RADIATION SAFETY AND PROTECTION FOR RADIATION THERAPY

Fundamentals of Radiologic Sciences

Dr. Theresa Hollaway

Radiation Safety and Protection
For Radiation Therapy

Fundamentals of Radiologic Sciences

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About This Book

I have been teaching radiation therapy students for many years and many more years for radiologic technology students. There are limited resources focused solely on Radiation Protection and Radiation Biology. Radiation Protection and Radiation Biology courses require multiple textbooks to piece together radiation safety and the effects of radiation in Radiation Therapy.

As I write this textbook, I am reminded of the old cliche, “What comes first, the chicken or the egg?” I relate it to the question, “Do the effects of biological radiation come before radiation’s biological effects?” They are both equally important and are intertwined in subject matter. They are both centered most on practicing radiation safety. The goal of the radiation therapist is to deliver a dose of radiation to the area of interest or target and reduce the radiation exposure (dose) to normal tissues surrounding the target, as well as protect occupational workers and the public.

It is my premise that you need to know what you are dealing with in order to apply it properly. The purpose of this OER is to provide students with a comprehensive textbook aligned with the Howard University College of Nursing and Allied Health Sciences Radiation Therapy Program. The OER textbook is organized so that each unit represents approximately a week in our term. It also includes video resources (short lectures on the topics) at the end of each unit section.

Features of this eBook include:

- Articles, journals, *web links, and video recommendations are embedded in each chapter.
- End of chapter glossary terms. *Flashcard icon links to “Creating flashcards in Microsoft Word” YouTube video.
- Creating flash cards in Microsoft word

Note: Links are not active in downloadable PDF. Use the title to search the internet for the item.

Dr. Theresa Hollaway has many years of experience in Healthcare, Academia, Institutional Effectiveness, Accreditation, and Assessment. She earned a Doctorate in Psychology with a certification in I/O psychology specializing in psychological principles and research methods. She is an Adjunct Faculty for the Radiography Bridge Program at PIMA Medical Institute, an Adjunct Faculty for Radiation Therapy at Howard University, and a Faculty for the Miami Dade College MRI Program.
Her education career began as an Assistant Professor of Radiologic Technology and Clinical Education Coordinator at Quinnipiac University in Hamden, CT. She was Director of Clinical Education at Quinnipiac University Hamden, CT, and in the same position at Miami-Dade College Miami, FL. She was the Imaging Manager at Hollywood Medical Center and the Radiologic Sciences Program Director at Keiser University. She served as Acting Program Director and faculty of Keiser University's Bachelor of Science Psychology Program. She has been a member of the Joint Review Committee on Education in Radiologic Technology (JRCERT) site visitor member and is currently a chair. And, with all of this, she's blessed with an awesome husband, three beautiful granddaughters, and a grandson! p.s. don't forget her furbabies Patch & Floyd and cockatiel Big Mama!

Acknowledgments

The Open@WRLC Course Transformation Program is a two-year pilot program developed by the WRLC Textbook Affordability Working Group (TAWG) (link) to fulfill the WRLC's Sharing Expertise Initiative (link) to "Identify and/or create faculty grant opportunities to support adoption of no-cost or low-cost materials for courses offered by
the WRLC partners." Using no-cost or low-cost materials advances educational equity and directly impacts
student retention and academic success. The Open@WRLC Faculty Course Transformation program is designed to promote a community of Open Educational Resource (OER) advocates among partnering institutions and create incentives to add to the availability of open course materials. ("Faculty Course Transformation Program | Open@WRLC") Creating an affordable curriculum for HU students is the primary task of this OER.

Developing and writing curricula are just some of the duties involved in being an instructor. Finding affordable, quality radiation therapy academic resources is a challenge facing all radiation therapy educational programs. This is further compounded by the lack of subject-specific textbooks such as Radiation Safety and Protection and Radiobiology for therapists. HU and Open Educational Resources have provided the opportunity to create this Radiation Safety and Protection OER.

