Radiation Safety Manual

Laboratory Safety Policies and Procedures

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Radiation Safety: Abbreviations and Definitions

- ***Absorbed dose*** means the energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the rad and the gray (Gy).
- ***ALARA*** (acronym for "as low as is reasonably achievable") means making every reasonable effort to maintain exposures to radiation as far below the dose limits in this part as is practically 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.
- ***Alpha Particles***- An alpha particle is two protons bound to two neutrons and the equivalent of the nucleus of a helium atom.
- ***Background radiation*** means radiation from cosmic sources; naturally occurring radioactive material, including radon (except as a decay product of source or special nuclear material); and global fallout as it exists in the environment from the testing of nuclear explosive devices or from past nuclear accidents such as Chernobyl that contribute to background radiation and are not under the control of the licensee. "*Background radiation*" does not include radiation from source, byproduct, or special nuclear materials regulated by the Commission.
- ***Beta Particles***- A beta particle is much smaller than a proton (identical to an electron) but can be negatively charged (negatron) or positively charged (positron).
- ***Bioassay*** The determination of kinds, quantities, or concentrations and, in some cases, locations of radioactive material in the human body, whether by direct measurement (in vivo counting) or by analysis and evaluation of materials excreted or removed (in vitro) from the human body.
- ***Committed Effective Dose Equivalent (CEDE)***- A measure of the probabilistic health effect on an individual as a result of an intake of radioactive material into the body.
- ***Declared pregnant woman*** means a woman who has voluntarily informed the licensee, in writing, of her pregnancy and the estimated date of conception. The declaration remains in effect until the declared pregnant woman withdraws the declaration in writing or is no longer pregnant.

- ***Dose* or *radiation dose*** is 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.
- ***Exposure, radiation*** describes the amount of radiation traveling through the air.
- ***Half-life*** is the length of time it takes for half the remaining atoms in a quantity of a particular radioactive element to decay.
- ***Individual monitoring*** means—
  (1) The assessment of dose equivalent by the use of devices designed to be worn by an individual.
  (2) The assessment of committed effective dose equivalent by bioassay (see Bioassay) or by determination of the time-weighted air concentrations to which an individual has been exposed, i.e., DAC-hours; or
  (3) The assessment of dose equivalent by the use of survey data.
- ***Individual monitoring*** *devices* (individual monitoring equipment) means devices designed to be worn by a single individual for the assessment of dose equivalent such as film badges, thermoluminescence dosimeters (TLDs), pocket ionization chambers, and personal ("lapel") air sampling devices.
- ***Limits*** (dose limits) means the permissible upper bounds of radiation doses.
- ***Monitoring*** (radiation monitoring, radiation protection monitoring) means the measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses.
- ***NRC*** means the Nuclear Regulatory Commission or its duly authorized representatives.
- ***Occupational dose*** means 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 doses received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released under § 35.75, from voluntary participation in medical research programs, or as a member of the public.
- ***Quarter*** means a period of time equal to one-fourth of the year observed by the licensee (approximately 13 consecutive weeks), providing that the beginning of the first quarter in a year coincides with the starting date of the year and that no day is omitted or duplicated in consecutive quarters.
- ***Radioactivity*** A general term for the process by which an atom with excess energy in its nucleus emits particles and energy to regain stability.
- ***Radiation*** (ionizing radiation) means alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation, as used in this part, does not include non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light.
- ***Somatic Effects of Radiation*** Effects of radiation limited to the exposed individual, as distinguished from genetic effects, that may also affect subsequent unexposed generations.
- ***Target Theory*** is the concept of radiation damage resulting from discrete and random events.

Units of Radiation Dose

- *Coulombs per Kilogram (C/Kg)* equal to an electrical charge of 1 C produced in a kilogram of dry air by ionizing radiation. An exposure of 1 C/kg= 3.88 x 10^3 R.
- *Gray* (Gy) is the SI unit of absorbed dose. One gray is equal to an absorbed dose of 1 Joule/kilogram (100 rads).
- *Rad* is the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 joule/kilogram (0.01gray).
- *Rem* is the special unit of any of the quantities expressed as dose equivalent. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor (1 rem=0.01 sievert).
- *Roentgen (R)* A unit of exposure to ionizing radiation. It is the amount of gamma or x-rays required to produce ions resulting in a charge of 0.000258 coulombs/kilogram of air under standard conditions. Named after Wilhelm Roentgen, the German scientist who discovered x-rays in 1895.
- *Sievert* is the SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sieverts is equal to the absorbed dose in grays multiplied by the quality factor (1 Sv=100 rems).

Regulatory Authority

AHU follows all federal and state-level radiation safety regulations from the following regulatory authorities:

Nuclear Regulatory Commission (NRC)

The Commission is responsible for licensing and regulating nuclear facilities and materials and for conducting research in support of the licensing and regulatory process, as mandated by the Atomic Energy Act of 1954, as amended; the Energy Reorganization Act of 1974, as amended; and the Nuclear Nonproliferation Act of 1978; and in accordance with the National Environmental Policy Act of 1969, as amended, and other applicable statutes. These responsibilities include protecting public health and safety, protecting the environment, protecting and safeguarding nuclear materials and nuclear power plants in the interest of national security, and assuring conformity with antitrust laws. Agency functions are performed through standards setting and rulemaking; technical reviews and studies; conduct of public hearings; issuance of authorizations, permits, and licenses; inspection, investigation, and enforcement; evaluation of operating experience; and confirmatory research. The Commission is composed of five members, appointed by the President and confirmed by the Senate. (Commission, 2020)

Florida Department of Health

The radiation machine program works to reduce exposure to workers and the public from machines that emit radiation for medical, scientific, educational, and industrial purposes. The program accomplishes this by:

- Stopping unauthorized uses and users,
- Preventing accidental or unintended exposures,
- Ending ineffective or inappropriate uses of radiation, and
- Reducing the amount of exposure needed to accomplish the task.

(Health, 2019)

Fundamentals of Electromagnetic Radiation

Ionizing Radiation

The NRC (2020) defines ionizing radiation as alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. For the purposes of this manual, non-ionizing radiation will not be discussed (including radio- or microwaves, or visible, infrared, or ultraviolet light). All forms of electromagnetic radiation are organized and represented on a spectrum called the electromagnetic spectrum. (See appendix figure 1)

Particulate Radiation

This form of radiation originates in a process called radioactivity or radioactive decay in which an atom with excess energy in its nucleus emits particles and energy to regain stability. In this process, two particles are emitted from the atom (Johnston & Fauber, 2020):

- ***Alpha Particles***- An alpha particle is two protons bound to two neutrons and the equivalent of the nucleus of a helium atom.
  - The positively charge particle (+2) is readily attracts free electrons, thereby becoming a neutral helium atom very quickly
  - For this reason, alpha particles have low penetrating power and a very small range (a few centimeters in air)
  - Although, this particle cannot penetrate the skin, it is hazardous when inside the body.
  - Examples include uranium-238 and radium-223
- ***Beta Particles***- A beta particle is much smaller than a proton (identical to an electron) but can be negatively charged (negatron) or positively charged (positron).
  - Have a mass of $9.10938356 \times 10^{-31}$ kilograms
  - Can penetrate up to 2 cm of tissue.
  - Larger range and may ionize atoms along their path of travel
  - Like the alpha particle, it is hazardous when inside the body.
  - Examples include lead-210, bismuth-214, thallium-206, potassium-40

A radioactive substance does not suddenly decay all at once. Decay is a process that may last minutes or billions of years. The term used to describe the rate at which a radioactive substance decays is *half-life* (Johnston & Fauber, 2020).

