Environmental Health and Safety Statement

Iowa State University strives to be a model for environmental, health and safety excellence in teaching, research, extension, and the management of its facilities. In pursuit of this goal, appropriate policies and procedures must be developed and followed to ensure this community operates in an environment free from recognized hazards. Faculty, staff, and students are responsible for compliance with established policies and are encouraged to enucleurate practices that ensure safety, protect health, and minimize the institution's impact on the environment.

As an institution of higher learning, Iowa State University

- fosters an understanding of and a responsibility for the environment,
- encourages individuals to be knowledgeable about environmental, health and safety issues that affect their discipline, and
- shares examples of superior environmental health and safety performance with peer institutions, the State of Iowa and the local community.

As a responsible steward of facilities and the environment, Iowa State University

- strives to provide and maintain safe working environments that minimize the risk of injury or illness to employees, students and the public,
- continuously improves operations, with the goal of meeting or exceeding required and applicable environmental, health and safety regulations, rules, policies, or voluntary standards, and
- employs innovative strategies of waste minimization and pollution prevention to reduce the use of toxic substances, promote reuse, and encourage the purchase of renewable, recyclable and recycled materials.

The intent of this statement is to promote environmental stewardship, protect health, and encourage safe work practices within the Iowa State University community. The cooperative efforts of the campus community to remain mindful of these goals will ensure that Iowa State University continues to be a great place to live, work, and learn.

Dr. Steven Leath
President
Directory of Service and Emergency Providers

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Emergency

Emergency - Ambulance, Fire, Police
911

Department of Public Safety/ Iowa State University Police
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A. Introduction

X-ray devices are important tools in various areas of modern research. The x-rays produced by such equipment, however, can pose a hazard to human health. For this reason, special precautions must be observed when these devices are used.

At Iowa State University, the Department of Environmental Health and Safety (EH&S) is responsible for ensuring that all users of x-ray producing devices are aware of both the potential hazards associated with the use of these devices and the proper precautions that must be employed to minimize these hazards. To accomplish this objective, EH&S has prepared this safety guide.

All individuals who wish to use x-ray equipment at the university must complete x-ray safety training and the associated examination before they can be authorized to use the equipment. In addition to training, all individuals must complete and return the Radiation / Laser Worker Application form. Additional authorization requirements are addressed in the guide. Questions concerning this guide or the authorization process should be directed to EH&S at (515) 294-5359.
Authorization for Use of X-Ray Systems

At Iowa State University, each new project which involves the use of a radiation-producing device must be specifically authorized by EH&S and by the Radiation Safety Committee (RSC). Minor changes to previously approved projects, such as the addition of new personnel, require the approval of EH&S. No student or member of the staff or faculty at Iowa State University may use x-ray equipment without this written approval. Additional details concerning application for initial authorization of a project are contained in the Radiation Safety Manual. Requirements for the authorization of an individual to work on a previously approved project are described in the following subsections.

Approval

Formal approval to work with an x-ray system is normally granted upon successful completion of training, including passing the written examination. If the x-ray system is new, it will need to be inspected for safe operation and registered with the Iowa Department of Public Health IDPH. Registration entails an annual fee for each x-ray tube, depending on the type of x-ray system.

Electron Microscopes

Currently, the IDPH requires the registration of electron microscopes. EH&S performs an annual survey of each electron microscope for radiation safety and registers the microscope along with x-ray machines. No radiation safety training is required for users of electron microscopes.

Training

Each individual who wishes to be authorized to use analytical x-ray equipment at Iowa State University must first receive training concerning the radiation hazards associated with the use of the equipment, the function and importance of the equipment’s safety devices, proper operating procedures, and procedures to follow in the event of a suspected radiation exposure. The training is provided, in part, through this safety guide and on-line or classroom x-ray safety training, followed by a written examination. The principal investigator in charge of the x-ray equipment, however, has the responsibility for providing any additional device specific training required to ensure the safe use of the particular equipment involved.
Training Requirements

Analytical X-ray Users: X-ray Defraction and X-ray Fluorescent

Users must be trained and approved by EH&S. Use of dosimetry is decided on a case by case basis.

Radiographic X-ray Users

Users must be trained and approved by EH&S. Use of dosimetry is required for operation of radiographic x-ray system.

Diagnostic X-ray Users

Users typically complete IDPH approved training or as part of qualification for DVM or MD degree. Licensed veterinarians and medical doctors are approved to supervise diagnostic systems used in the practice of veterinary medicine or human medicine, respectively. Use of dosimetry is required for users of diagnostic medical x-ray systems. For users who are not licensed professionals, annual x-ray safety training is required.

Operating Requirements

Procedures

Normal operating procedures shall be written and available to all analytical x-ray equipment workers. Note that these procedures also need to address possible emergencies.

Bypassing Safety Devices

No individual shall bypass a safety device or interlock unless the individual has obtained written approval of the Radiation Safety Officer (RSO).

Altering System Components

No operation involving the removal or alteration of shielding materials, tube housing, shutter, collimators, or beam stops shall be performed until it has been determined that the beam is off and will remain off until safe conditions have been restored.

Personnel Monitoring Requirements

State and federal laws require that any individual who is likely to receive more than 10% of any annual occupational dose limit be monitored for radiation exposure. There are a number of types of materials or devices that are used to assess an individual’s
cumulative external radiation dose. These are collectively termed “dosimeters.”

A commonly used dosimeter for monitoring exposures encountered in various research, teaching, and clinical settings at Iowa State University is the whole body badge. This consists of a small piece of radiation-sensitive material placed in a special holder. The badge is worn by the researcher whenever working with or near sources emitting penetrating radiation (e.g., energetic beta particles, x-rays, or gamma rays). Periodically, the badge is replaced by EH&S and the exposed badge forwarded to the vendor’s laboratory for analysis.

Another commonly used dosimeter is the ring badge. This consists of a small chip of radiation sensitive material (e.g., LiF or CaF$_2$) which is in a ring holder. In research laboratories, ring badges are worn by individuals handling relatively large quantities of energetic beta or gamma emitting radionuclides or working near strong x-ray sources.

In order for a dosimeter to provide an accurate indication of an individual’s dose, it must be worn properly. For assessing whole-body doses, the dosimeter should be worn on some area of the torso from the neck to the waist, such as a breast pocket, lapel, or belt. If a protective lead apron is worn and only one dosimeter has been issued, it should be worn under the apron at the waistline. If a second badge has been issued, it should be worn at the location likely to receive the highest dose. Ring badges should be worn so that the ring faces the source of radiation.

