notes or other reference materials may be used during the testing process. The test must be passed before an individual will be allowed to work with x-ray equipment.

Please contact the Radiation Safety Office at (540)231-5364 or dcon@vt.edu if there are any questions regarding the information presented in this training or any other questions relating to the safe use of x-ray equipment.

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Slide 6 - Principles of Operation of X-Ray Equipment

Slide 7 - Introduction

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Introduction

X-rays were discovered in 1895 when Conrad Röntgen (also spelled as Roentgen) observed that a screen coated with a barium salt fluoresced when placed near a cathode ray tube. Roentgen concluded that a form of penetrating radiation was being emitted by the cathode ray tube and called the unknown rays, x-rays.

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Slide 8 - Introduction continued

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Like radio waves, visible light, and gamma rays, x-rays are a form of electromagnetic radiation (Figure 1). All electromagnetic radiation is characterized by massless packages of energy called photons. Photons travel at the speed of light and have a characteristic wavelength and frequency which defines the specific type of electromagnetic radiation. The amount of energy carried by a photon is directly proportional to the frequency of the radiation and inversely proportional to the wavelength. Thus x-rays, which have a relatively short wavelength and high frequency, possess a great deal of energy.

ELECTROMAGNETIC SPECTRUM

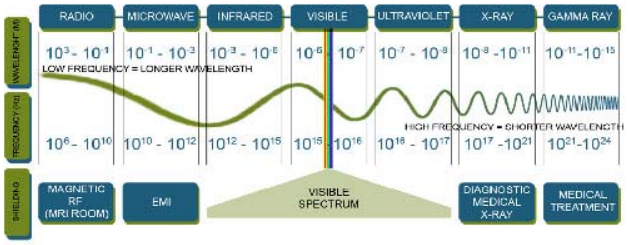

Figure 1 Electromagnetic Radiation (from Shielding Systems)

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Slide 9 - Introduction continued

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X-rays and gamma rays are termed ionizing radiation because they contain sufficient energy to penetrate matter and excite or dislodge orbital atomic electrons. The resultant electrically charged atom is called a positive ion and the free electron is termed a negative ion. These ions are capable of damaging human tissue. Although x-rays and gamma rays interact with matter identically they differ in two ways. X-rays originate outside the nucleus from changes in the electron configuration of the atom, and may be released at discrete energies or as a broad spectrum of energies. Gamma rays, however, originate within the nucleus and are always released at discrete energies.

Probably the best known use of x-rays has been in the medical field. Physicians were using x-rays as a diagnostic tool within months of Roentgen's discovery. Today, approximately 240 million medical x-ray examinations are performed annually.

Radiography is also used as an industrial and research tool. Industrial applications include the location of internal defects in materials, such as in weld joints, and inspection of the internal parts of machinery. Principal applications of x-rays in research are x-ray diffraction and x-ray spectroscopy. These procedures are used to analyze both the chemical composition and the crystalline structure of substances.

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Slide 10 - Producing X-Rays

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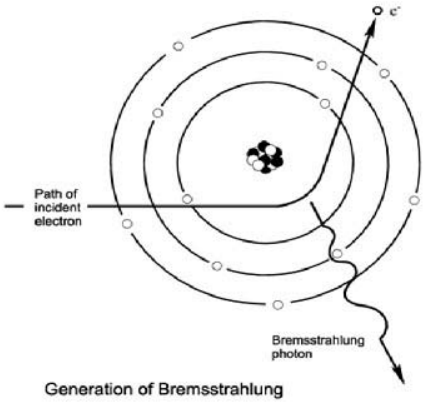
Producing X-Rays



Generation of Bremsstrahlung

Figure 2 (from UNC)

X-rays are produced by two different processes when high speed electrons collide with a metal target. The first process, known as the Bremsstrahlung (German for braking radiation) effect occurs when a high speed incident electron is attracted towards the positive nucleus (Figure 2). The electron is deflected from its original course and loses part of its original kinetic energy. This loss of energy results in an x-ray photon being produced in order to maintain conservation of energy. The energy of the x-ray photon is dependent on the angle of deflection of the incident electron, thus with many incident electrons a continuous distribution of energies can be produced. Bremsstrahlung represents the predominant method of x-ray production in a medical diagnostic x-ray tube.

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Slide 11 - Producing X-Ray's continued

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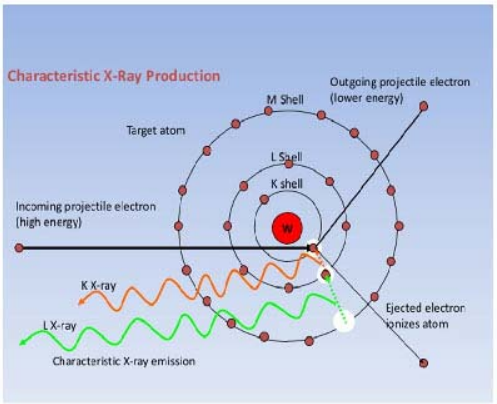

Figure 3 (SMCH Dr. D. Chavan and Dr. M. Dey)

The second method by which x-rays are generated is termed the characteristic radiation effect and results in the production of very discrete energies characteristic of the target material (Figure 3). Characteristic radiation is produced when the incident high speed electrons collide with an orbital electron of the target material. The orbital electron is ejected from the atom and creates a vacancy in the electron shell. An electron from an outer energy shell or free electron passing by falls into this vacancy, releasing energy in the form of an x-ray photon. Characteristic radiation is important in research because each element produces a characteristic spectrum that allows for the identification of unknown samples.

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Slide 12 - The X-Ray Tube

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The X-Ray Tube

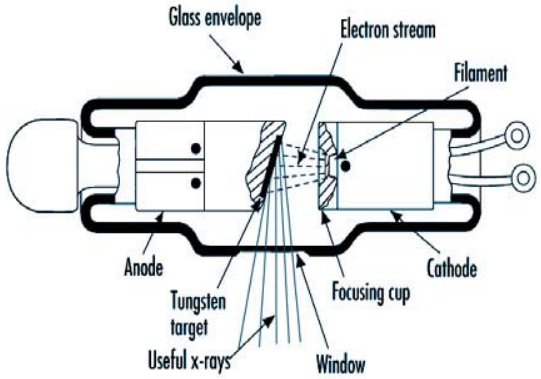

Figure 4 X-Ray Tube (ILO Encyclopaedia of Occupational Health and Safety, 4th Edition)

An x-ray generating system requires a source of electrons, a means to accelerate the electrons, and a target to stop the electrons. In 1913, Coolidge developed the basic type of x-ray tube that is still in use today. A typical tube, called a hot cathode x-ray tube, consists of a cathode with a tungsten filament for generating electrons and a tungsten target embedded in a copper anode that stops the electrons (Figure 4). The cathode and anode are enclosed in a highly evacuated shielded glass tube. The x-rays are directed out of the tube through a small window in the housing.

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Slide 13 - The X-Ray Tube continued

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Electrons are produced at the cathode by heating the tungsten filament to incandescence. The filament is located in a concave cup that focuses the electron beam on a small area of the target called the focal spot. The electrons are accelerated towards the positive anode by a high voltage potential. X-rays are produced when the high-speed electrons strike the target set into the anode.

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Slide 14 - Controlling the X-ray Tube

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Controlling the X-ray Tube

By adjusting the number of electrons released from the cathode and the accelerating force, the intensity and penetrability of an x-ray beam can be controlled. The number of electrons flowing per second to the anode is termed the current and is expressed in milliamperage (mA). The total charge arriving at the target is obtained by multiplying the current by the exposure time, and is expressed in seconds or mAs. The quantity of electrons is controlled by varying the temperature of the cathode filament. As the temperature of the filament increases, the current and hence the intensity (quantity) of the generated x-ray photons also increases.

A large positive potential difference between the anode and cathode accelerates the electron towards the anode. This potential difference is expressed in peak kilovoltage (kVp) and represents the maximum energy of the x-rays produced. The penetrating power of the x-ray beam in turn depends on this value. However, only a small percentage of the x-rays will have this energy because a continuous spectrum of energies is produced by the Bremsstrahlung effect. Increasing the kVp causes the electrons to accelerate faster and strike the anode with greater force, resulting in x-rays that have shorter wavelengths and greater penetrating power.