Sources of Radiation

Natural Background (Environmental) Source

- **Cosmic Radiation**- A source of natural background radiation, which originates in outer space and is composed of penetrating ionizing radiation (both particulate and electromagnetic). The sun and stars send a constant stream of cosmic radiation to Earth, much like a steady drizzle of rain. Differences in elevation, atmospheric conditions, and the Earth's magnetic field can change the amount (or dose) of cosmic radiation that we receive. Secondary cosmic rays, formed by interactions in the Earth's atmosphere, account for about 45 to 50 millirem of the 360 millirem of background radiation that an average individual receives in a year (Commission, 2020).
- **Terrestrial**- Radioactive material found in soil, water, plants, radioactive Radon
- **Internal**- Inhaled radioactive Radon, ingested radioactive Potassium (Potassium-40), etc.

Natural sources account for 50% of the public's exposure to ionizing radiation, averaging 310 millirem (0.31 rem)

Electronic Radiation Sources

Equipment designed to produce x-rays, electrically heat a filament to produce a space-charge, comprising free electrons, via the process of Thermionic Emission. The free electrons are accelerated through a potential difference towards an anode made of material with a high atomic number. Through the slowing or stopping of the electrons, radiation is emitted. These sources must be supplied with power to emit ionizing radiation and have the ability to terminate exposure.

Emission Spectrum

These forms of radiation sources produce two types of radiation:

- ***Bremsstrahlung radiation***- This type of radiation has a continuous range of energy levels and results from the slowing of an electron with kinetic energy, thus the broad translation of Bremsstrahlung to English, "braking radiation" or "deceleration radiation". In this interaction, an incident electron loses energy due to the electrostatic attraction of the electron to the positively charged nucleus of the target atom. There is no physical interaction, but the incident electron loses energy as it passes at a certain distance from the nucleus (see appendix figure 3).
- ***Characteristic Radiation***- This type of radiation has discrete (specific) energy levels that result from the elemental atom involved in the interaction. In this interaction, an electron with sufficient energy removes an inner-shell orbital electron, causing a "characteristic cascade as outer-shell orbital electrons release energy to fill the voids left in this interaction (see appendix figure 2).

Overall, the energy spectrum of the radiation produced is continuous and ranges from near 0 to the keV equivalent of the voltage set by the operator.

Medical Equipment

- Diagnostic X-ray, fluoroscopic X-ray, and Computed Tomography machines.
- Portable X-ray
- Portable C-arm/O-arm
- Linear Accelerator and HDR Units (Radiation Oncology)

Radioactive Materials

These materials are elements that are composed of atoms with unstable nuclei that continually decay over a defined period of time. The rate of time at which a radioactive substance decays is called the ***half-life***. This is defined as the length of time it takes for half the remaining atoms in a quantity of a particular radioactive element to decay (Johnston & Fauber, 2020). These sources are heavily monitored and regulated for the following reasons:

  - They produce constant ionizing radiation
  - They also present a contamination risk

- These materials are mostly found in the form of radiopharmaceuticals in departments such as:
  - Nuclear Medicine
  - Nuclear Cardiology
  - PET
  - Radiation Oncology

Radiation Exposure and Contamination

Interactions with Matter

Interactions between ionizing radiation and matter occur at the atomic level due to the high frequency and low wavelength of the EMR. Ionizing radiation can transfer a portion or all of its energy to an orbital electron, thereby, overcoming the binding energy to the nucleus of the atom, and removing the electron. Although all medical imaging methods deposit some form of energy in the patient's body (Sprawls, 1993), the ability of radiation to ionize the atom should be given special attention during diagnostic examinations.

X-rays can have the following interactions with atoms (see appendix, fig. 4):

1. **No interaction**- The x-ray passes by the atom and does not deposit any energy.
2. **Absorption**- Photoelectric absorption occurs when the x-ray transfers all energy to an orbital electron and that electron is ejected from the orbital shell becoming a photoelectron.

3. **Scatter**- Depending on the frequency of the incident x-ray, a scattering interaction will involve an outer-shell orbital electron or the entire atom.
    a. Also known as Compton scatter, this interaction occurs when a higher-energy x-ray interacts directly with an outer-shell orbital electron and only transfers a portion of its initial energy to the electron. The x-ray photon deflects off the electron, retaining a significant portion of its initial energy with the potential to undergo further interactions. The outer-shell electron, now with increased energy, has the ability to overcome the binding energy of the outer shell and leaves the atom as a recoil electron with, with enough energy to undergo further ionizing interactions.
    b. Also known as Classical or Unmodified or Rayleigh scattering, this interaction occurs with low-energy photons and involves excitation of all or some of the atom's electrons. As the frequency is so low, the atom as a whole is excited causing oscillation of the orbital electrons. The oscillations of all the electrons combine to form a single scattered photon of equal wavelength to the original incident photon with a different direction.

The electrons freed from the atoms in these interactions deposit energy on a continual basis.

Biologic Damage Potential

The biologic damage to the tissues from ionizing radiation is due to the transfer of energy and ejection of orbital electrons from the atoms. This molecular change can cause cellular damage or death. If excessive cellular damage occurs, the living organism will have a significant possibility of exhibiting genetic or somatic changes (Statkiewicz-Sherer et al., 2014).

Radiation Exposure

Radiation exposure occurs when an individual is in close proximity to a source of radiation and expresses the concentration of radiation delivered to a specific area, such as the surface of the human body. The level of radiation exposure can be described using the following various methods:

- ***Coulombs per Kilogram (C/kg)***- Equal to an electrical charge of 1 C produced in a kilogram of dry air by ionizing radiation. An exposure of 1 C/kg= 3.88×10^3 R.
- ***Air Kerma***- **K**inetic **E**nergy **R**eleased in a unit **M**ass (kilogram) of **A**ir and is express in metric units of joule per kilogram (J/kg). This is equal to the SI unit Gray (Gy). *Dose Area Product (DAP)* is also interconnected with air kerma as it is essentially the sum total of air kerma over the exposed area of the patient's surface. DAP is specified in units of mGy/cm^2.
- ***Absorbed Dose***- The amount of energy deposited in a volume per unit mass. Atomic number (Z), the mass density of the tissue (measured in kg/m^3), and the energy of the incident photon all govern the amount of energy absorbed.

- ***Surface Integral Dose (SID)***- The total amount of radiant energy transferred by ionizing radiation to the body during a radiation exposure. AKA- *exposure area product*. The traditional unit for SID is R-cm^2 and the equivalent SI unit for SID is Gy-m^2.
- ***Equivalent Dose (EqD)***- The product of the average absorbed dose in a tissue or organ in the human body and its associated *radiation weighting factor (W_R)* chosen for the type and energy of the radiation in question. Obtained with the following formula:

$$EqD = D \times W_R$$

- ***Effective Dose (EfD)***- The sum of the weighted equivalent doses for all irradiated tissues or organs. EfD is expressed in sieverts (Sv) or millisieverts (mSv). The EfD is obtained with the following formula:

$$EfD = D \times W_R \times W_T$$

- ***Collective Effective Dose (ColEfD)***- Used to describe radiation exposure of a population or group from low doses of different sources of ionizing radiation. It is determined as the product of the average EfD for an individual belonging to the exposed population or group and the number of persons exposed. The radiation unit for this quantity is *person-sievert.*
- ***Total Effective Dose Equivalent (TEDE)***- The sum of effective dose equivalent from external radiation exposures and a quantity called *committed effective dose equivalent (CEDE)* from internal radiation exposures.

**See Appendix, Figure 5 for Summary of Radiation Quantities and Units*

Radiation Dose- Why Worry About It?