Finger or wrist dosimeters shall be provided to and shall be used by all analytical x-ray equipment workers using systems having open-beam configurations and not equipped with a beam shut-off device. EH&S issues ring dosimeters to all regular users of x-ray diffraction devices, if there is a possibility of radiation exposure. Users of veterinary or healing arts x-ray systems are issued whole-body badges, and, if necessary, ring badges. Users of radiographic type analytical x-ray systems may be issued whole-body badges or ring badges, as appropriate for the particular machine and the procedures to be used.

**Types and Characteristics of X-Ray Systems**

The two major types of x-ray equipment used at Iowa State University are diagnostic devices, used at the College of Veterinary Medicine and the Thielens Student Health Center, and analytical/radiographic x-ray units used for research.

The use of diagnostic x-ray units is restricted to certified radiographers or, in the case of Veterinary Medicine, to those trained and directly
supervised by a staff radiologist. Only those individuals who have received appropriate training and approval from EH&S may use analytical x-ray units.

All individuals who operate diagnostic x-ray equipment are provided with whole body badges for monitoring whole body radiation exposures. Individuals using analytical x-ray units may receive either ring or whole-body badges depending upon the particular type of device and use.

**Analytical X-ray Diffraction System (XRD)**

X-ray diffraction (XRD) is used extensively for analyzing the structure and properties of solid materials. Figure 6 illustrates the basic configuration of a diffraction system. In this mode of operation, the primary beam from the target of the x-ray tube emerges from the machine through a collimator and strikes the sample, which diffracts it in a characteristic manner. The diffraction pattern is measured with photographic film or a radiation counter.

![Schematic diagram of x-ray diffraction](image)

**Analytical X-ray Fluorescence System (XRF)**

X-ray fluorescence (XRF) spectroscopy is an analytical method for determining the elemental composition of a sample. The primary radiation beam strikes the sample inside a shielded enclosure, and only scattered radiation and secondary radiation produced in the sample emerges from the machine for analysis. Since the primary beam is shielded, x-ray fluorescence systems tend to pose less of a hazard than diffractions systems.
X-Ray Systems Manual

Analytical Radiographic X-ray System

X-ray radiographic systems consist of an x-ray source, a place for the sample that is to be examined, and a device such as x-ray film or an image intensifier for producing an image of the x-ray beam after it has interacted with the sample. Radiographic systems are often used for inspection of parts for defects. Radiographic systems are often placed inside a shielded room called an x-ray vault.

Healing Arts and Veterinary Medicine X-ray System

X-ray systems are often used for medical diagnosis. Personnel operating x-ray systems that involve human exposure must receive appropriate training and be certified by the State of Iowa.

Radiation Hazards of X-Ray Systems

Because they utilize extremely high intensity x-ray beams, analytical x-ray systems have the potential for posing significant hazards if operated inappropriately. Radiation exposures can result not only from the primary beam but also from scattered (or diffracted) rays and secondary radiation from the sample or shielding material. All x-ray systems pose a chronic exposure hazard and thus appropriate procedures must be developed and followed to insure that exposures are “as low as is reasonably achievable” (ALARA).

Primary X-ray Beam

The x-rays utilized most commonly in analytical systems have wavelengths in the range of 0.5 to 10 angstroms (about 10 to 160 keV). These are often referred to as “soft” x-rays because of the ease by which they are absorbed in matter. While this characteristic enables soft x-rays to be readily shielded (generally
requiring only a few millimeters of lead or iron), it also makes them particularly hazardous since they are highly absorbed even by soft tissue. The x-ray beam for radiographic or healing arts x-ray systems usually consists of x-rays in the energy region of 50 to 200 keV.

The primary beams from analytical x-ray systems are generally very narrow with beam diameters of less than one centimeter. Because of their intensity and their high degree of absorption in tissue, they can produce severe and permanent local injury from exposures of only a fraction of a second. Potential exposure to the primary x-ray beam is generally not a major concern for analytical systems operating in the fluorescence mode since the beam in these systems is contained within a shielded enclosure. The possibility of leakage of the primary beam through the shield, however, cannot be discounted.

Exposure to the primary beam of diffraction units is a major concern. In fact, the greatest risk of acute accidental exposures from analytical systems occurs in manipulations of the sample to be irradiated by the direct beam in diffraction studies. Exposure rates on the order of 10,000 R/sec can exist at the tube housing port. At these levels, erythema would be produced from exposures of only 0.03 second and permanent injury could be inflicted in only 0.1 second. The fingers, of course, are the part of the body most at risk from such high exposures.

**Diffracted X-ray Beam**

For x-ray diffraction systems, the diffracted beam is also small and well collimated with an intensity of up to 80 R/hr. Prolonged or repeated exposures to a beam of this intensity could result in an individual exceeding the annual extremity dose limit.

**Scattered and Secondary X-rays**

Through interactions with the sample and shielding material, the primary beam in diffraction systems often produces diffuse patterns of scattered and secondary x-rays in the environment around the equipment. Exposure rates of 150 mR/hr near the shielded sample are not uncommon. In contrast, scattered and secondary radiation levels in the vicinity of a fluorescence system (where only secondary radiation emerges from the shielded target-sample assembly) is generally an order of magnitude less.

**Hazard Control Measures for Analytical X-Ray Systems**

Requirements for controlling potential hazards associated with analytical x-ray systems are specified in most states by law. In
Iowa, these requirements are found in 641-45.5(136C) of the Iowa Administrative Code. Portions of these hazard control and safety measures are summarized here.

**Equipment Requirements**

**Beam Entry Shut-off Device**

A device which prevents the entry of any portion of an individual’s body into the primary beam path or which causes the beam to be shut off upon entry into its path shall be provided on all open-beam configurations.

**Shutters**

For open-beam configurations, each port on the source housing shall be equipped with a shutter that cannot be opened unless a collimator or coupling has been connected to the port.

**Housing Interlock**

Each x-ray tube housing shall be equipped with an interlock that shuts off power to the tube if the tube is removed from the housing or if the housing is disassembled.

**Shielding Provided by Housing**

Each x-ray tube housing shall be constructed so that, with all shutters closed, the radiation, measured at a distance of five centimeters from its surface, is not capable of producing a dose in excess of 2.5 millirems in one hour.

**Warning Lights**

An easily visible warning light with the words “X-RAY ON” shall be located near any switch that energizes an x-ray tube and shall be illuminated only when the tube is energized.

**Labeling**

All analytical x-ray equipment shall be labeled with a readily discernible sign bearing the radiation symbol and the words: “CAUTION - HIGH INTENSITY X-RAY BEAM” or words having a similar intent, on the x-ray source housing, and “CAUTION - RADIATION - THIS EQUIPMENT PRODUCES RADIATION WHEN ENERGIZED” or words having a similar intent, near any switch that energized an x-ray tube.
Area Requirements

Radiation Levels

The components of an analytical x-ray system shall be arranged and shall be sufficiently shielded to ensure that radiation levels near the components cannot result in an individual receiving a dose in excess of the allowed occupational limits.