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Slide 15 - Interaction with Matter

Slide 16 - Interaction with Matter continued

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In passing through matter energy is transferred from the incident x-ray photon to orbital and free electrons of the target material. An electron can be ejected from the atom with the subsequent creation of an ion. The amount of energy lost to the electron is dependent on the energy of the incident photon and the type of material through which it traverses.

There are three basic methods in which x-rays can interact with matter: the photoelectric effect, Compton scattering, and pair production. In the photoelectric effect, an incident x-ray photon strikes an orbital electron and is totally absorbed by the electron (Figure 5). The electron is then ejected from the atom.

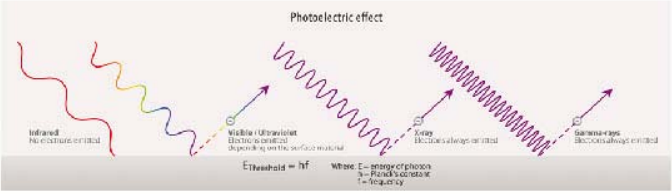

Figure 5 Photoelectric Effect (from ESA image)

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Slide 17 - Interaction with Matter continued

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Compton scattering occurs when an x-ray photon scatters from an orbital or free electron (Figure 6). Unlike the photoelectric process, only part of the photon's energy is transferred to the electron. The electron is ejected from the atom and the incident x-ray photon is scattered with a reduction in energy. A less energetic photon then continues to interact with orbital electrons by additional Compton or photoelectric processes.

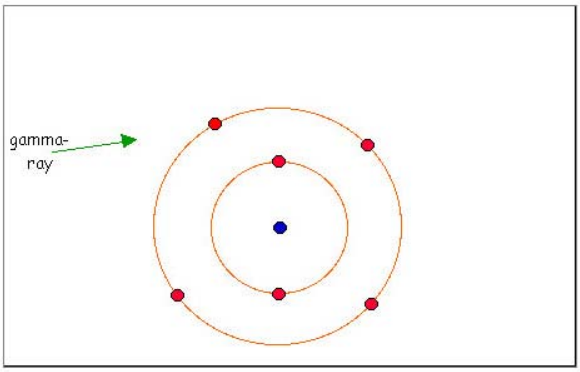

Figure 6 Compton Scattering (from WikiMedia Commons public use)

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Slide 18 - Interaction with Matter continued

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The third mechanism, pair production, is only encountered if the incident photon possesses a minimum energy of 1.02 MeV. In pair production an x-ray photon interacts with the nuclear force field around the nucleus and undergoes transformation into matter, with the creation of an electron and positron (positive electron) (Figure 7). The positron is quickly annihilated by interaction with an electron which creates two 0.511 MeV gamma photons (annihilation radiation). These photons then interact with matter by Compton and photoelectric collisions.

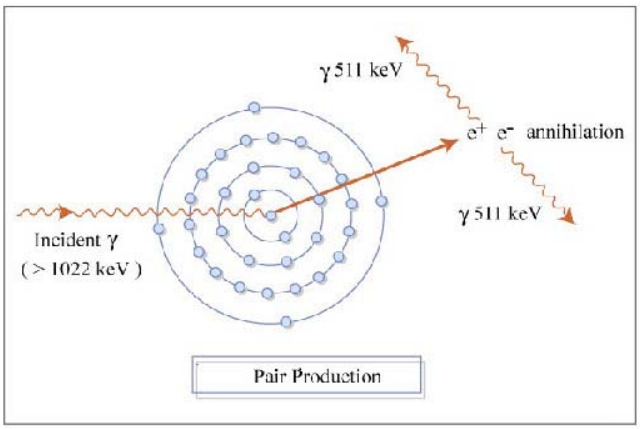

Figure 7 Pair Production (MIT OpenCourseWare)

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Slide 19 - Interaction with Matter continued

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Thus, all three processes result in x-ray photon energy being absorbed by orbital and free electrons. Whereas total absorption occurs in the photoelectric effect only partial absorption occurs in Compton collisions, with the subsequent production of scattered radiation. In pair production the electron-positron pair will absorb all of the incident energy in excess of 1.02 MeV. However, secondary photons are emitted in the annihilation process.

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Slide 20 - Scattered Radiation

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Scattered Radiation

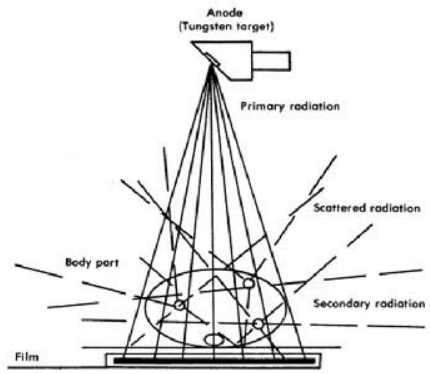

Figure 8 Scattered Radiation (Free-ed.net course Fundamentals of Dental Radiology)

When the primary beam traverses through an object, part of the beam will be scattered in all directions by Compton interactions (Figure 8). These secondary photons are undesirable because they contribute to the background density of the film and decrease the contrast of the image. Scattered radiation is also considered undesirable because it can increase the radiation exposure to personnel in the room. Therefore, for optimum radiographic quality and to reduce radiation exposure to personnel, methods should be employed to reduce scatter radiation (e.g. using "masking" technique in cabinet x-ray systems).

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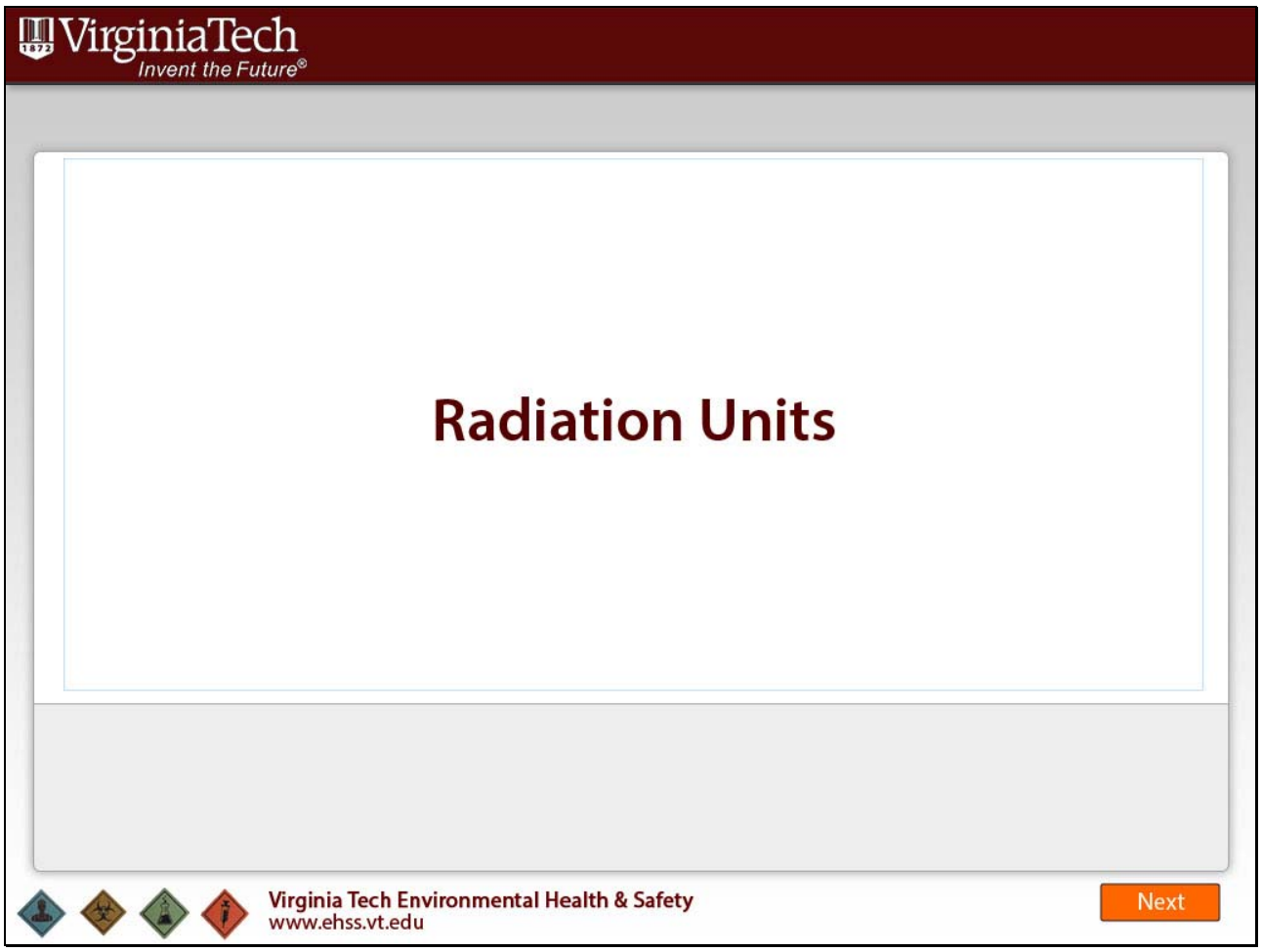
Slide 21 - Radiation Units