Radiation can cause biologic damage on three levels:

- Molecular
- Cellular
- Organic

The most pressing concern associated with radiation exposure is the potential of damaging effects to DNA, the material that allows cells to reproduce and function. The affected locations in a cell or, more specifically, on a vital molecule within the cell are known as "targets". The probability that those locations are struck by radiation is a random process and evidence appears to demonstrate that producing serious damage usually requires more than one exposure on the specific target. This is known as ***target theory***. Generally, the more absorbed dose the higher probability of interaction with DNA. The effected cells may either die or be changed permanently.

- Most cells that die are easily replaced.
- Cells that are changed permanently may go on to produce abnormal cells that, when they divide, can become cancerous.

At lower absorbed doses, such as what we receive every day from background radiation, cells repair DNA damage rapidly.

AdventHealth Program Policies

AdventHealth Radiography Program Policies

Radiation Protection and Safety Guidelines

AdventHealth University and the Department of Imaging Sciences promote a safe learning environment for all students. In the Radiography Program, it is vital that students adhere to the guidelines set forth to maintain their safety in the laboratory and clinical environment.

The following rules have been established for your protection against ionizing radiation during laboratory and clinical education. Exposure to radiation always involves a risk of damage to DNA, resulting in cell damage or cell death. Although, as a diagnostic tool, the benefits of diagnosis of disease certainly outweigh the risk, students are not receiving this benefit. Therefore, these rules are established for the students' safety and must be strictly adhered to:

- At any time during activation of the x-ray tube (when x-rays are being generated), observation will be made from the protection of the control booth.
- Specifically, students must not hold or support a patient or phantom (lab setting) during exposure, nor will they hold or support an image receptor during exposure.
- During activation of the x-ray tube, students must not be in direct visual line with either tube or patient. Thus, they may not observe the patient during exposure from an adjacent room or hall unless through a lead glass protective window.
- During an exposure or procedure, do not place yourself in direct line with the central ray, even though you are wearing a lead apron, and even though a lead

shield is interposed between the tube and yourself. The tube must, in all cases, be pointing away from your body.

- Under no circumstances will students permit themselves or fellow students (or any other human being) to serve as "patients" for test exposures or experimentation.

- During fluoroscopic procedures and bedside radiography, students will remain in the room with the patient. The following will prevail:

    - A lead apron will be worn at all times, or you will remain behind a lead protective screen and not in visible line with either tube or patient.

    - Students must stand as far from the patient and tube as possible, consistent with the conduct of the examination.

- A radiation monitoring badge dated for the current wear period must be worn at all times in any environment where exposure to ionizing radiation is possible. This includes the Radiography Laboratory. When wearing a lead apron, the badge must be worn on the outside close to the neck region. Pregnant students must follow guidelines for the appropriate wearing of a fetal dosimeter as outlined in the AHU Radiography Pregnancy Policy.

Failure to comply with safe radiation protection practices is grounds for discipline and dismissal from the Radiography Program. The first instance of non-compliance with program and site-specific radiation safety policies will result in a written reprimand and the associated grade deductions (refer to the *A.S. Radiography Program Manual, Section 3)*. Instances of gross negligence of radiation safety policies will bypass written reprimand and result in immediate program dismissal with no possibility for re-admission.

Radiation Dose Limit Policy

All students enrolled in the Imaging Sciences programs must comply with keeping their radiation exposure as low as reasonably achievable (ALARA) according to the Nuclear Regulatory Commission (NRC). Students are expected to wear their monitoring device as instructed by program faculty.

- Loss or mishandling must be reported to faculty as soon as possible. A student who has lost their monitoring device will be assigned a spare to continue monitoring in the interim until their new quarterly dosimeter arrives. No student may attend clinicals without a radiation monitoring device. A student that loses their dosimeter may not attend clinicals until the spare dosimeter is obtained. This clinical time must be made up.

- Radiography students will receive new monitoring devices every quarter. Lost or late monitoring devices will incur a non-refundable $10.00 charge to the student's account. Students may not proceed to their clinical rotation until the dosimeter exchange has been completed (all missed clinical time must be made up). Extenuating circumstances may require a student to extend the dosimeter wear period and may only be approved by the Radiography faculty. Students may be subject to Program disciplinary standards for non-compliance.

ALARA Notifications

Doses must NOT exceed National Council on Radiation Protection and Measurements (NCRP) requirements. Should a monitor report indicate an exposure of 10%, 30%, or 100% of 1250 mrem per quarter or 5000 mrem per year or higher for a student, ALARA notifications are employed to officially document the ALARA event. These notifications fall into the following three classifications:

- **ALARA Level I: 125-374 mrem**
  - Email notification- No formal response is needed by the individual.
- **ALARA Level II: 375-1249 mrem**
  - An email notification with required written response/signature by the individual.
  - In-person interview/observation and written documentation.
- **ALARA Level III: >1250 mrem**
  - An email notification with required written response/signature by the individual.
  - In-person interview/observation and written documentation.

AdventHealth University students that fall into any of the three categories may require some or all of the following steps to be taken:

1. Notification of student of excessive dose
2. A conference will be held between the student, Radiation Safety Officer, Program Director and/or Clinical Coordinator.
3. Consultation with the certified medical physicist will determine an action plan to reduce future excessive exposure.

Any level II and III ALARA notifications and the associated procedures must be completed within four business days from the notification. Students failing to complete any or all parts of the ALARA notification process within the required period will be suspended from clinicals pending completion of the ALARA notification process.

Any student found to be practicing gross neglect of established program or site-specific radiation safety policies can be subject to program dismissal (refer to the *A.S. Radiography Program Manual, Section 3)*

Planned External Exposures

The goal of occupational radiation exposure monitoring programs (REMP) is to measure the most accurate occupational exposure level possible. Only by excluding any external background or medical exposure to ionizing radiation can a more precise estimate of a monitored individual's occupational exposure be made. Therefore, the following policy seeks to provide guidance to those monitored individuals who, as a patient themselves, will be exposed to any ionizing radiation as a result of diagnostic or therapeutic medical procedures.

- Students undergoing diagnostic imaging exams that utilize ionizing radiation may not wear their radiation dosimeter during the exam. Additionally, the dosimeter should remain outside the room during exposures made as a part of the exam.

- Students receiving radiotherapies (brachytherapy or systemic therapy) must provide official documentation from the ordering physician outlining the source or radionuclide used, the amount, the half-life, and the duration of isolation (if applicable), and other pertinent information.

The Process

- Although not required, it is recommended that the Radiation Safety Officer be notified of the upcoming therapy in advance. Students who wish to notify the faculty of their treatment will complete and sign the Voluntary Declaration of Radiotherapy form.

- Prior to the radiotherapy, a medical physicist will be consulted to establish a dosimetry plan to account for the significant planned external radiation exposure.

- If a student is required to isolate for any period of time, they will be required to turn in their dosimeter to avoid any external exposure that could be registered on the device until a physician clears their clinical return.

For student voluntarily disclosing their radiotherapy, failure to provide external exposure documentation may result in clinical suspension for up to 80 days or at least ten half-lives of the source or radionuclide.

Pregnancy Policy

The AHU Radiography Program adheres to the published Nuclear Regulatory Commission (NRC) standards regarding the requirements for monitoring external and internal occupational dose to a voluntarily-declared pregnant individual, including the appropriate courses of action once the declaration of pregnancy has occurred.

The NRC requires that occupationally exposed individuals ensure the dose equivalent to the embryo/fetus does not exceed 500 mrem or five mSv for the duration of the pregnancy

The Risk of Radiation Exposure during Pregnancy

It is important to note that radiation levels seen in a typical hospital radiation environment should not be high enough to cause any of the effects discussed below. In fact, none of the effects below have been documented at fetal exposures below 500 mrem, the regulatory limit for fetal exposure during pregnancy. However, having an accurate and timely exposure record for the assigned fetal badge will help to ensure that fetal exposure levels are kept within safe limits.