Surveys

Radiation surveys of all analytical x-ray systems sufficient to show compliance with the radiation levels established above must be performed:

1. Upon installation of the equipment and at least every twelve months thereafter.

2. Following any change in the number, type, or arrangement of components in the system.

3. Following any maintenance requiring the disassembly or removal of a system component.

4. During the performance of maintenance and alignment procedures if the procedures require the presence of a primary x-ray beam when any local component in the system is disassembled or removed.

Postings

Each area containing analytical x-ray equipment shall be conspicuously posted with a sign bearing the radiation symbol and the words “CAUTION - X-RAY EQUIPMENT.”

Each area containing analytical x-ray equipment shall be conspicuously posted with the Iowa Department of Public Health (IDPH) “NOTICE TO EMPLOYEES” sign.
C. Fundamentals of X-Ray Physics

In 1895, the German professor Wilhelm Roentgen was performing experiments with high-speed electrons generated by an electron tube. During the course of his experiments, he discovered that the interaction of these electrons with matter produced a form of highly penetrating radiation, which he termed x-rays.

The ability of x-rays to penetrate matter differentially, as a function of density and elemental composition, was recognized almost immediately after their discovery and led to widespread applications for observing the internal structure of various objects, including the human body. Progressive improvements in x-ray technology throughout the last century and into this one have greatly expanded the uses of x-ray devices as analytical and diagnostic tools.

Nature of X-rays

X-rays consist of photons of electromagnetic radiation and are distinguished from gamma rays only by their origin. Whereas gamma rays arise from transitions in the nuclei of radioactive atoms, x-rays are produced by processes outside the nucleus involving electrons. X-rays ionize material with which they interact, and are, thus, a form of ionizing radiation.

Production of X-rays

There are two principal mechanisms by which x-rays are produced. The first mechanism involves the rapid acceleration or deceleration of an electron as it enters the electrical field of a nucleus. During this process the electron is deflected and emits a photon of x-radiation. This type of x-ray is often referred to as bremsstrahlung or “braking radiation.” For a given source of electrons, a continuous spectrum of bremsstrahlung will be produced up to the maximum energy of the electrons.

The second mechanism by which x-rays are produced is through transitions of electrons between atomic orbits. Such transitions involve the movement of electrons from outer orbits to vacancies within inner orbits. In making such transitions, electrons emit photons of x-radiation with discrete energies given by the differences in energy states at the beginning and end of the transition. Because such x-rays are distinctive for the particular element and transition, they are called characteristic x-rays.

Both of these basic mechanisms are involved in the production of x-rays in an x-ray tube. Figure 1 is a schematic diagram of a standard x-ray tube. A tungsten filament is heated to 2000°C to emit electrons. These electrons are accelerated in an electric field toward a target, also often made of tungsten. The interaction
of electrons in the target results in the emission of a continuous bremsstrahlung spectrum along with characteristic x-rays from the particular target material.

**Interaction of X-rays with Matter**

X-rays transfer their energy to matter through chance encounters with bound electrons or atomic nuclei. These chance encounters result in the ejection of energetic electrons from the atom. Each of the electrons liberated goes on to transfer its energy to matter through thousands of direct ionization events (for example, events involving collisions between charged particles). Since x-rays and gamma rays transfer energy in this “indirect” manner, they are referred to as “indirectly ionizing radiations.”

Because the encounters of photons with atoms are by chance, a given x-ray has a finite probability of passing completely through the medium it is traversing. The probability that an x-ray will pass completely through a medium depends upon numerous factors including the energy of the x-ray and the medium’s composition and thickness.

**Radiation Quantities and Terms**

The following quantities and terms are essential to the description and measurement of various forms of ionizing radiation.

**Exposure**

Exposure is a measure of the strength of a radiation field at some point. It is usually defined as the amount of charge (such as, sum of all ions of one sign) produced in a unit mass of air when the electrons liberated by interaction with the photons are
completely absorbed in that mass. The most commonly used unit of exposure is the roentgen (R) which is defined as that amount of x-ray or gamma radiation which produces $2.58 \times 10^{-4}$ coulombs of charge per kilogram of dry air. In cases where exposure is to be expressed as a rate, the unit would be R/hr or, more commonly, milliroentgen per hour (mR/hr). The International System of Units (S.I.) for exposure is coulomb per kilogram (C/kg.)

Absorbed Dose

Whereas exposure is defined for air, the absorbed dose is the amount of energy imparted by radiation to a given mass of any material. The most common unit of absorbed dose is the rad which is defined as a dose of 100 ergs of energy per gram of the material being exposed. Absorbed dose may also be expressed as a rate with units of rad/hr or mrad/hr. The S.I. unit for absorbed dose is the 1 gray = 1 joule/kg. 1 gray = 100 rad.

Dose Equivalent

Although the biological effects of radiation are dependent upon the absorbed dose, some types of particles produce greater effects than others for the same amount of energy delivered to the biological target. In order to account for these variations when describing human health risk from radiation exposure, the concept of or term “dose equivalent” is used. This is the absorbed dose multiplied by certain “quality” and “modifying” factors indicative of the relative biological-damage potential of the particular type of radiation. The unit of dose equivalent is the “rem” or, more commonly, “millirem.” Dose equivalent may likewise be expressed as a rate with units of rem/hr or mrem/hr. For gamma or x-ray exposures, the numerical value of the rem is essentially equal to that of the radiation. The S.I. unit for dose equivalent is the sievert = 100 rem. In soft tissue, 1 R is nearly equivalent to 0.96 rem.

Shielding

Shielding is any material that is placed around or adjacent to a source of penetrating radiation for the purpose of attenuating the exposure rate from the source. For shielding x-rays, materials composed of high atomic number elements, such as lead, are highly effective.

Half-Value Layer

The half-value layer is that thickness of a given material (shielding) required to reduce the exposure rate from a source of gamma or x-rays to one-half its unshielded value.

Table 1 gives the half-value layer (HVL) and tenth-value layer (TVL) for various energy x-rays with broad-beam conditions.
kVp is the peak or maximum voltage in thousand of volts used to produce the x-rays. Many x-ray systems use a high-voltage system that gives a variable voltage – the highest such voltage is of interest for shielding and for registering the unit.