Slide 22 - Radiation Units continued

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In order to properly interpret radiation monitoring equipment and protection guidelines, the units associated with radiation measurements must be understood. Three units are commonly employed: the ROENTGEN, RAD, and REM.

The Roentgen (R) is a unit for expressing exposure from X or gamma radiation in terms of the number of ionizations produced in air. One Roentgen of radiation will produce ionizations equal to one electrostatic unit of charge in one cubic centimeter of dry air at standard temperature and pressure.

The Roentgen defines a radiation field but it does not provide a measure of absorbed dose in ordinary matter or tissue. The Rad is used to express the radiation dose absorbed in any medium from any type of radiation. Although the Roentgen is defined in terms of ion pairs, the Rad is defined in terms of energy absorbed. One Rad is equal to the amount of radiation that results in the absorption of 100 ergs per gram in any material. It is approximately equal to the absorbed dose delivered to soft tissue by one Roentgen of X or gamma radiation.

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Slide 23 - Radiation Units continued

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In terms of human exposure, however, another factor must be considered, exposure to equal amounts of different types of radiation do not result in equal damage to human tissue. Therefore, in order to account for these varying effects, a unit is employed termed Rem (Roentgen equivalent man). The Rem estimates the equivalent amount of any radiation that would be necessary to produce the same biological effects in humans as one Rad of X or gamma radiation. The Rem is equal to the Rad multiplied by a quality factor that estimates the relative biological effectiveness of different types of radiation. This biological effectiveness depends upon the number of ionizations created per unit distance in tissue as the radiation traverses through the body. The quality factor for x-rays is one, however, quality factors for other types of radiation can be as high as twenty (e.g. alpha particles). Therefore, a dose of 0.05 Rads from alpha particles could do the same biological damage as 1 Rad of x-rays because they both equal one Rem (0.05 x 20). One advantage of using Rem units is that dosages delivered from different types of radiation become additive.

In summary, the Roentgen is a unit of exposure, the Rad is a unit of absorbed dose, and the Rem is a unit of biological dose. The Rem is the unit that is used to measure radiation doses to personnel. For practical purposes, however, the Roentgen, Rad, and Rem are essentially equivalent for x-rays and can be used interchangeably. Commonly used subunits are the milliroentgen (mR), millirad (mRad), and millirem (mRem), which are equal to 1/1000 of these units.

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Slide 24 - Radiation Units continued

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These units can be put into perspective by looking at some known values. Each person receives approximately 20 millirem per year from exposure to radioactive potassium in the body. Total natural background radiation exposure can vary from 200 to 400 millirem per year, depending on where a person lives. A normal chest x-ray delivers a dose to the skin of approximately 20 millirem, while a lumbar spine x-ray can deliver more than 2,500 millirem to the skin. In radiation therapy local areas of the body can receive doses as high as 5,000 to 7,000 rads.

The International System of Units (SI) are used by the medical community and in most other countries. In SI units, the Gray replaces the Rad and 1 Gray (Gy) equals 100 Rads. The Sievert replaces the Rem and 1 Sievert (Sv) equals 100 Rem.

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Slide 25 - Area and Personnel Monitoring Equipment

Slide 26 - Radiation Survey Instruments

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Radiation Survey Instruments

Radiation survey instruments are used to detect potential radiation hazards, measure radiation intensities, monitor the effectiveness of shielding arrangements, and estimate exposure to personnel. There are two main categories of radiation survey devices: gas filled detectors and scintillation detectors.

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Slide 27 - Slide 27

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Gas Filled Detectors

These instruments are based on the principle that ions are produced when radiation traverses through a gas filled chamber. Electrons liberated in the chamber are attracted to the central electrode (anode) by a positive voltage potential and the positive ions are attracted towards the walls (cathode) of the chamber. An electrical pulse or current is then produced which can be detected and recorded by an instrument called a scaler.

There are three types of gas filled radiation detectors: ionization chambers, proportional counters, and Geiger-Mueller (GM) detectors. The primary difference between these detectors is the voltage applied to the chamber. The kind of detector used is based on the intensity and the type of radiation field encountered. The GM is the most useful detector for most analytical applications.

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Slide 28 - Ionization Chambers

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Ionization Chambers

At very low applied voltages ion pairs may recombine before they are collected. As the voltage of a gas filled detector is increased eventually every ion pair produced by the incident radiation will be collected and counted. Survey instruments operating at this voltage are called ionization chambers and can be used to detect and quantitate radiation intensities. Ionization chambers have a wide range and are typically used to measure high X and gamma radiation intensities.

Ionization chambers (Figure 9) are widely used as a survey instrument for x-ray equipment. Other more accurate types of ionization chambers known as condenser-r meters are used to calibrate x-ray tubes.

Figure 9 Ionization Chamber

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Slide 29 - Proportional Counters

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Proportional Counters

Creation of discrete avalanches in a proportional counter

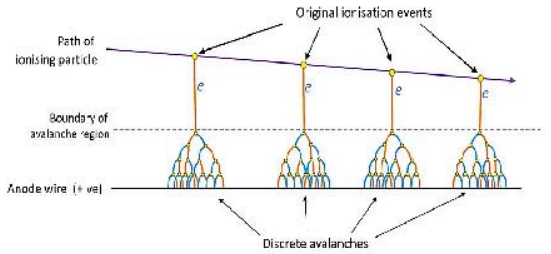

Figure 10 Proportional Counter (from Wikipedia.org)

As the voltage is increased further, electrons are accelerated more rapidly and achieve sufficient energy to create secondary ionizations and electrons in the gas (Figure 10). These secondary electrons will dramatically increase the size of the electrical pulse at the central electrode. Instruments operating in this voltage region are called proportional counters.

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Slide 30 - Proportional Counters continued

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The size of the electrical pulse produced is dependent on the ionizations created by the incident radiation. Since alpha particles can produce a larger number of ions in the gas than beta particles, proportional counters can distinguish between these two types of radiation. Proportional counters are usually very inefficient for counting X and gamma radiation and are not normally used for this purpose. Proportional counters are used primarily for the detection of low level contamination from alpha and beta particles and find little application for surveying x-ray equipment.

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Slide 31 - Geiger-Mueller Counters

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Geiger-Mueller Counters

Primary ionizations produced by the incident x-ray photons are accelerated by a very high voltage potential in a Geiger-Mueller (GM) counter. Secondary ionizations are created from collisions with these accelerated ions. The secondary ions, in turn, are also accelerated and achieve sufficient energy to create ions. This process continues with the resulting formation of an avalanche of millions of ion pairs produced from a single ionization event. Because of this avalanche of electrons a very large electrical pulse is produced at the anode. The size of the electrical pulse, however, is independent of the energy and the type of initiating radiation. Because gas amplification has now reached its maximum value, all radiation, regardless of the number of primary ions produced by a single incident photon, will result in the same current flow. Differences in radiation intensities are determined only by the number of initiating photons entering the tube.