The potential risk of radiation exposure during pregnancy is related to both the time of radiation exposure and the amount of exposure. There are three distinct time periods during pregnancy with associated risks to radiation exposure: pre-implantation, organogenesis, and fetal development. These time periods and the radiation risks associated with them are discussed below.

Pre-implantation There is a grave misconception that the most critical time for irradiation is during the first two weeks when it is most unlikely that the expectant mother knows of her condition. In actuality, this is probably the safest time. The biologic response to radiation exposure during the first two weeks of pregnancy is reabsorption of the embryo, also known as spontaneous abortion. No other type of response is likely. One should not be concerned with the possibility of the induction of congenital abnormalities during the first two weeks of pregnancy, because such a response has not been demonstrated in experimental animals or humans following any exposure level.

Organogenesis The period from approximately the second week through the eighth week of pregnancy is called the period of major organogenesis. During this time, the major organ systems of the body are developing. If the radiation exposure is sufficient, congenital abnormalities can result. Early in this time interval, the most likely congenital abnormalities are associated with skeletal deformities. Later in this time period, neurologic deficiencies are more likely to occur.

Fetal Growth Stage
During the second and third trimesters of pregnancy, the responses previously noted are unlikely. There is a strong suggestion from the results of numerous investigations that if a response occurs following radiation exposure during the latter two trimesters, the only

response possible would be the appearance during childhood of malignant disease: leukemia or cancer. Malignant disease induction in childhood is also a possible response during the first trimester.
There are no other significant responses following radiation exposure during pregnancy.

Risks Associated with Each Time Period
As one might imagine, there is relatively little information at the human level to construct dose-response relationships for irradiation during pregnancy. There is, however, a large body of data from animal irradiation, particularly rats and mice, from which we can estimate such relationships. The Dose Dependence statements which follow are a combination of both human exposures to radiation, primarily from Japanese World War II Atomic Bomb Survivors, and extrapolation from other mammalian studies.
Again, it is important to note that radiation levels seen in a typical hospital radiation environment should not be high enough to cause any of the effects discussed below. In fact, none of the effects listed below have been documented at fetal exposures below 500 mrem, the regulatory limit for fetal exposure during pregnancy.

Spontaneous abortion following irradiation during the first two weeks of pregnancy is not likely to occur at radiation doses less than 250 mGy (25,000 mrad). The precise nature of the dose-response relationship is unknown, but a reasonable estimate of risk suggests that 0.1% of all conceptions would be reabsorbed following a dose of 100 mGy (10,000 mrad). One should keep in mind, however, that the incidence of spontaneous abortion in the absence of radiation exposure is estimated to be in the 25-50% range.

When assessing the risk of inducing congenital abnormalities, one should be aware that in the absence of radiation exposure, approximately 5% of all live births exhibit a manifest congenital abnormality. A 1% increase in congenital abnormalities is estimated to follow a 100 mGy (10,000 mrad) fetal dose and a proportionately lower increase at lower doses. The induction of a childhood malignancy following irradiation during pregnancy is difficult to assess. Risk estimates are even lower than those reported for spontaneous abortions and congenital abnormalities.

In Conclusion…
If ALARA concepts (time, distance, and shielding) are used, there should be very little concern for pregnant employees working in typical hospital radiation environments. Accurate and timely radiation monitoring will help confirm safe levels of radiation exposure. Again, if there are any questions or concerns not addressed in this document, please feel free to contact the AdventHealth Radiation Safety Office at 407-834-2210.

Procedures

- If declared to the Program Director, Clinical Coordinator, or RSO, the student will complete and sign the Voluntary Declaration of Pregnancy Form.
- It is further recommended that the pregnant student discuss her pregnancy and clinical education with her physician.

- Once the RSO has received a written declaration of pregnancy, the RSO will schedule a counseling session with the student as soon as possible, no longer than one week after declaration.
- The student will be provided REMP educational materials that discuss radiation monitoring of pregnant individuals in the clinical area of a Radiology Department.

Clinical Options

The student will be given the following options with regard to their clinical education:

Option 1:
Terminate the clinical education and continue the didactic (classroom) portion of the program. Lost clinical time will be made up after delivery. This may result in postponing graduation from the program.

Option 2:
Continue clinical rotations with no changes in the types of assignment (fluoro, portables, etc.).

Option 3:
Remain in all program courses and request special modifications related to the higher dose potential duties (e.g. portable imaging, surgery, fluoroscopy, etc.). The Clinical Coordinator and RSO will make the determinations for specific work area assignments during the pregnancy period, and each case will be handled on an individual basis.

Option 4:
The student may voluntarily withdraw from the program and apply for readmission at a later date so long as the duration of leave does not exceed 24 months (*reapplication does not guarantee readmission*).

The pregnant student will read and sign an election form indicating her choice. Their signature will attest to the fact that they have been given proper attention and understand the level of risk associated with their continued training if so chosen.

Supplying a Spare Fetal Badge and Ordering a Monthly Fetal Badge

Upon receiving the completed Voluntary Declaration of Pregnancy form, the student will be issued an additional radiation monitor.

Knowing How to Properly Exchange and Wear Fetal Badges

Fetal badges will be exchanged monthly. If, as common practice, the pregnant employee does not wear a protective lead apron, the employee shall always wear the radiation monitor at waist level at work to estimate dose to the fetus.

If, as common practice, the pregnant employee does wear a protective lead apron, the employee shall wear the assigned fetal radiation monitor at waist level under the lead apron to estimate dose to the fetus. The employee shall always wear their personal radiation monitor on the collar of the protective lead apron to estimate dose to the employee.

Students who do not wish to voluntarily disclose their pregnancy are assuming all risks associated and must continue through the program with no modifications.

At any time, the student has the right to submit a written Withdrawal of Declaration of Pregnancy to the Program Director and/or Clinical Coordinator.

AdventHealth Nuclear Medicine Program Policies

Radiation Protection and Safety

AdventHealth University and the Department of Imaging Sciences promote a safe learning environment for all students. In the Nuclear Medicine Technology Program, it is vital that students adhere to the guidelines set forth to maintain their safety in the clinical environment.

Radiation Protection Guidelines

1. A radiation monitoring body badge and ring badge must be worn during all clinical rotations. If your assigned badge is lost, please see AHU faculty for a spare badge. There is a **$10.00 fee** for the spare badge.

2. Wear protective clothing such as lab coats.

3. Wear disposable gloves when handling radioactive materials.

4. Monitor yourself for contamination before leaving the department.

5. Use syringe shields.

6. Do not eat, drink, smoke or apply cosmetics where radioactive materials are stored or used.

7. Do not store food or drink in areas where radioactive materials are stored or used.

8. Dispose of radioactive waste in designated receptacles.

9. Administer radiopharmaceuticals only under the direct supervision of a technologist.

10. Do not pipette by mouth.

Radiation Dose Limit Policy

All students enrolled in the Imaging Sciences programs must comply with keeping their radiation exposure as low as reasonably achievable (ALARA) according to the Nuclear Regulatory Commission (NRC). Students are expected to wear their monitoring device as instructed by program faculty.

- Loss or mishandling must be reported to faculty as soon as possible. A student who has lost their monitoring device will be assigned a spare to continue monitoring in the interim until their new quarterly dosimeter arrives. No student may attend clinicals without a radiation monitoring device. A student that loses their dosimeter may not attend clinicals until the spare dosimeter is obtained. This clinical time must be made up.