<table>
<thead>
<tr>
<th>peak voltage (kVp)</th>
<th>HVL lead (mm)</th>
<th>TVL lead (mm)</th>
<th>HVL concrete (cm)</th>
<th>TVL concrete (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.06</td>
<td>0.17</td>
<td>0.43</td>
<td>1.5</td>
</tr>
<tr>
<td>70</td>
<td>0.17</td>
<td>0.52</td>
<td>0.84</td>
<td>2.8</td>
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<tr>
<td>100</td>
<td>0.27</td>
<td>0.88</td>
<td>1.6</td>
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<td>125</td>
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<td>0.93</td>
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<td>150</td>
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<td>200</td>
<td>0.52</td>
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<tr>
<td>1000</td>
<td>7.9</td>
<td>26</td>
<td>4.4</td>
<td>14.7</td>
</tr>
</tbody>
</table>

X-Ray shielding

D. Measurement of Ionizing Radiation

Ionizing radiation cannot be detected by the human senses. Radiation detection requires the identification of physical or chemical changes in the medium (gas, liquid, or solid) through which it passes. Measurement of ionizing radiation requires the quantification of these physical or chemical changes. In general, detection and measurement methods can be categorized as being either active or passive.

Active Detection Methods

Active radiation detection systems can be loosely defined as those that require an electrical power source for operation. Such detectors are generally used to characterize dose rates or count rates, though some also have the capability of measuring cumulative dose. There are two principal types of active detectors: gas ionization and scintillation.

Gas Ionization Detectors

Most gas ionization detectors consist of a gas-filled chamber with a voltage applied, such that a central wire becomes the anode and the chamber wall the cathode (Figure 10). Any ion pairs produced by radiation interacting with the chamber move to the electrodes, where they are collected to form an electronic pulse that can be measured and quantified. Depending upon the voltage applied to the chamber, the detector may be considered an ion chamber, a proportional counter, or a Geiger-Mueller (GM) detector.

Because of its versatility and dependability, the GM detector is the most widely-used portable survey instrument. The GM meter is useful in detecting radiation levels near relatively large sources of medium-to-high energy x-rays. The GM detector, however, is not particularly sensitive to low-energy x-rays.

Unlike some other types of portable survey instruments, the GM detector does not actually “measure” exposure or dose rate. It instead “detects” the number of particles interacting in its sensitive...
volume per unit time. Therefore, the GM detector should most appropriately be read-out in counts per minute (cpm), although it can be calibrated to approximate mrem/hr for certain situations, with certain limitations.

**Scintillation Detectors**

Scintillation detectors are based upon the use of various phosphors (scintillators) that emit light in proportion to the quantity and energy of the radiation they absorb. The light flashes are converted to photoelectrons that are multiplied in a series of dynodes (such as, a photo multiplier) to amplify the electrical pulse (Figure 11). Because the light output and resultant electrical pulse is proportional to the amount of energy deposited by the radiation, scintillators can be used in systems designed to identify the amount of specific radionuclides present.

Solid scintillation detectors are particularly useful in identifying and quantifying x-rays. The common gamma well counter employs a large crystal of NaI within a lead-shielded well. The sample vial is lowered directly into a hollowed chamber within the crystal for counting. Such systems are extremely sensitive, but do not have the resolution of more recently developed semiconductor counting systems. Portable solid scintillation detectors are also widely used for conducting various types of radiation surveys. Of particular use to researchers working with radioiodines is the thin crystal NaI detector that is capable of detecting the emissions from $^{125}$I with efficiencies nearing 20% (a GM detector is much less than one percent efficient for $^{125}$I).

**Instrument Operation and Calibration**

Whether an active detection system is stationary or portable, it must be properly maintained and calibrated in order to provide
valid measurements. The specific requirements in this area, in terms of calibration frequencies and procedures, are generally detailed in an institution’s license application. Ideally, calibrations should involve the use of a source traceable to the National Institute of Standards and Technology, with radiation of similar type and energy as that being monitored. The date of the most recent calibration must be indicated by a sticker attached to each instrument. This sticker may also indicate the counting efficiencies determined for various radionuclides. In addition to these formal calibrations (which are generally done on at least an annual basis), a check of the instrument’s response to radiation should be performed with a small radioactive source each time the instrument is operated.

There are 5 operational checks to be performed prior to using a meter:

- Check the calibration date (must have been calibrated within last year)
- Check the condition of the meter (no broken dial faces or frayed cords)
- Check the battery to insure adequate power to operate the meter correctly
- Check the response to a real source of radiation (proper response to a check source)
- Measure and record the background radiation level

Be sure to record the background reading and survey readings in a log book

**Passive Detection Methods**

Radiation detection methods that do not require a power source are referred to as "passive" methods or systems. The detection medium is usually a solid and is used almost exclusively to characterize cumulative dose rather than dose rate or particle fluence rate (as is the case for many active detection systems). An important use for such detectors is as personnel dosimeters (For example, devices used to assess an individual’s cumulative external radiation exposure). The two principal types of personnel dosimeters used at Iowa State University are whole-body badges (Figure 12), used to determine the whole-body dose and ring badges (Figure 5), used to determine the hand or extremity dose.
E. Biological Effects of Ionizing Radiation

Cellular Effects

The energy deposited by ionizing radiation as it interacts with matter may result in the breaking of chemical bonds. If the irradiated matter is living tissue, such chemical changes may result in altered structure or function of constituent cells.

Mechanisms of Radiation Damage

Less than 20% of the energy deposited in cells by ionizing radiation is absorbed directly by macromolecules. This is due to the fact that such molecules make up a relatively small proportion of the cell’s mass. More than 80% of the energy deposited in the cell is absorbed by water molecules that make up the majority of the cell’s mass. This results in the formation of highly reactive free radicals:

\[
2H_2O \xrightarrow{\text{radiation}} 2H^0 + 2OH^0 \rightarrow H_2O_2 + H_2
\]

These radicals and their products, for example hydrogen peroxide, may initiate numerous chemical reactions that result in damage to macromolecules and a corresponding alteration of structure or function. Damage produced within the cell by the radiation-induced formation of free radicals is described as being by indirect action of radiation.

Changes in Structure and Function

As a result of the chemical changes in the cell caused by the direct or indirect action of ionizing radiation, large biological molecules may undergo a variety of structural changes which lead to altered function. Some of the more common effects that have been observed are inhibition of cell division, denaturation of proteins and inactivation of enzymes, alteration of membrane permeability, and chromosome aberrations.

Radiosensitivity

The cell nucleus is the major site of radiation damage leading to cell death. This is due to the importance of the DNA within the nucleus in controlling all cellular function. Damage to the DNA molecule may prevent it from providing the proper template for the production of additional DNA or RNA. This hypothesis is supported by research that has shown that cells are most sensitive to radiation damage during reproductive phases, such as during DNA replication.
In general, it has been found that cell radiosensitivity is directly proportional to the rate of cell division and inversely proportional to the degree of cell differentiation. Table 2 presents a list of cells that generally follow this principle.