The GM counter is the most widely used area survey instrument for the detection of low-level radioactive contamination (Figure 11). It is a very sensitive, relatively inexpensive, and rugged instrument. With sufficiently thin windows, different types of radiation can also be detected. However, Geiger counters respond only to the number of ionizing events rather than the energy of the radiation. They should only be used as a detection instrument, reading in counts/minute, and not for quantitative measurements of radiation intensities, unless used in a radiation field for which they have been calibrated.

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Slide 32 - Geiger-Mueller Counters continued

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The major disadvantage of GM counters is their limitation to low radiation field measurements, typically below 200 mR/hr. Once ionizations have been initiated in a GM tube it becomes insensitive for a short time, called the dead time, and will not respond to further ionizing events. As a result of this phenomenon, the number of counts recorded will be less than the true count rate. This error is relatively small at low radiation intensities, however, in high radiation fields (i.e. above 200 mR/hr) large errors can be introduced. In extremely high radiation fields the Geiger counter may read zero.

Figure 11 Geiger Mueller (GM) Counter

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Slide 33 - Scintillation Detectors

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Scintillation Detectors

Scintillation detectors use a crystal that scintillates or releases light when exposed to x-rays or gamma rays. The crystal is coupled to a photomultiplier tube that converts the light flashes to amplified electrical pulses. The number of pulses is directly proportional to the intensity, and the size of the pulse is directly proportional to the energy of the incident radiation. These pulses can then be fed to a counter, spectrometer, oscilloscope, or computer for further analysis.

Since scintillation crystals are solid, rather than gaseous, their higher density makes scintillation detectors very efficient and sensitive instruments for the measurement of x-rays and gamma rays. Portable scintillation detectors are even more sensitive than Geiger counters because of their increased efficiency. Scintillation detectors are also widely used in the medical field.

In summary, radiation survey instruments are used to detect and/or measure radiation. The primary survey instruments used for x-ray equipment are portable ionization chambers. These instruments are capable of accurately quantitating low and high radiation intensities. Geiger-Mueller counters should typically be used only to detect the presence of low-level radioactive contamination or x-ray leakage. They should only be used to measure radiation intensities for which they have been calibrated. Regardless of the radiation survey instrument used it must always be kept in perfect operating condition and calibrated on an annual basis.

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Slide 34 - Personnel Monitoring

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Personnel Monitoring

Personnel monitoring is used to detect and measure radiation exposure to individuals. The purpose of personnel monitoring is to document the exposure a worker receives in order to determine if radiation exposure limits have been exceeded, and to aid in keeping exposures as low as reasonably achievable (ALARA). Personnel monitoring is required if there is a possibility that a radiation worker will receive greater than 10 % of the occupational limits. Personnel monitors are relatively inexpensive, reasonably reliable, and portable. They are usually worn on the belt, shirt or lab coat pocket/collar, or finger.

There are four basic types of personnel monitoring devices: electronic personal dosimeters, film badges, thermoluminescent dosimeters and optically stimulated luminescent dosimeters. The electronic personal dosimeters are direct reading so that the dose being received and the dose rate are shown. Alarms can be set to warn of high doses and these dosimeters are often used in higher or variable radiation fields.

The film badge consists of one or more photographic emulsions contained in light tight envelopes inside a plastic holder. Windows and filters are built into the badge to aid in differentiation between these radiations and to allow for an estimation of radiation energies. The film is developed and the density of the exposed film is proportional to the exposure received by the film badge. The degree of darkening is then compared with film exposed to known quantities of radiation. Because of many disadvantages such as false readings as a result of improper handling, heat, humidity and age, this type of badge is no longer used at Virginia Tech.

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Slide 35 - Personnel Monitoring continued

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Thermoluminescent dosimeters (TLDs) in use at the University have lithium fluoride (LiF) crystals. The TLD crystals can be used in the form of powder, as small chips, or impregnated in plastic. The incident radiation creates excited states in the crystals which trap electrons. This energy is released in the form of light by heating the chip in a carefully controlled heating cycle. The amount of light released is proportional to the integrated radiation exposure. The chips are used in badges, similar to those for film, with filters to characterize the radiation.

A TLD can be used many times to provide accurate and reliable radiation readings. The process of reading destroys the information, so a badge can only be read once. There are two types of TLD badges that can be used. The first is called a body badge which is used to determine whole body, lens and skin doses. The second, and the only TLD form used at Virginia Tech, is called a ring badge and is used for extremities, specifically the hands. Ring badges are changed on either a monthly or quarterly basis. They are sent to an outside company for processing to determine personnel doses.

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Slide 36 - Personnel Monitoring continued

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The optically stimulated luminescent dosimeters (OSLDs) in use at the University use aluminum oxide crystalline material. Plastic strips impregnated with aluminum oxide are stimulated with selected frequencies of laser light causing them to luminesce in proportion to the amount of radiation exposure and the intensity of stimulation light. The strips are used in badges, similar to those for TLDs, with filters to characterize the radiation. These dosimeters can be reanalyzed numerous times to confirm the accuracy of the measurement. Body badges at Virginia Tech are OSLDs. The badges are changed on either a monthly or quarterly basis and are sent to an outside company for processing to determine personnel doses.

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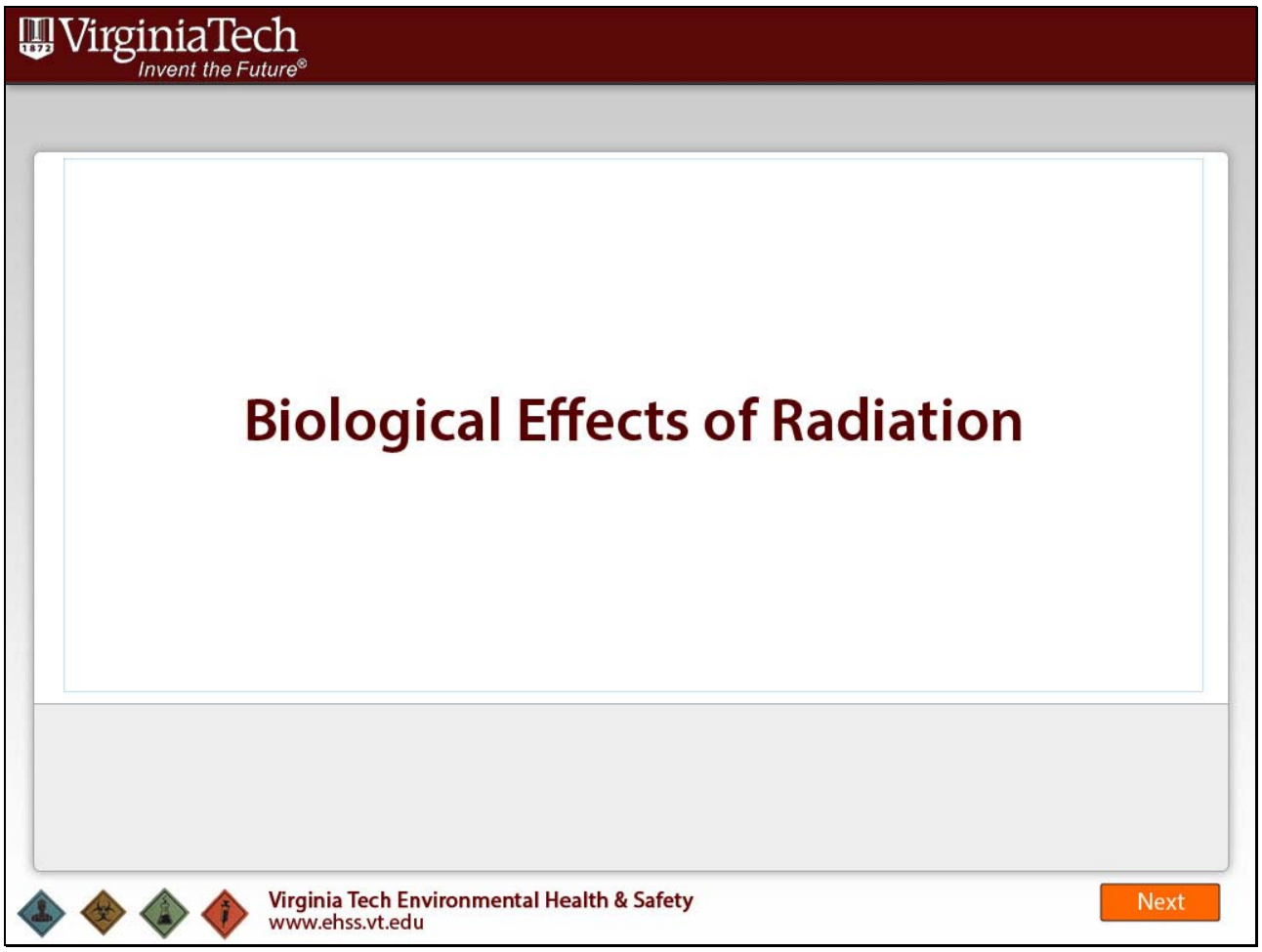
Slide 37 - Biological Effects of Radiation