- Nuclear Medicine students will receive new monitoring devices every month. Lost or late monitoring devices will incur a non-refundable $7.00 charge to the student's account. Students may not proceed to their clinical rotation until the dosimeter exchange has been completed (all missed clinical time must be made up). Extenuating circumstances may require a student to extend the dosimeter wear period and may only be approved by the Nuclear Medicine faculty. Students may be subject to Program disciplinary standards for non-compliance.

ALARA Notifications

Doses must NOT exceed National Council on Radiation Protection and Measurements (NCRP) requirements. Should a monitor report indicate an exposure of 10%, 30%, or 100% of 1250 mrem per quarter or 5000 mrem per year or higher for a student, ALARA notifications are employed to officially document the ALARA event. These notifications fall into the following three classifications:

- **ALARA Level I: 125-374 mrem**
  - Email notification- No formal response is needed by the individual.
- **ALARA Level II: 375-1249 mrem**
  - An email notification with required written response/signature by the individual.
  - In-person interview/observation and written documentation.
- **ALARA Level III: >1250 mrem**

- An email notification with required written response/signature by the individual.
- In-person interview/observation and written documentation.

AdventHealth University students that fall into any of the 3 categories may require some or all of the following steps to be taken:

1. Notification of student of excessive dose
2. A conference will be held between the student, Radiation Safety Officer, Program Director and/or Clinical Coordinator.
3. Consultation with the certified medical physicist will determine an action plan to reduce future excessive exposure.

Any level II and III ALARA notifications and the associated procedures must be completed within four business days from the notification. Students failing to complete any or all parts of the ALARA notification process within the required period will be suspended from clinicals pending completion of the ALARA notification process.

<u>Any student found to be practicing gross neglect of established program or site-specific radiation safety policies can be subject to program dismissal</u>

Planned External Exposures

The goal of occupational radiation exposure monitoring programs (REMP) is to measure the most accurate occupational exposure level possible. Only by excluding any external background or medical exposure to ionizing radiation can a more precise estimate of a monitored individual's occupational exposure be made. Therefore, the following policy seeks to provide guidance to those monitored individuals who, as a patient themselves, will be exposed to any ionizing radiation as a result of diagnostic or therapeutic medical procedures.

- Students undergoing diagnostic imaging exams that utilize ionizing radiation may not wear their radiation dosimeter during the exam. Additionally, the dosimeter should remain outside the room during exposures made as a part of the exam.

- Students receiving radiotherapies (brachytherapy or systemic therapy) must provide official documentation from the ordering physician outlining the source or radionuclide used, the amount, the half-life, and the duration of isolation (if applicable), and other pertinent information.

The Process

- Although not required, it is recommended that the Radiation Safety Officer be notified of the upcoming therapy in advance. Students who wish to notify the faculty of their treatment will complete and sign the Voluntary Declaration of Radiotherapy form.

- Prior to the radiotherapy, a medical physicist will be consulted to establish a dosimetry plan to account for the significant planned external radiation exposure.

- If a student is required to isolate for any period of time, they will be required to turn in their dosimeter to avoid any external exposure that could be registered on the device until a physician clears their clinical return.

For student voluntarily disclosing their radiotherapy, failure to provide external exposure documentation may result in clinical suspension for up to 80 days or at least ten half-lives of the source or radionuclide.

Pregnancy Policy

The AHU Nuclear Medicine Program adheres to the published Nuclear Regulatory Commission (NRC) standards regarding the requirements for monitoring external and internal occupational dose to a voluntarily-declared pregnant individual, including the appropriate courses of action once the declaration of pregnancy has occurred.

The NRC requires that occupationally exposed individuals ensure the dose equivalent to the embryo/fetus does not exceed 500 mrem or five mSv for the duration of the pregnancy

The Risk of Radiation Exposure during Pregnancy

<u>It is important to note that radiation levels seen in a typical hospital radiation environment should not be high enough to cause any of the effects discussed below. In fact, none of the effects below have been documented at fetal exposures below 500 mrem, the regulatory limit for fetal exposure during pregnancy.</u> However, having an accurate and timely exposure record for the assigned fetal badge will help to ensure that fetal exposure levels are kept within safe limits.

The potential risk of radiation exposure during pregnancy is related to both the time of radiation exposure and the amount of exposure. There are three distinct time periods during pregnancy with associated risks to radiation exposure: pre-implantation, organogenesis, and fetal development. These time periods and the radiation risks associated with them are discussed below.

Pre-implantation There is a grave misconception that the most critical time for irradiation is during the first two weeks when it is most unlikely that the expectant mother knows of her condition. In actuality, this is probably the safest time. The biologic response to radiation exposure during the first two weeks of pregnancy is reabsorption of the embryo, also known as spontaneous abortion. No other type of response is likely. One should not be concerned with the possibility of the induction of congenital abnormalities during the first two weeks of pregnancy, because such a response has not been demonstrated in experimental animals or humans following any exposure level.

Organogenesis The period from approximately the second week through the eighth week of pregnancy is called the period of major organogenesis. During this time, the major organ systems of the body are developing. If the radiation exposure is sufficient, congenital abnormalities can result. Early in this time interval, the most likely congenital abnormalities are associated with skeletal deformities. Later in this time period, neurologic deficiencies are more likely to occur.

Fetal Growth Stage
During the second and third trimesters of pregnancy, the responses previously noted are unlikely. There is a strong suggestion from the results of numerous investigations that if a response occurs following radiation exposure during the latter two trimesters, the only response possible would be the appearance during childhood of malignant disease: leukemia or cancer. Malignant disease induction in childhood is also a possible response during the first trimester.
There are no other significant responses following radiation exposure during pregnancy.

Risks Associated with Each Time Period
As one might imagine, there is relatively little information at the human level to construct dose-response relationships for irradiation during pregnancy. There is, however, a large body of data from animal irradiation, particularly rats and mice, from which we can estimate such relationships. The Dose Dependence statements which follow are a combination of both human exposures to radiation, primarily from Japanese World War II Atomic Bomb Survivors, and extrapolation from other mammalian studies.
Again, it is important to note that radiation levels seen in a typical hospital radiation environment should not be high enough to cause any of the effects discussed below. In fact, none of the effects listed below have been documented at fetal exposures below 500 mrem, the regulatory limit for fetal exposure during pregnancy.

Spontaneous abortion following irradiation during the first two weeks of pregnancy is not likely to occur at radiation doses less than 250 mGy (25,000 mrad). The precise nature of the dose-response relationship is unknown, but a reasonable estimate of risk suggests that 0.1% of all conceptions would be reabsorbed following a dose of 100 mGy (10,000 mrad). One should keep in mind, however, that the incidence of spontaneous abortion in the absence of radiation exposure is estimated to be in the 25-50% range.

When assessing the risk of inducing congenital abnormalities, one should be aware that in the absence of radiation exposure, approximately 5% of all live births exhibit a manifest congenital abnormality. A 1% increase in congenital abnormalities is estimated to follow a 100 mGy (10,000 mrad) fetal dose and a proportionately lower increase at lower doses.

The induction of a childhood malignancy following irradiation during pregnancy is difficult to assess. Risk estimates are even lower than those reported for spontaneous abortions and congenital abnormalities.

In Conclusion…

If ALARA concepts (time, distance, and shielding) are used, there should be very little concern for pregnant employees working in typical hospital radiation environments. Accurate and timely radiation monitoring will help confirm safe levels of radiation exposure. Again, if there are any questions or concerns not addressed in this document, please feel free to contact the AdventHealth Radiation Safety Office at 407-834-2210.