<table>
<thead>
<tr>
<th>Very radiosensitive</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>lymphocytes</td>
<td>cellular elements of lymph</td>
</tr>
<tr>
<td>erythroblasts</td>
<td>red marrow cells that synthesize hemoglobin and that are an intermediate in the initial stage of red blood cell formation</td>
</tr>
<tr>
<td>spermatogonia</td>
<td>primitive male germ</td>
</tr>
<tr>
<td>basal cells</td>
<td>innermost cells of the deeper epidermis of the skin</td>
</tr>
<tr>
<td>endothelial cells</td>
<td>thin flattened cells that line the internal body cavities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Moderately radiosensitive</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoblasts</td>
<td>bone forming cells</td>
</tr>
<tr>
<td>granulocytes</td>
<td>polymorphonuclear white blood cells with granule containing cytoplasm</td>
</tr>
<tr>
<td>osteocytes</td>
<td>cells characteristic of adult bone and isolated in small cavities of the bone substance</td>
</tr>
<tr>
<td>sperm</td>
<td>mature male germ cell</td>
</tr>
<tr>
<td>erythrocytes</td>
<td>red blood cells</td>
</tr>
<tr>
<td>fibroblasts</td>
<td>cells that produce the fibrous connective tissue</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relatively radioresistant</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>fibrocytes</td>
<td>fibrous connective tissue cells</td>
</tr>
<tr>
<td>chondrocytes</td>
<td>cartilage tissue cells</td>
</tr>
<tr>
<td>muscle cells</td>
<td></td>
</tr>
<tr>
<td>nerve cells</td>
<td></td>
</tr>
</tbody>
</table>

The considerable variation in the radiosensitivities of various tissues is due, in part, to the differences in the sensitivities of the cells that compose the tissues. Also important in determining tissue sensitivity are such factors as the site of nourishment of the cell, interactions between various cell types within the tissue, and the ability of the tissue to repair itself.
The relatively high radiosensitivity of tissues consisting of undifferentiated, rapidly dividing cells suggests that, at the level of the human organism, a greater potential exists for damage to the fetus or young child than to an adult for a given dose. This has, in fact, been observed in the form of increased birth defects following irradiation of the fetus and an increased incidence of certain cancers in individuals who were irradiated as children.

**Human Health Effects**

The effects of ionizing radiation upon humans can be classified as being either stochastic, meaning random, or non-stochastic, meaning non-random.

**Stochastic Effects**

Stochastic effects are those that occur by chance. These effects consist primarily of cancer and genetic effects. As the dose to an individual increases, the probability that cancer or a genetic effect will occur also increases. However, at no time, even for high doses, is it certain that cancer or genetic damage will result. Similarly, for stochastic effects, there is no threshold dose below which it is relatively certain that an adverse effect cannot occur. In addition, because stochastic effects can occur in unexposed individuals, one can never be certain that the occurrence of cancer or genetic damage in an exposed individual is due to radiation exposure.

**Non-Stochastic Deterministic or Latent Effects**

Unlike stochastic effects, non-stochastic deterministic or latent effects are characterized by a threshold dose below which they do not occur. In addition, the magnitude of the effect is directly proportional to the size of the dose. Furthermore, for non-stochastic effects, there is a clear causal relationship between exposure and the effect. Examples of non-stochastic effects include sterility, erythema (skin reddening), and cataract formation. Each of these effects differs from the others in both its threshold dose and in the time over which this dose must be received to cause the effect (i.e., acute vs chronic exposure). Because cells contain a repair mechanism inherent to their biochemistry (repair enzymes), repair and recovery may occur when cells are exposed to sublethal doses of ionizing radiation. After irradiation, surviving cells begin to repopulate. This permits an organ that has sustained functional damage to regain some or more of its functional ability. *Research has shown that repeated radiation injuries have a cumulative effect. Hence a percentage (about 10%) of the radiation induced damage is irreparable, whereas the remaining 90% may be repaired one time.*
Factors Determining Health Effects

The occurrence of particular health effects from exposure to ionizing radiation is a complicated function of numerous factors including the size of the dose received, the rate at which dose was imparted, the specific tissues or parts of the body irradiated, and the type of radiation involved.

Dose vs. Dose Rate

Radiation effects in humans have been shown to be directly dependent upon the total dose received. For many types of effects, however, the rate at which a given dose is imparted has also been shown to be important. This has been particularly evident for non-stochastic effects. For example, a dose of 300 rads to the skin, given within one hour (an acute exposure), will likely exceed the threshold for erythema. If the same dose is spread over a period of five years (a chronic exposure), erythema will not occur. The most likely explanation for such results is that spreading the dose over longer periods allows cellular repair mechanisms sufficient time to operate, thus minimizing the effects of the radiation damage. This repair phenomenon is also believed to operate, to some extent, for stochastic effects such as cancer, although the current conservative philosophy is to assume that the risk of such effects depends solely on the total dose. In other words, for the previous example, the risk of skin cancer would be presumed to be identical in both exposure situations.

Portion of Body Irradiated

The effectiveness of a given dose of radiation in producing biological damage in humans is also dependent upon the portion of the body irradiated. This is due to the differences in the radiosensitivities of the various tissue types and organs within the body. For example, a given dose to the eye is more likely to result in an adverse health effect than is the same dose to the hand. Similarly, a given dose to the whole body has a greater potential for causing an adverse health effect than does the same dose to only a portion of the body.

Dose Equivalent

Although the biological effects of radiation are dependent upon the absorbed dose, some types of ionizing radiation produce greater effects than others for the same amount of energy imparted. For example, for equal absorbed doses, alpha particles may be 20 times as damaging as beta particles or gamma rays. In order to account for these variations when describing human health risk from radiation exposure, the quantity, dose equivalent, is used. This is the absorbed dose multiplied by certain “quality” (Q) and “modifying” factors indicative of the relative biological damage potential of the particular type of radiation. The special unit for dose equivalent is in the rem. The SI unit for dose equivalent is the sievert (Sv). The relationship of the units to those of absorbed dose is as follows:

\[
1 \text{ gray} = 100 \text{ rad} \quad 1 \text{ sievert} = 100 \text{ rem} \quad 1 \text{ rem} = 1 \text{ rad} \times Q \\
1 \text{ sievert} = 1 \text{ gray} \times Q
\]

For gamma and x-ray exposures and for most beta particle exposures, the numerical value of the rem or sievert is essentially equal to that for the rad or gray, respectively. That is, for gamma and x-rays, and for most beta particle exposures, Q = 1.

Radiation Risk

The risk estimates of cancer or genetic effects from low doses of radiation are based upon conservative extrapolation of the risks associated with high doses. This is due to the fact that the risk is too small to determine meaningful experimental numbers using only low dose data.