Slide 38 - Biological Effects of Radiation continued

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Exposure of the human body to ionizing radiation can result in harmful biological effects. The nature and severity of the effects depends on the dose of radiation absorbed and the rate at which it is received. The biological effects of ionizing radiation are generally grouped into three categories: somatic, genetic and teratogenic effects.

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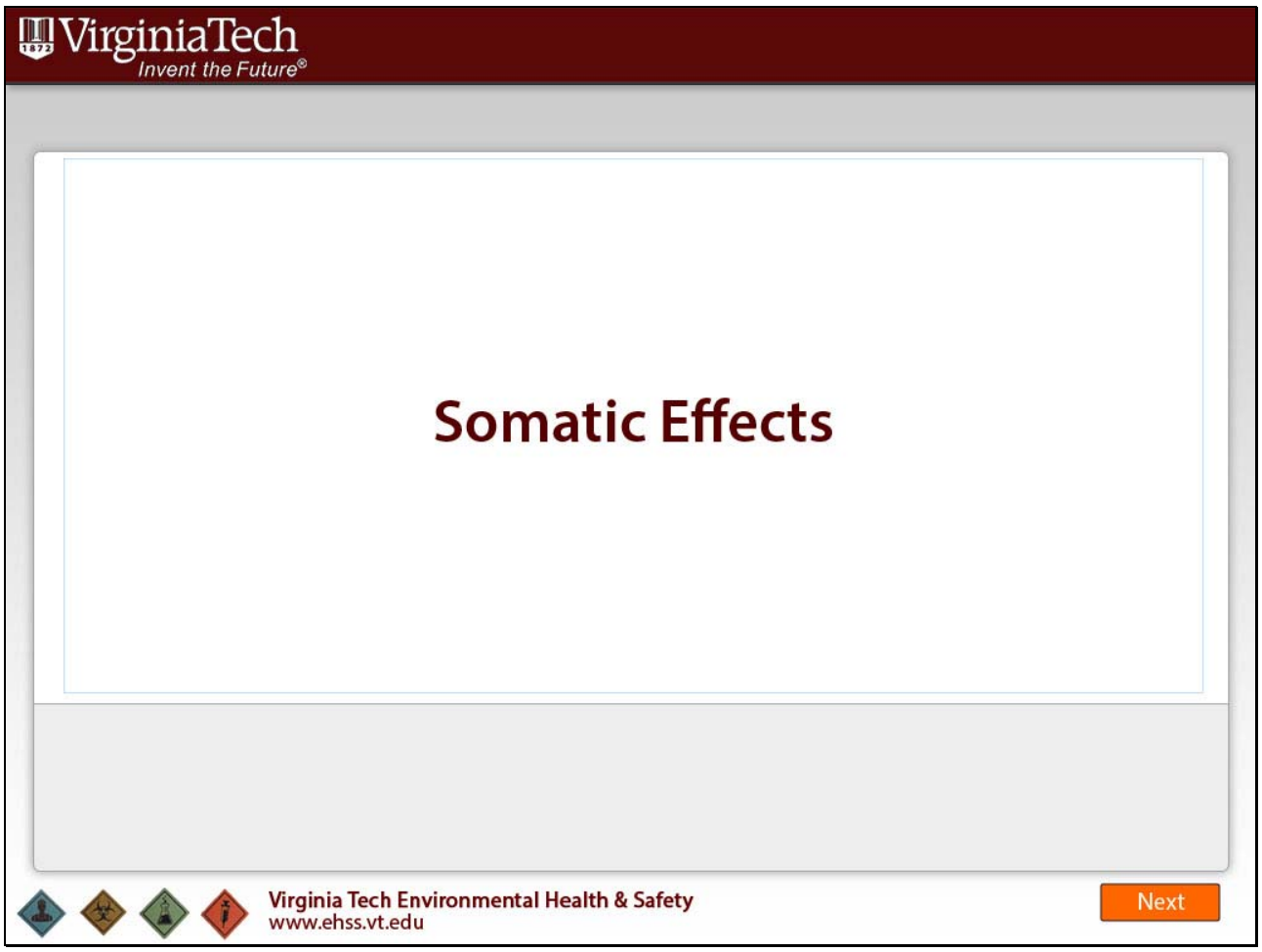
Slide 39 - Somatic Effects



Slide 40 - Acute Somatic Effects

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Acute Somatic Effects

Observable changes in the exposed individual are called somatic effects and can be classified as either short or long term. Short term effects occur after exposure to large doses of radiation in a short period of time, usually greater than 100 Rem to the whole body in a few hours. However, transient somatic effects can be observed for exposures as low as 25 Rem.

The sequence of events that follow exposure to high levels of radiation is termed the "acute radiation syndrome (ARS)". Symptoms can become apparent within a few hours or days depending on the dose received. The first stage of the acute radiation syndrome is usually characterized by nausea, vomiting and diarrhea. Following this initial period of sickness the symptoms may subside and the individual may feel well. This stage can last from hours to weeks and while no symptoms are present, changes are occurring in the internal organs.

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Slide 41 - Acute Somatic Effects continued

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Severe illness, which may lead to death, follows this asymptomatic period. Depending on the dose initially received, hematological, gastrointestinal and/or neuromuscular symptoms will appear. Hematological symptoms can include fatigue, progressive anemia, and the inability to resist infection. Gastrointestinal and neuromuscular symptoms include vomiting, severe diarrhea, dehydration, disorientation, respiratory and cardiovascular collapse. The radiation dose at which 50% of those exposed will die within 30 days, if untreated, is approximately 400-500 Rem.

Another effect which results after an acute over-exposure to radiation, usually greater than 100 rem, is erythema or reddening of the skin. Because the skin is on the surface of the body it can absorb greater doses of radiation than other tissues. This is especially true for low energy x-rays. Large exposures may lead to other changes in the skin such as pigmentation changes, blistering, and ulceration.

Doses of the magnitude necessary to elicit the acute radiation syndrome or erythema are not typically found using x-ray systems under normal operating conditions. However, severe burns to localized areas of the skin are possible from finely collimated high-intensity x-ray beams produced by analytical x-ray equipment.

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Slide 42 - Chronic Somatic Effects

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Chronic Somatic Effects

X-ray personnel can be exposed to small doses of radiation over long periods of time resulting in delayed effects that may become apparent years after the initial exposure. Delayed effects may include life span shortening, premature aging and chronic fatigue. However, the principal somatic delayed effect from chronic exposure to radiation is an increased incidence of cancer. Radiation is a well known carcinogenic agent in animals and humans and has been implicated as capable of inducing all types of human cancers. Those types of cancer with the strongest association with radiation exposure include leukemia, cancer of the lung, thyroid, bone, female breast, liver, and skin.

It is not known how radiation induces cancer. However, several theories have been proposed to explain the carcinogenic properties of radiation. Cancer is characterized by an over-proliferation of cells in any tissue. According to one theory, radiation damages the chromosomes in the nucleus of a cell resulting in the abnormal replication of that cell. Another theory postulates that radiation decreases the overall resistance of the body and allows existing viruses to multiply and damage cells. A third theory suggests that as a result of irradiation of water molecules in the cell, highly reactive and damaging agents called "free radicals" are produced which may play a part in cancer formation.