Procedures

- If declared to the Program Director, Clinical Coordinator, or RSO, the student will complete and sign the Voluntary Declaration of Pregnancy Form.
- It is further recommended that the pregnant student discuss her pregnancy and clinical education with her physician.
- Once the RSO has received a written declaration of pregnancy, the RSO will schedule a counseling session with the student as soon as possible, no longer than one week after declaration.
- The student will be provided REMP educational materials that discuss radiation monitoring of pregnant individuals in the clinical area of a Radiology Department.

Clinical Options

The student will be given the following options with regard to their clinical education:

Option 1:

Terminate the clinical education and continue the didactic (classroom) portion of the program. Lost clinical time will be made up after delivery. This may result in postponing graduation from the program.

Option 2:

Continue clinical rotations with no changes in the types of assignment (fluoro, portables, etc.).

Option 3:

Remain in all program courses and request special modifications related to the higher dose potential duties (e.g. portable imaging, surgery, fluoroscopy, etc.). The Clinical Coordinator and RSO will make the determinations for specific work area assignments during the pregnancy period, and each case will be handled on an individual basis.

Option 4:

The student may voluntarily withdraw from the program and apply for readmission at a later date so long as the duration of leave does not exceed 24 months (*reapplication does not guarantee readmission*).

The pregnant student will read and sign an election form indicating her choice. Their signature will attest to the fact that they have been given proper attention and understand the level of risk associated with their continued training if so chosen.

Knowing How to Properly Exchange and Wear Fetal Badges

Fetal badges will be exchanged monthly. If, as common practice, the pregnant employee does not wear a protective lead-apron, the employee shall always wear the radiation monitor at waist level at work to estimate dose to the fetus.

If, as common practice, the pregnant employee does wear a protective lead-apron, the employee shall wear the assigned fetal radiation monitor at waist level under the lead-apron to estimate dose to the fetus. The employee shall always wear their personal radiation monitor on the collar of the protective lead-apron to estimate dose to the employee.

At any time, the student has the right to submit a written Withdrawal of Declaration of Pregnancy to the Program Director and/or Clinical Coordinator.

AdventHealth Doctor of Nurse Anesthesia Practice (DNAP) Program Policies

Radiation Protection and Safety

AdventHealth University and the Nurse Anesthesia Department promote a safe learning environment for all students. In the DNAP Program, it is vital that students adhere to the guidelines set forth to maintain their safety in the clinical environment.

Wearing and Exchange of Radiation Exposure Monitoring Badges

1. Badges must be worn at all times when the student is in a potential and/or actual radiation area.
2. When a lead protective apron is **NOT** worn, the badge should be worn at one of the following locations: Waist, chest, or neck area.
3. When a lead protective apron **IS** worn, the badge must be worn outside the apron at the collar level.
4. When not in use, radiation badges are to be stored in non-radiation areas, away from heat and moisture.
5. Exchange of monitoring badges will be quarterly and must be returned to the NAP series badge coordinator within one week of the end of the wear period. Students will be notified via email or personal communication by the NAP series badge coordinator.
6. It is the student's responsibility to ensure s/he exchanges the existing radiation monitoring badge for a new one within one week of the end of the wear period. Failure

to do so may result in clinical suspension (with time deducted from the student's Personal Time bank), at the discretion of NAP faculty.

7. In the event of a lost badge, the NAP series badge coordinator must be notified immediately so that a new badge can be provided. If a badge is found at a later date, the student must report the location it was found to the NAP badge coordinator.

ALARA Notifications

Doses must NOT exceed National Council on Radiation Protection and Measurements (NCRP) requirements. Should a monitor report indicate an exposure of 10%, 30%, or 100% of 1250 mrem per quarter or 5000 mrem per year or higher for a student, ALARA notifications are employed to officially document the ALARA event. These notifications fall into the following three classifications:

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AdventHealth University students that fall into any of the three categories may require some or all of the following steps to be taken:

4. Notification of student of excessive dose
5. A conference will be held between the student, Radiation Safety Officer, Program Director and/or Clinical Coordinator.
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Any level II and III ALARA notifications and the associated procedures must be completed within four business days from the notification. Students failing to complete any or all parts of the ALARA notification process within the required period will be suspended from clinicals pending completion of the ALARA notification process.

Any student found to be practicing gross neglect of established program or site-specific radiation safety policies can be subject to program dismissal (refer to the *A.S. Radiography Program Manual, Section 3)*

Planned External Exposures

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  - Although not required, it is recommended that the Radiation Safety Officer be notified of the upcoming therapy in advance. Students who wish to notify the faculty of their treatment will complete and sign the Voluntary Declaration of Radiotherapy form.

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Pregnancy Policy

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- The student will be provided REMP educational materials that discuss radiation monitoring of pregnant individuals in the clinical area.

Clinical Options

The student will be given the following options with regard to their clinical education:

Option 1:
Terminate the clinical education and continue the didactic (classroom) portion of the program. Lost clinical time will be made up after delivery. This may result in postponing graduation from the program.

Option 2:
Continue clinical rotations with no changes in the types of assignments.

Option 3:
Remain in all program courses and request special modifications related to the higher dose potential duties. The Clinical Coordinator and RSO will make the determinations for specific work area assignments during the pregnancy period, and each case will be handled individually.

Option 4:
The student may voluntarily withdraw from the program and apply for readmission at a later date so long as the duration of leave does not exceed 24 months (*reapplication does not guarantee readmission*).

The pregnant student will read and sign an election form indicating her choice. Their signature will attest to the fact that they have been given proper attention and understand the level of risk associated with their continued training if so chosen.

Supplying a Spare Fetal Badge and Ordering a Monthly Fetal Badge

Upon receiving the completed Voluntary Declaration of Pregnancy form, the student will be issued an additional radiation monitor.

Knowing How to Properly Exchange and Wear Fetal Badges

Fetal badges will be exchanged monthly. If, as common practice, the pregnant employee does not wear a protective lead-apron, the employee shall always wear the radiation monitor at waist level at work to estimate dose to the fetus.

If, as common practice, the pregnant employee does wear a protective lead-apron, the employee shall wear the assigned fetal radiation monitor at waist level under the lead-apron to estimate dose to the fetus. The employee shall always wear their personal radiation monitor on the collar of the protective lead-apron to estimate dose to the employee.

At any time, the student has the right to submit a written Withdrawal of Declaration of Pregnancy to the Program Director and/or Clinical Coordinator.