In an average group of 10,000 people, we can expect about 1,833 to eventually die from cancer. A report from the National Research Council (NRC) has stated that, if 10,000 workers were to each receive a radiation dose of 1 rem in a single exposure, we could estimate that 8 of those 10,000 will eventually die from cancer due to that radiation exposure. Thus, a single dose of 1 rem is seen to increase the risk of death due to cancer from 18.33% to 18.41%.

Another way of expressing the risk from exposure to radiation is by computing the average number of days of life expectancy lost due to various doses. These values can then be compared to life expectancy losses computed for other activities. (Table 3). The estimates in Table 3 indicate that the health risks from occupational radiation exposure are no greater than the risks associated with many other activities and events encountered in life. It is also important to note that the average occupational exposure resulting from the types and quantities of radioactive materials used in typical research labs or
from the commonly used x-ray systems is much less than the 1 rem/ year indicated in the table.

<table>
<thead>
<tr>
<th>Health Risks</th>
<th>Estimates of Days of Life Expectancy Lost, Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smoking 20 cigarettes/day</td>
<td>2410 (6.6 years)</td>
</tr>
<tr>
<td>Overweight (by 20%)</td>
<td>366 (1.0 years)</td>
</tr>
<tr>
<td>Alcohol consumption (U.S. average = 2.54 gal. ethanol)</td>
<td>365 (1.0 years)</td>
</tr>
<tr>
<td>Dangerous jobs - accidents (such as farming or heavy industry)</td>
<td>300</td>
</tr>
<tr>
<td>Auto accidents</td>
<td>207</td>
</tr>
<tr>
<td>Home accidents</td>
<td>74</td>
</tr>
<tr>
<td>Safest jobs (such as teaching)</td>
<td>30</td>
</tr>
<tr>
<td>Smoke alarm in home</td>
<td>-10</td>
</tr>
<tr>
<td>Natural background radiation, calculated</td>
<td>8</td>
</tr>
<tr>
<td>Medical x-rays (U.S. average), calculated</td>
<td>6</td>
</tr>
<tr>
<td>All catastrophes (earthquake, etc.)</td>
<td>3.5</td>
</tr>
<tr>
<td>0.1 rem/yr for 30 years, calculated</td>
<td>9.9</td>
</tr>
<tr>
<td>1 rem/yr for 30 years, calculated</td>
<td>5</td>
</tr>
<tr>
<td>1 mrem occupational dose, calculated</td>
<td>.001</td>
</tr>
</tbody>
</table>

F. Human Exposure to Ionizing Radiation

Sources of Exposure

Human exposures to ionizing radiation can be classified broadly according to whether they result from sources within the work environment (occupational exposures) or from sources outside the work environment (non-occupational exposures).

Occupational Exposures

Occupational exposures are those received by individuals as a result of working with or near radioactive material or radiation-producing devices as an employee or for an employer. Occupational exposures differ from non-occupational exposures in that they are generally received during the course of a 40-hour work week as opposed to a 168-hour week for natural exposures. In addition, whereas the non-occupational exposure received by a given individual is largely unknown, an individual's occupational exposure is closely monitored and controlled.

Non-Occupational Exposures

Non-occupational exposures can be divided into one of two categories: those originating from natural sources and those resulting from man-made sources.

All individuals are continuously exposed to ionizing radiation from various natural sources. These sources include cosmic radiation and naturally occurring radionuclides within the environment and within the human body. The radiation levels resulting from natural sources are collectively called “natural background.” Natural background exposure (and the associated dose it imparts) varies considerably from one location to another in the United States. Historically, the estimated value for the average whole body dose equivalent from natural background in the U.S. has been about 100 mrem/person/year. More recently, this figure has been revised upward to between 250 to 300 mrem/person/year to account for the dose contribution from indoor radon. (Chart 1, Table 4)

The primary source of artificial radiation exposures is medical irradiation, particularly diagnostic x-ray and nuclear medicine procedures. Such procedures contribute an average of about 55 mrem/person/year in the United States. All other sources of exposures to man-made produced ionizing radiation such as nuclear weapons fallout, nuclear power plant operations, and the use of radiation sources in industry and universities contribute an average of less than one mrem/person/year in the United States. The following table shows the yearly dose from the various non-
occupational sources for the average person in the United States.

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DOSE in mrem/yr</th>
<th>DOSE in msievert/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>radon</td>
<td>200</td>
<td>2.00</td>
</tr>
<tr>
<td>cosmic rays</td>
<td>28</td>
<td>0.28</td>
</tr>
<tr>
<td>terrestrial radiation</td>
<td>28</td>
<td>0.28</td>
</tr>
<tr>
<td>radioactivity in body</td>
<td>39</td>
<td>0.39</td>
</tr>
<tr>
<td>x-rays (diagnostic)</td>
<td>39</td>
<td>0.39</td>
</tr>
<tr>
<td>nuclear medicine</td>
<td>14</td>
<td>0.14</td>
</tr>
<tr>
<td>consumer products</td>
<td>10</td>
<td>0.10</td>
</tr>
<tr>
<td>occupational</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>miscellaneous</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>360</strong></td>
<td><strong>3.60</strong></td>
</tr>
</tbody>
</table>

From NCRP 1987 report # 93

**Routes of Exposure**

There are two principal routes by which humans are exposed to ionizing radiation, external and internal. Since x-ray exposure only involves external sources, we only discuss external exposures.

**External Exposures**

External exposures are those that are due to sources located outside of the body that emit radiation of a type and energy sufficient to reach and penetrate the body. Examples of penetrating radiations include gamma rays, x-rays, and high-energy beta particles.

As with all radiation exposures, the size of the dose resulting from an external exposure is a function of:

1. the strength of the source
2. the distance from the source to the tissue being irradiated
3. the duration of the exposure

In contrast to the situation for internal exposures, these factors can be altered for a particular external exposure situation with a resultant modification of the dose received.

**Exposure Limits**

Concern over the biological effects of ionizing radiation began shortly after the discovery of x-rays in 1895. From that time to the present,
numerous recommendations regarding occupational exposure limits have been proposed and modified by various radiation protection groups, the most important being the International Commission on Radiological Protection (ICRP). These guidelines have, in turn, been incorporated into regulatory requirements for controlling the use of materials and devices emitting ionizing radiation.

**Basis of Guidelines**

In general, the guidelines established for radiation exposure have had as their principal objectives: (1) the prevention of acute radiation effects (e.g., erythema, sterility, etc.); and (2) the limiting of the risks of late stochastic effects (e.g., cancer and genetic damage) to “acceptable” levels. Numerous revisions of standards and guidelines have been made over the years to reflect both changes in the understanding of the risk associated with various levels of exposure and changes in the perception of what constitutes an “acceptable” level of risk. The current annual occupational dose limits have been established at a level where the risk of death from radiation-induced cancer should not exceed the risk of accidental death to an average worker in a safe, non-nuclear industry.