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Slide 43 - Chronic Somatic Effects continued

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Evidence that ionizing radiation can induce cancer in humans has been demonstrated among radiation workers exposed to high doses of radiation, children exposed in-utero to diagnostic x-rays, patients receiving therapeutic x-rays and internal radiation exposure, individuals exposed to fallout, and the Japanese A-bomb survivors.

Some of these evidences are summarized below:

- Increased incidences of cancer have been noted among several groups of radiation workers. Among these were the early radiologists, uranium miners and radium watch dial painters.
- Increased incidences of leukemia were demonstrated in children x-rayed in-utero. An increase in breast cancer was noted among women with tuberculosis who received repeated fluoroscopic examinations.
- Exposure to therapeutic x-rays has resulted in increased incidences of cancer among patients treated for ringworm of the scalp, arthritis of the spine, and enlargement of thymus glands.
- Mortality from liver cancer was increased among patients who received a radiocontrast material, Thorotrast. This compound contained thorium, a naturally occurring alpha emitting radioisotope.
- Residents of the Marshall Islands were accidentally exposed to fallout from a nuclear bomb test in 1954. Increased incidences of thyroid carcinoma have been demonstrated in these individuals.

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Slide 44 - Chronic Somatic Effects continued

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(evidences continued)

- The strongest evidence for radiation induced carcinogenesis has come from studies of the Japanese A-bomb survivors. These data have suggested that radiation may be a general carcinogenic agent in humans. Increased incidences of leukemia, cancer of the breast, respiratory organs, digestive organs, and urinary organs have been reported.
- Twenty eight of 600 workers involved in the Chernobyl accident in 1986 died within the first four months after the event. Another 106 workers developed acute radiation sickness and another 200,000 cleanup workers from 1986-1987 received doses between 1 and 100 rem (average annual radiation dose for a U.S. citizen is about 0.6 rem).
- Children's internal radiation exposures associated with the accident in Chernobyl have shown an increase in thyroid cancer cases.

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Slide 45 - Chronic Somatic Effects continued

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These increases in cancer were observed from whole body exposures considerably higher than those experienced by radiation workers using radiographic or analytical x-ray systems. Increases in cancer have not been clearly demonstrated at levels below the occupational limit of 5,000 mRem/year. However, the cancer risks associated with these levels have been extrapolated from the observable effects on those populations exposed to large doses of radiation.

The Nuclear Regulatory Commission (NRC) and Commonwealth of Virginia have adopted a linear model for calculating the cancer risks associated with low level radiation exposure. According to the NRC, this model neither seriously underestimates nor overestimates the risks involved from radiation exposure. Under the linear model, the risks decrease proportionally to the dose of radiation. Thus, a worker who receives 5,000 mRem/yr is assumed to have incurred ten times the risk as a worker who receives 500 mRem/yr.

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Slide 46 - Chronic Somatic Effects continued

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Approximately 25% of all adults between the ages of 20 and 65 will develop cancer from all causes during their lifetime. It is not known what an individual's chances are of getting cancer from exposure to ionizing radiation. However, risk estimates can be made based on statistical increases in the incidence of cancer among large populations. Based on linear extrapolation from high doses, the best risk estimates available today are that an additional 300 cancer cases would occur among a population of one million individuals exposed to 1,000 mRem each of radiation. Therefore, in a group of 10,000 workers not exposed to radiation on the job, 2,500 cancer cases would be expected to occur. An additional 3 cancer cases would result in a group of 10,000 radiation workers exposed to 1,000 mRem each.

It is important to realize that these risks are extrapolated from high doses and may not apply to low doses. Controversial studies have suggested that linear extrapolation from high doses may significantly underestimate the actual cancer risks involved from exposure to chronic low doses of radiation. Other studies have indicated that extrapolated levels may overestimate these risks. However, both sets of data have lacked sufficient validity to be used confidently for the estimation of cancer risks at this time.

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Slide 47 - Genetic Effects

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Genetic Effects

Radiation exposure to the genetic material in the reproductive cells can alter the genetic code and result in mutations in future generations. Genetic mutations resulting from radiation have been clearly demonstrated in animals, but genetic mutations have not been observed in human populations exposed to radiation.

Based on irradiation of animals the following inferences can be made regarding genetic effects in humans:

- Radiation is a powerful mutagenic agent and any amount of radiation can potentially damage a reproductive cell.
- The vast majority of genetic mutations are recessive. Both a male and female must possess the same genetic alteration in their chromosomes in order for the mutation to be expressed.
- Most genetic mutations are harmful. Therefore, genetic mutations tend to decrease the overall biological fitness of a species.

Because genetic mutations may decrease the viability of the human species it is desirable that the level of genetic defects in the population be kept as low as possible. This can be accomplished by avoiding any unnecessary radiation exposure to the reproductive cells.

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Slide 48 - Teratogentic Effects

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Teratogenic Effects

The Nuclear Regulatory Commission and the Commonwealth of Virginia require that radiation workers be informed of the health protection problems associated with exposure to radiation. The following information describes the health risks associated with radiation exposure to the unborn child.

Because an unborn child is more sensitive to radiation injury than an adult, the Federal and Virginia regulations require that the maximum permissible dose to an unborn child from occupational exposure of the expectant mother should not exceed 500 mRem. Further, if a voluntary declaration of pregnancy is documented with the supervisor, the pregnant worker must not exceed 500 mRem during the entire pregnancy. It is highly unlikely that a pregnant radiation worker at Virginia Tech could receive a dose to her unborn child in excess of this amount. However, the expectant mother must decide if she is willing to work in an area where she may be exposed to radiation. This information is presented so that she may make an informed decision.

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Slide 49 - Effects on Growth and Development

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Effects on Growth and Development

The sensitivity of cells to radiation damage is directly related to their reproductive activity and inversely related to their degree of specialization. Thus, a developing embryo or fetus, whose cells are rapidly dividing and unspecialized, is very sensitive to radiation damage.

There is no time during the development of the unborn child when it can be exposed to radiation without incurring some risk of biological damage. The human fetus is particularly sensitive to radiation damage during the first trimester and especially during the first few weeks when the organs are forming. It is during this time that a woman may not even be aware that she is pregnant. Radiation damage to the fetus during the first 2 weeks results in a high risk of spontaneous abortion. The second through sixth weeks are the most critical with respect to the development of visible abnormalities. Exposure during the second and third trimesters has also been associated with abnormal growth and development of the fetus.

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Slide 50 - Effects on Growth and Development continued

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These observations are based on studies performed on experimental animals and from human epidemiological (population) studies. Visible abnormalities in animals have been produced from exposure of the embryo to doses as low as 25 Rem. Subtle changes in the nerve cells of rats have been observed from exposures to short term doses in the range of 10 to 20 Rem. Abnormalities in animals resulting from exposure to doses below 10 Rem have not been conclusively shown. Chronic exposures of up to one Rem per day over a large part of the period before birth have shown no radiation induced changes in experimental animals.

Although it is difficult to extrapolate the results from animal experiments to humans, the data suggest that a human embryo would have to be exposed to at least 25 Rem before visible malformations would occur. This level is considerably above the whole body occupational limit of 5 Rem/year. Animal studies further suggest that doses of approximately 10 Rem to the human embryo may produce small alterations in intelligence or behavior.

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Slide 51 - Effects on Growth and Development continued

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In humans, epidemiological studies of children who were exposed to radiation while in-utero, have shown an increased incidence of abnormal growth and development. These data come primarily from the Japanese A-bomb survivors and women who received diagnostic x-rays during their pregnancies. Among the children of the Japanese A-bomb survivors, increased risk of neuro-developmental problems, small head size and a generally smaller body size than normal have been observed. Doses received by these children were above 50 Rem. It has been theorized, although not yet proven, that less severe effects on intelligence and behavior may have occurred at doses considerably below 50 Rem.