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Appendix

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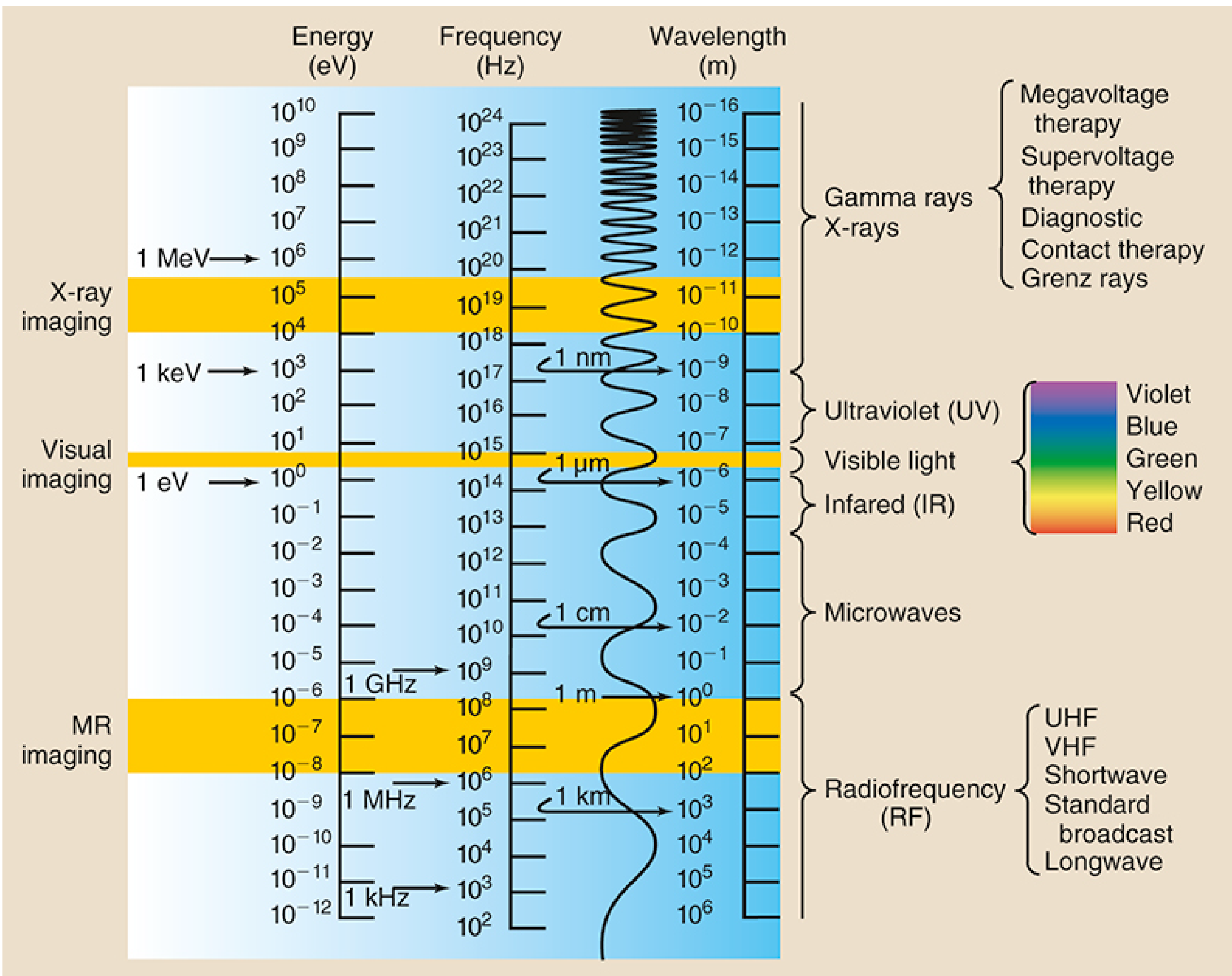
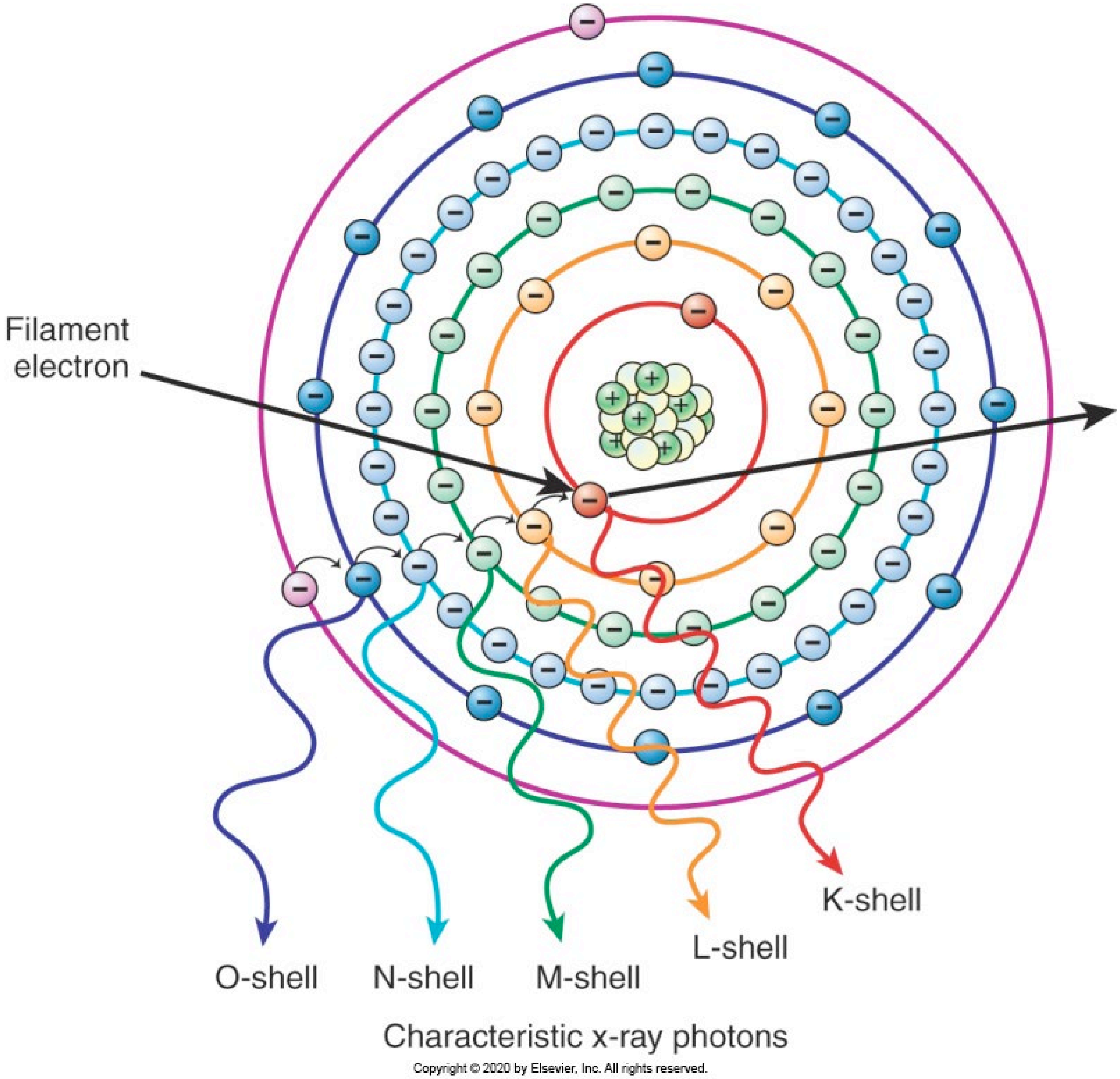


(Figure 2)