Current guidelines for radiation exposure are based upon the conservative assumption that there is no safe level of exposure. In other words, even the smallest exposure is assumed to have some probability of causing a delayed effect such as cancer or genetic damage. This assumption has led to the general philosophy of not only keeping exposures below recommended levels or regulatory limits, but of also maintaining all exposures “as low as is reasonably achievable” (ALARA). ALARA for x-ray devices means using all appropriate shielding such as leaded aprons or portable shields, not bypassing interlocks, keeping the machine secure from unauthorized users, and use of dosimetry. This is a fundamental tenet of current radiation safety practice and is a regulatory requirement to be followed by all occupational users of radioactive materials and radiation producing devices.

**Regulatory Limits for Occupational Exposure**

Many of the recommendations of the ICRP and other radiation protection groups regarding radiation exposure have been incorporated into regulatory requirements by various countries. In the United States, annual radiation exposure limits are found in Title 10, Part 20 of the Code of Federal Regulations (10CFR20), or equivalent state regulations. These limits are based on external, internal, and external plus internal exposures. The definitions of the various types of dose are given below.
External Dose

Shallow-Dose Equivalent (SDE) is the external dose to the skin of the whole-body or extremity from an external source of ionizing radiation. This value is the dose equivalent at a tissue depth of 0.007 cm. (7 mg/cm²) averaged over an area of 10 cm².

Eye Dose Equivalent (LDE) is the dose equivalent to the lens of the eye from an external source of ionizing radiation. This value is the dose equivalent at a tissue depth of 0.3 cm. (300 mg/cm²).

Deep Dose Equivalent (DDE) is the external whole-body dose from an external source of ionizing radiation. This value is the dose equivalent at a tissue depth of 1 cm. (1000 mg/cm²).

Table 5 provides a summary of the current annual occupational dose limits. ALARA is also part of the dose restrictions.

### Annual occupational dose limits for adult workers

<table>
<thead>
<tr>
<th>Limit</th>
<th>Sievert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow Dose Equivalent, Whole-body</td>
<td>50 rem</td>
</tr>
<tr>
<td>Shallow Dose Equivalent, Max. Extremity</td>
<td>50 rem</td>
</tr>
<tr>
<td>Eye Dose Equivalent, Lens of the Eye</td>
<td>15 rem</td>
</tr>
<tr>
<td>Total Organ Dose Equivalent</td>
<td>50 rem</td>
</tr>
<tr>
<td>Total Effective Dose Equivalent</td>
<td>5 rem</td>
</tr>
</tbody>
</table>

Iowa Administration Code 641-40.15

### Regulatory Dose Limits to Declared Pregnant Workers

Because of the increased susceptibility of the human embryo and fetus to damage from ionizing radiation, the National Council on Radiation Protection and Measurement (NCRP) recommends that the whole-body radiation dose received by a female worker during the nine months of her pregnancy not exceed 500 mrem (10 percent of the annual occupational dose limit). The NRC has published Regulatory Guide 8.13 that details potential health risks of prenatal exposures and suggests precautions and options for the pregnant worker. Copies of Regulatory Guide 8.13 may be obtained from EH&S.

Federal and state regulatory agencies have adopted the NCRP recommendations. However, the regulations only apply when a worker voluntarily declares her pregnancy to her employer in writing. If a declaration of pregnancy is made, the worker grants consent to her employer to limit her dose to a TEDE of 500 mrem throughout the entire pregnancy. If no declaration is made to
the employer, her occupational dose limits are not restricted. A declaration can be revoked by the pregnant worker at any time.

A Declaration of Pregnancy can be sent to the Radiation Safety Officer (RSO) in writing.

**Regulatory Limits for Dose to an Embryo/Fetus**

The dose to the embryo/fetus during the entire pregnancy, due to occupational exposure of a declared pregnant worker, must not exceed 500 mrem. The dose will be the sum of (1) the deep dose equivalent (DDE) to the declared pregnant worker and (2) the dose to the embryo/fetus from radionuclides within the embryo/fetus and the declared pregnant worker. The records of dose for the embryo/fetus will be permanently maintained in the declared pregnant worker’s dosimetry files.

**Regulatory Limits for Minors**

A minor is anyone under 18 years of age. The occupational dose limits for minors are 10% of any annual occupational dose limit specified for adult workers in Table 5 of this guide.

**Regulatory Limits for Dose to Individual Members of the Public**

In general, the limits for dose to non-radiation workers and members of the public are 2 percent of the annual occupational dose limits. For the whole body dose, this would equal a TEDE of 100 mrem/year. This would be in addition to the 300 mrem/year received, on average, by individuals in the United States from natural background radiation and the 55 mrem/person/yr. received from man-made sources such as medical x-rays, nuclear medicine, etc.
Glossary

Absorbed Dose the amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose is the Rad, which is 100 ergs/gram.

Absorption the phenomenon by which radiation imparts some or all of its energy to any material through which it passes.

Acute Exposure the absorption of a relatively large amount of radiation (or intake of radioactive material) over a short period of time.

Acute Health Effects prompt radiation effects (those that would be observable within a short period of time) for which the severity of the effect varies with the dose, and for which a practical threshold exists.

Adult an individual 18 or more years of age.

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

Atom smallest particle of an element that is capable of entering into a chemical reaction.

Attenuation the process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux density of the beam when projected through matter.

Background Radiation ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

Bremsstrahlung electromagnetic (x-ray) radiation produced by the deposition of charged particles in matter. Secondary photon radiation (x-ray) produced by the deceleration of charged particles through matter.

Calibration determination of variation from standard, or accuracy, of a measuring instrument to ascertain necessary correction factors. The check or correction of the accuracy of a measuring instrument to assure proper operational characteristics.

Chronic Exposure the absorption of radiation (or intake of radioactive materials) over a long period of time, i.e., over a lifetime.

Committed Effective Dose Equivalent the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

Controlled Area an area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason.
Declared Pregnant Worker a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Deep Dose Equivalent applies to external whole-body exposure and is the dose equivalent at a tissue depth of one centimeter (1000 mg/cm²).

Delayed Health Effects radiation health effects which are manifested long after the relevant exposure. The vast majority are stochastic, that is, the severity is independent of dose and the probability is assumed to be proportional to the dose, without threshold.

Dose or Radiation Dose a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent, as defined in other paragraphs of this section.

Dose Equivalent the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and the sievert (Sv). The ICRP defines this as the equivalent dose, which is sometimes used in other countries.

Dose Rate the radiation dose delivered per unit of time. Measured, for example, in rem per hour.