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Slide 52 - Childhood Cancers

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Childhood Cancers

The primary concern from exposure of the unborn child to ionizing radiation is an increased incidence of childhood cancers, especially leukemia, during the first ten years of a child's life. An increased incidence of leukemia and other childhood cancers has been associated with radiation exposure to the fetus during all stages of development. However, the carcinogenic effect is greatest for exposure during the first trimester. Studies have shown the risk of leukemia and other cancers in children increases if the mother was exposed during pregnancy to estimated radiation doses averaging 2 Rem, with a range of 0.2 to 20 Rem. One study involved the followup of 77,000 children exposed to diagnostic x-rays before birth. Another study followed 1,292 children who were exposed before birth during the bombing of Hiroshima and Nagasaki. The evidence from these studies suggests an association between exposure of the unborn child and an increased risk of childhood cancer.

Based on these studies the incidence of leukemia among children from birth to 10 years of age in the U.S. could rise from 3.7 cases per 10,000 children to 5.6 cases per 10,000 children if the children were exposed to 1 Rem of radiation before birth. An equal number of other types of cancer could result from this level of radiation. Other studies, have suggested a much smaller effect from exposure of the unborn child to radiation. However, because the biological effects or exposure to low level ionzing radiation are not fully understood it is prudent to maintain radiation doses at levels that are as low as reasonably achievable (ALARA concept).

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Slide 53 - Permissible Dose

Slide 54 - Permissible Dose continued

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The evidence from animal studies and human epidemiological studies indicates that the embryo and fetus are more sensitive to radiation than adults. The effects produced are strongly related to the developmental stage during which the radiation was received, with the unborn child becoming more resistant to radiation as it develops.

Adult radiation workers are permitted to receive 5,000 mRem/yr. Since the unborn child is more sensitive to radiation injury, a pregnant radiation worker may want to limit her exposure to below this amount. To minimize potential biological injury to the unborn child, it is recommended that the occupational exposure of the expectant mother should not exceed 500 mRem during the course of her pregnancy.

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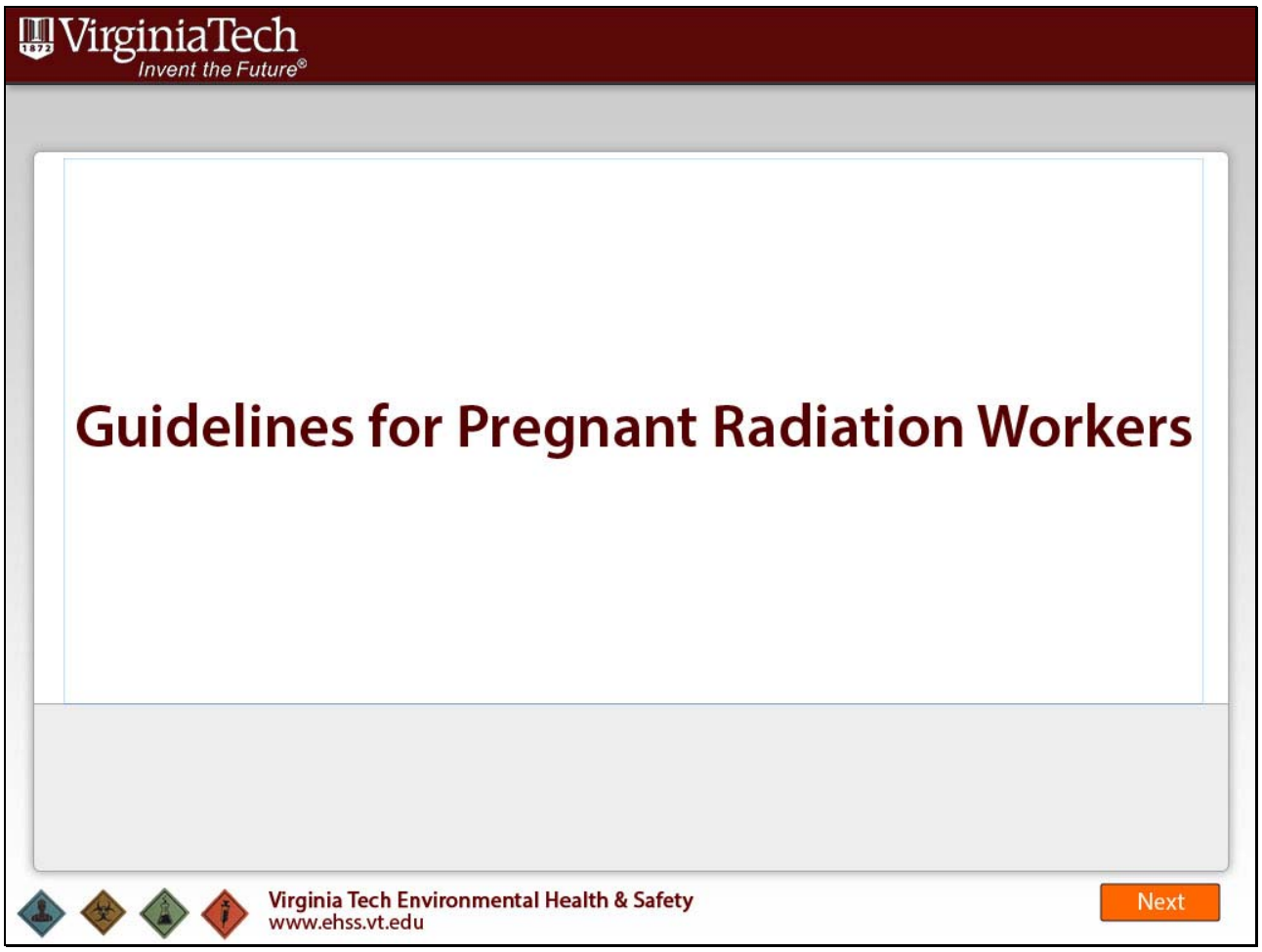
Slide 55 - Guidelines for Pregnant Radiation Workers



Slide 56 - Guidelines for Pregnant Radiation Workers continued

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It is the employer's responsibility to take all practical steps to reduce radiation exposure to its employees. It is the responsibility of the expectant mother to decide if she wishes to continue to work with radioactive materials or x-ray producing equipment. The woman has a choice to declare her pregnacy by notifying the supervisor or keep it confidential. If she chooses not to declare, she is encouraged to contact the Radiation Safety Officer (confidentiality will be maintained) to review radiation levels in the work area. Several facts should be considered when making this decision. The first three months of the pregnacy are the most critical so a decision should not be delayed. Because the mother's body will absorb some of the exposure, the actual dose received by the unborn child will probably be less. The actual risk to an unborn child at the present occupational worker limit of 5,000 mRem is small, but experts disagree on the exact amount of risk. If the expectant mother declares her pregnancy, the limit is 500 mRem for the entire pregnancy. After review she may:

- Decide not to continue working in the area.
- Ask for reassignment to areas involving less radiation exposure.
- Attempt to decrease her exposure through the proper application of time, distance, and shielding.

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Slide 57 - Guidelines for Pregnant Radiation Workers continued

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Pregnant radiation workers who decide to continue to work with radioative material or x-ray equipment will:

- Wear a whole body personnel monitoring device if working with penetrating X or gamma radiation sources.
- Wear a second whole body monitoring device at waist level to better determine dose to the fetus.
- Be informed of her radiation exposure on a quarterly basis.
- Limit her exposure to 500 mRem or less during the course of the pregnancy.
- Keep her exposure to the very lowest practical level by reducing the amount of time spent in a radiation area, increasing the distance from a radiation source, and using shielding.