Filament
electron
O-shell
N-shell
M-shell
L-shell
K-shell
Characteristic x-ray photons
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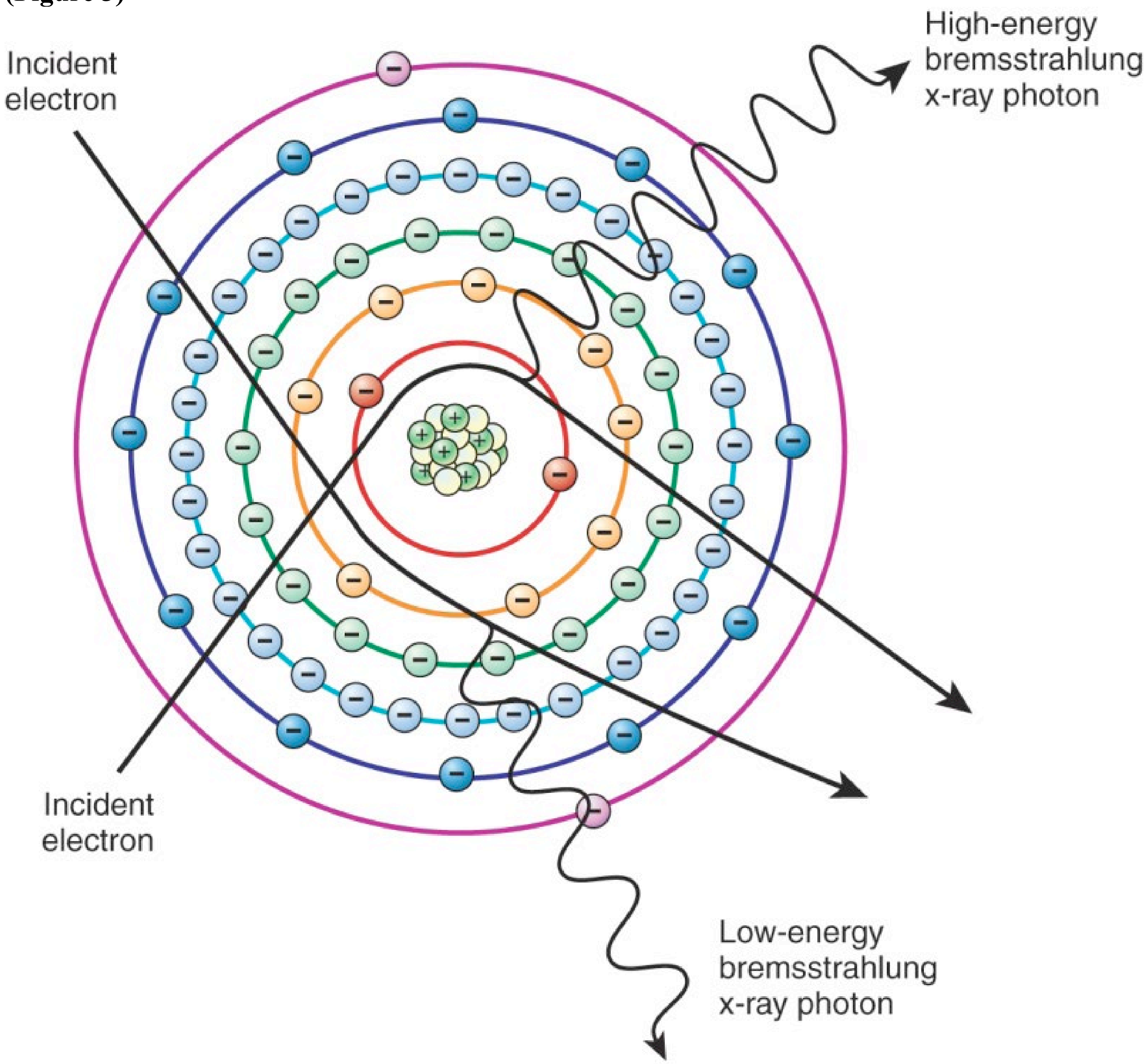
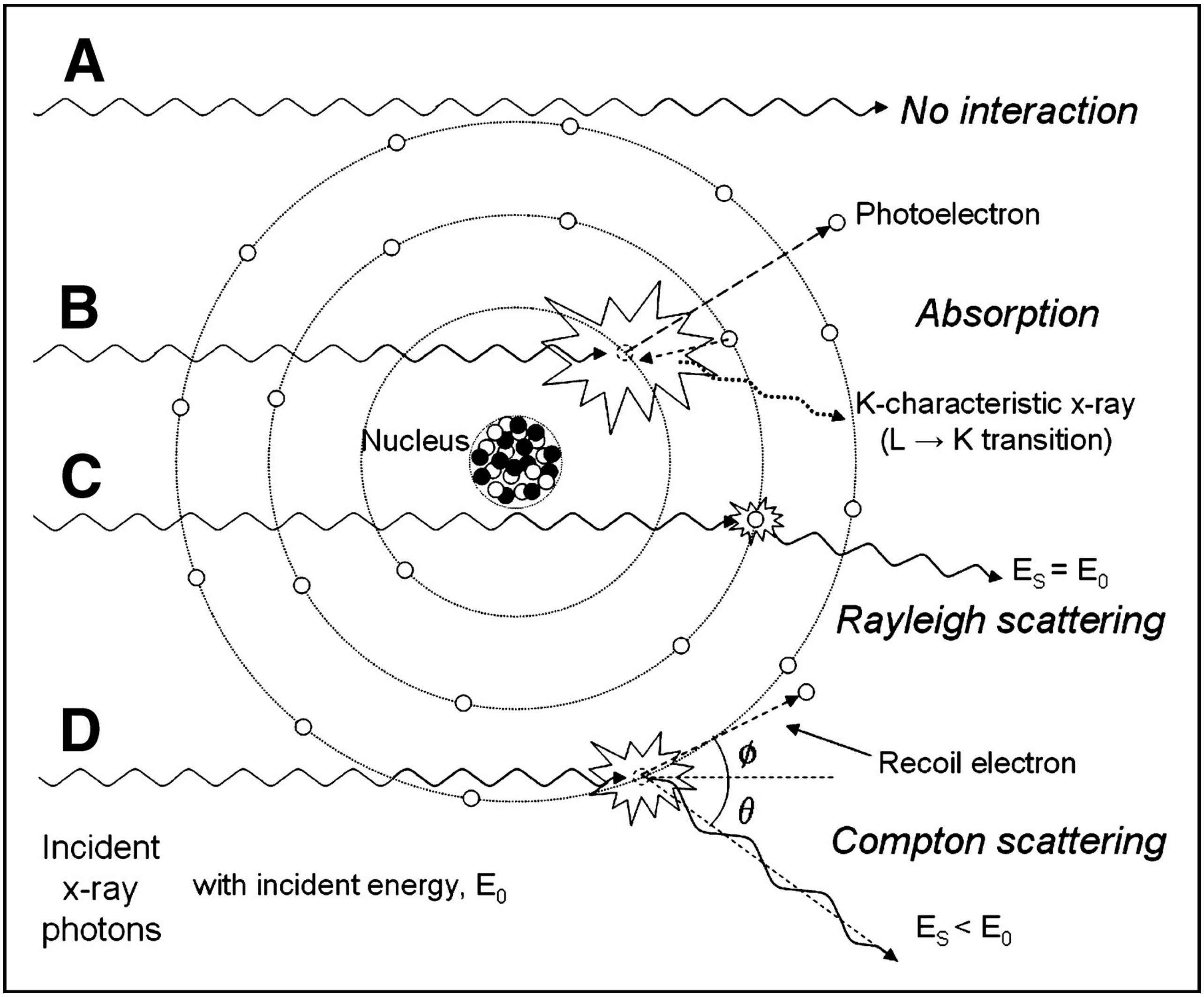
(Figure 3)



Incident electron
High-energy bremsstrahlung x-ray photon
Incident electron
Low-energy bremsstrahlung x-ray photon

(Figure 4)


A
No interaction
Photoelectron
B
Absorption
K-characteristic x-ray
(L → K transition)
Nucleus
C
$E_S = E_0$
Rayleigh scattering
D
ϕ
Recoil electron
θ
Compton scattering
Incident
x-ray
photons
with incident energy, E_0
$E_S < E_0$

(Figure 5)

TABLE 4.6 Summary of Radiation Quantities and Units

Type of Radiation	Quantity	SI Unit	Measuring Medium	Radiation Effect Measured
X-radiation or gamma radiation	Exposure (X)	Coulombs per kilogram (C/kg)	Air	Ionization of air
	Air kerma	Gray (Gy_{a})		
All ionizing radiations	Absorbed dose (D)	Gray (Gy_{t})	Any object	Amount of energy per unit mass absorbed by object
	Air kerma	Gray (Gy_{t})		
All ionizing radiations	Equivalent dose (EqD)	Sievert (Sv)	Body tissue	Biologic effects
All ionizing radiations	Effective dose (EfD)	Sievert (Sv)	Body tissue	Biologic effects