Dosimeter a portable instrument for measuring and registering the total accumulated exposure to ionizing radiation. (see dosimetry.)

Dosimetry the theory and application of the principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with the use of various types of radiation instruments with which measurements are made (see film badge; thermoluminescent dosimeter; Geiger-Mueller counter).

Effective Dose Equivalent the sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

Electromagnetic Radiation a traveling wave motion resulting from changing electric and magnetic fields. Familiar electromagnetic radiations range from x-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wavelength. All electromagnetic radiations travel in a vacuum with the velocity of light (see photon).

Electron Volt a unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Abbreviated eV. X-ray energy is typically measured in keV. (thousand electron volts). One electron volt is 1.602 X E-12 erg.

Exposure (1) Being exposed to ionizing radiation or radioactive material. (2) a measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the Roentgen.

External Dose that portion of the dose equivalent received from radiation sources outside the body.

Extremity hand, elbow, arm below the elbow, foot, knee, or leg below the knee.

Eye Dose Equivalent applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeter (300 mg/cm²).

Geiger-Mueller (G-M) Counter a radiation detection and measuring instrument. It consists of a gas-
filled tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation.

**Gray** The international (SI) unit of absorbed dose in which the energy deposited is equal to one Joule per kilogram (1 J/kg).

**Half Value Layer** the thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

**Health Physics** a term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation. The science concerned with the recognition, evaluation and control of health hazards from ionizing and non ionizing radiation.

**High Radiation Area** an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in one hour at thirty centimeters from the radiation source or from any surface that the radiation penetrates.

**Inverse Square Law** the intensity of radiation at any distance from a point source varies inversely as the square of that distance. For example: if the radiation exposure is 100 Rem/hr at 1 inch from a source, the exposure will be 0.01 Rem/hr at 100 inches.

**Ionization** the process by which a neutral atom or molecule acquires either a positive or a negative charge.

**Ionization Chamber** an instrument designed to measure the quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

**Ionizing Radiation** alpha particles, beta particles, gamma rays, x-rays, neutrons, high speed electrons, high speed protons, and other particles or electromagnetic radiation capable of producing ions.

**Limits** the permissible upper bounds of radiation exposures, contamination or releases.

**Millirem** (mrem) a sub multiple of the Rem equal to one-thousandth (1/1000th) of a Rem. (see Rem)

**Minor** an individual less than 18 years of age, as pertains to radiation exposure limits, who works with radioactive materials (not a member of the general public).

**Monitoring** the measurement of radiation levels, and the use of the results of these measurements to evaluate potential exposures and doses.

**Natural Radiation** ionizing radiation, not from manmade sources, arising from radioactive material other than the one directly under consideration. Natural radiation due to cosmic rays, soil, natural radiation in the human body and other sources of natural radioactivity are always present. The levels of the natural radiation vary with location, weather patterns and time to some degree.

**Occupational Dose** the dose received by an individual in the course of employment in which the individual’s assigned duties involve exposure to radiation or to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.
Particle Accelerator any machine capable of accelerating electrons, protons, deuterons, or other charged particles in a vacuum and of discharging the resultant particulate or other radiation into a medium at energies usually in excess of 1 MeV.

Personnel Monitoring Badge a packet of photographic film, thermoluminescent material or other passive systems used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or more detection elements of differing sensitivity, and it may contain filters to aid in determining the types of radiation and the energy.

Photon a quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.

Pocket Dosimeter a small ionization detection instrument that indicates radiation exposure directly. An auxiliary charging device is usually necessary.

Principal Investigator (PI) a faculty member, assistant professor or higher (no visiting faculty), appointed by the licensee, who has been approved through the Radiation Safety Committee for the purchase and use of radioactive materials or an x-ray device.

Protective Barriers barriers of radiation absorbing material, such as lead, concrete, plaster and plastic, that are used to reduce radiation exposure.

Public Dose the dose received by a member of the public from exposure to radiation and to radioactive material released by a licensee, or to another source of radiation. It does not include occupational dose or doses received from background radiation, as a patient from medical practices, or from voluntary participation in medical research programs.

Quality Factor (QF) a modifying factor that is used to derive dose equivalent from absorbed dose. It corrects for varying risk potential due to the type of radiation.

Rad the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram.

Radiation Area an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in one hour at thirty centimeters from the radiation source or from any surface that the radiation penetrates.

Radiation Worker an individual who uses radioactive materials or x-ray equipment under the licensee’s control. Individuals must be trained and have passed a radiation safety examination prior to beginning work with radioactive materials or x-ray equipment.

Radiography the making of shadow images on photographic film by the action of ionizing radiation.

Radiology that branch of medicine dealing with the diagnostic and therapeutic applications of radiant energy, including x-rays and radioisotopes.

Radiosensitivity the relative susceptibility of cells, tissues, organs, organisms, or other substances to the injurious action of radiation.

Relative Biological Effectiveness for a particular living organism or part of an organism, the ratio of the absorbed dose of a reference radiation that produces a specified biological effect to the absorbed dose of the radiation of interest that produces the same biological effect.

Rem the special unit of dose equivalent. The dose equivalent in rem is numerically equal to the absorbed
dose in rads multiplied by the quality factor, distribution factor, and any other necessary modifying factors.

**Restricted Area** an area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. Restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be set apart as a restricted area.

**Roentgen (R)** the quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 gram of dry air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. Amount of energy is equal to 2.58 x 10-4 coulombs/kg air. The Roentgen is a special unit of exposure.

**Shallow Dose Equivalent** applies to the external exposure of the skin or an extremity and is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7 mg/cm²) averaged over an area of ten square centimeters.

**Shielding Material** any material which is used to absorb radiation and thus effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, water and plastic are examples of commonly used shielding material.

**Sievert** The international unit (SI) of dose equivalent (DE, human exposure unit), which is equal to 100 rem. It is obtained by multiplying the number of grays by the quality factor, distribution factor, and any other necessary modifying factors.

**Somatic Effects** radiation effects of radiation limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent unexposed generations.

**Stochastic Effects** health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

**Survey** an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present.

**Terrestrial Radiation** the portion of the natural radiation (background) that is emitted by naturally occurring radioactive materials in the earth.

**Thermoluminescent Dosimeter (TLD)** crystalline materials that emit light if heated after being exposed to radiation.

**Very High Radiation Area** an area accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in one hour at one meter from a radiation source or from any surface that the radiation penetrates.

**Whole Body** for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knee.

**X-rays** penetrating electromagnetic radiations having wavelengths shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and those
originating in the extranuclear part of the atom as x-rays. These rays are sometimes called Roentgen rays after their discoverer, W.C. Roentgen.
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