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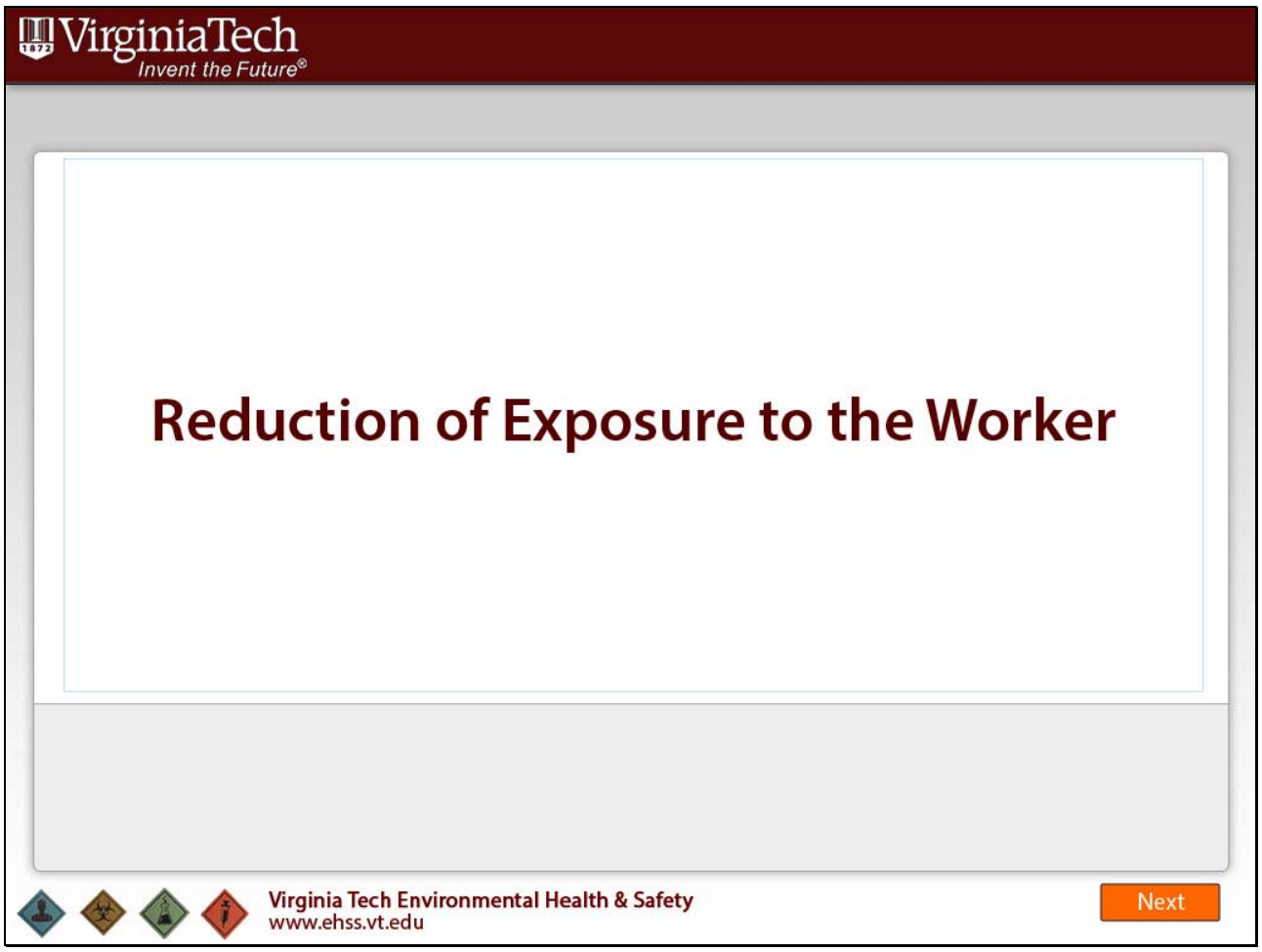
Slide 58 - Reduction of Exposure to the Worker



Slide 59 - Reduction of Exposure to the Worker continued

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Because any amount of radiation is potentially harmful every effort should be made by personnel to reduce their doses to the lowest practical level.

The three most practical methods a radiation worker can use to minimize radiation exposure are through the proper application of time, distance and shielding. The dose a radiation worker receives is directly proportional to the amount of time spent in a radiation field. Thus, decreasing the time spent in a radiation field by a factor of two will reduce the radiation dose to the worker by one-half. Therefore radiation workers should always strive to work as quickly as possible when working with radiation.

Radiation exposure decreases rapidly as the distance between the worker and the x-ray source increases. The decrease in exposure from a point source, such as an x-ray tube, can be calculated by using the inverse square law. This law states that the amount of radiation at a given distance from a point source varies inversely with the square of the distance. For example, doubling the distance from an x-ray tube will reduce the dose by one-fourth, increasing the distance by a factor of three will reduce the exposure by one-ninth. Although the inverse square law does not accurately describe scattered radiation, distance will still dramatically reduce the intensity from this source of exposure. Thus, distance represents one of the simplest and most effective methods for reducing radiation exposure to a worker.

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Slide 60 - Reduction of Exposure to the Worker continued

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Placing an attenuating material between a worker and a source of ionizing radiation can also decrease radiation exposure. Compton and photoelectric interactions in the shielding material reduce the energy of the incident x-ray photon. Shielding can be incorporated into the equipment, such as a metal lining surrounding the x-ray tube. It may also consist of permanent barriers such as: concrete and lead walls, lead impregnated gloves and aprons, leaded glass, and movable screens. Plexiglas or metal enclosures may also be used to attenuate low-energy x-rays generated by analytical x-ray equipment.

The amount of shielding necessary to reduce the radiation intensity to a desired level can be calculated from the half-value layer of the material. The half-value layer is the thickness of the material necessary to reduce the radiation intensity to one-half its original intensity. These values are dependent on the tube potential (kVp) and the shielding material.

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Slide 61 - Conclusion

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Review

This training has presented an overview of how radiation interacts with matter, the biological effects and risks associated with radiation, the methods for detecting radiation and monitoring personnel, the methods by which radiation exposures can be reduced to levels as low as reasonably achievable (ALARA), and basics for operation of x-ray equipment.

Radiation, at any level of exposure, involves some health risk that can potentially induce genetic, carcinogenic, or teratogenic effects in humans. Because of the potentially harmful effects associated with radiation, workers have a responsibility to protect themselves and others from unnecessary radiation exposure.

Radiation workers should always be acutely aware of the hazards involved and the methods of protection at their disposal. Because radiation cannot be detected by our senses, it is easy to forget that radiation may be potentially harmful many years later. The routine use of x-ray equipment may also induce a sense of indifference in the operator which lessens one's respect for the hazards involved. Carelessness and unnecessary radiation exposure can thus follow.

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Slide 62 - Conclusion continued

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Objectives Review (continued)

Radiation exposures can be reduced by employing the latest advances in technology, regulating x-ray equipment, licensing x-ray personnel, and the development of sound quality control programs. However, probably the most important consideration in reducing radiation exposure is through training programs that increase the radiologic health awareness of radiation workers. This has been the purpose of this training. It is intended that the information presented will develop a healthy respect for the risks associated with the use of x-ray equipment rather than unnecessary fear or lack of concern. X-ray equipment can be used safely and with a minimum of exposure to personnel if the guidelines presented are followed.

A multiple-choice test will be administered at the completion of this session. Notes or other materials may be used during the testing process.

Radiation Safety personnel are always available (540-231-5364) if any questions develop concerning the information presented in this program, or during the course of your utilization of x-ray equipment.

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Slide 67 - X-Ray Safety Manual

Slide 68 - Next Steps

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Review (for Analytical)

- X-ray users must be familiar with the physical fundamentals related to working with radiation.
- There are biological effects and risks associated with ionizing radiation.
- Virginia Tech manages x-ray safety through the Radiation Safety Office and has established protocols for compliance.
- Reducing exposure risks is imperative to safely operating x-ray systems.
- There are equipment requirements for analytical open and enclosed beam x-ray instruments which include warning lights, labeling, beam traps, and safety interlocks to control access to x-ray tube/beam.

For more information:

Virginia Tech EHS Web Site

VT EHS Radiation Safety

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Slide 69 - Next Steps

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Review (for Cabinet)

- X-ray users must be familiar with the physical fundamentals related to working with radiation.
- There are biological effects and risks associated with ionizing radiation.
- Virginia Tech manages x-ray safety through the Radiation Safety Office and has established protocols for compliance.
- Reducing exposure risks is imperative to safely operating x-ray systems.
- There are equipment requirements for cabinet x-ray instruments which include key activated control, independent means to determine when x-rays are being generated, labeling, and safety interlocks to control access to interior of instrument.

For more information:

Virginia Tech EHS Web Site

VT EHS Radiation Safety

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