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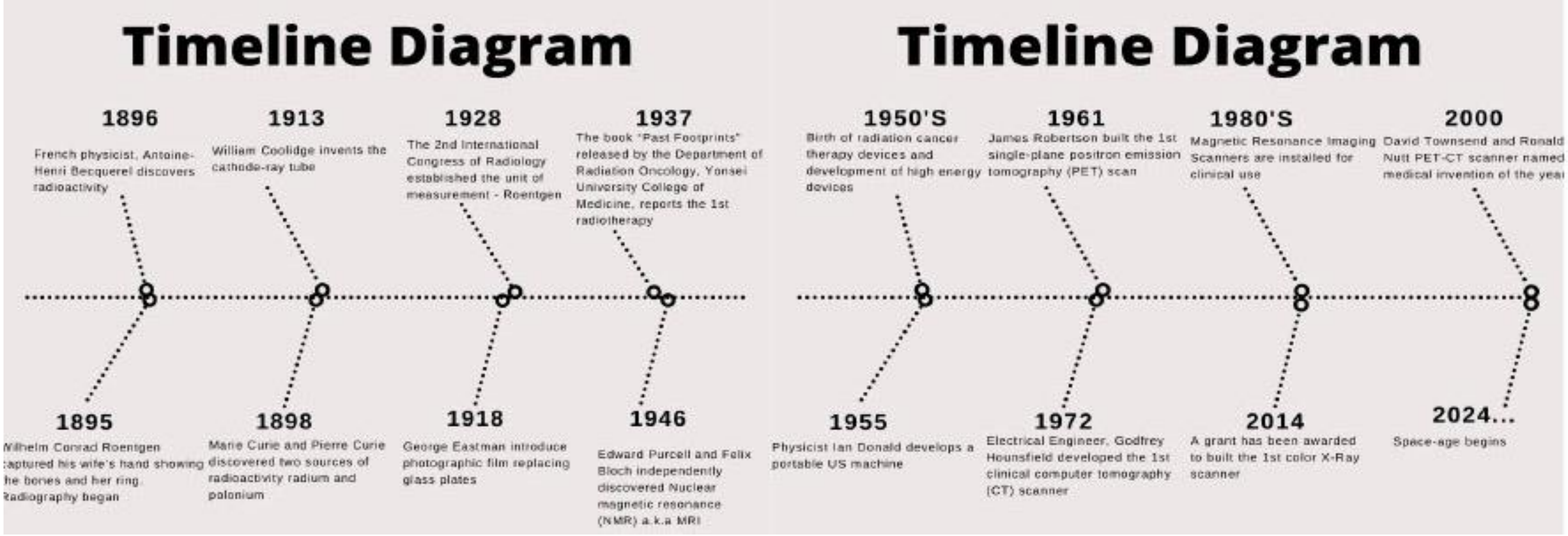
INTRODUCTION

Radiology is a medical specialty in which X-rays, gamma, and radioactive substances are applied in the diagnosis and treatment of patients. This textbook will focus on four main questions.

1. What is radiologic science?
2. What is the history behind radiology?
3. What is the science behind radiology?
4. What are the methods for protecting against unnecessary radiation exposure?

The concept of the Radiologic Sciences is best illustrated by a time continuum. From the discovery of X-rays until today, there have been tremendous discoveries for the use of medical radiation and rapid applicational growth. Radiologic Sciences have two different branches, diagnostic imaging and radiation therapy.



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Diagnostic

Radiologic Sciences, also known as Radiology, Radiography, Diagnostic Imaging, and Imaging, encompasses multiple methods of obtaining pictures (radiographs) or images of the human anatomy. There are various modalities. Some of the most common are:

- X-rays (Digital Imaging, Digital Radiography [DR], and Computerized Radiography [CR)
- Computerized Tomography (CT)
- Nuclear Medicine

Radiology focuses on a wide range of procedures, which are classified by the type of imaging test. Common procedures/exams include:

- Radiographs: X-rays to look at bones, the chest, or the abdomen.
- CT (Computed Tomography): A CT captures multiple x-ray angles of the patient using a doughnut-shaped machine, then creates computer-processed images.
- Mammograms: Specially powered X-rays that look at breast tissues.
- Fluoroscopy: X-rays that make moving images of the body in real time. This imaging is crucial for many procedures, especially those involving the gastrointestinal tract.
- Nuclear medicine: These are short-acting radioactive substances that generate light from bodily processes. A camera collects the light, so a computer can process it and develop an image.

Therapy

Radiation Therapy, also known as radiotherapy, is a branch of Radiologic Sciences that treats cancer. It uses an intense radiation beam or energy to kill cancer cells. X-ray energy is most often used for treatment planning. Other types of radiation, including electron beams or proton radiation, are used as part of cancer therapy to either kill tumors, shrink tumors or control the growth of malignancies.

It has been slightly less than 130 years since W. C. Roentgen, a German physicist, discovered X-rays on November 8, 1895. The method of generating X-rays was applied to treat cancer not long after the historic discovery. On January 29, 1896, the E. H. Grubb company, a vacuum tube manufacturer, assisted in using X-rays for the first time in cancer treatment. A single exposure was applied to a patient with breast cancer.

Over time, radiation therapy has rapidly evolved. The past century has seen many technological growths. Radiation therapy methods and equipment have changed at the same rate as analog TVs to smart TVs! Radiotherapy is individualized. Treatment is based on several factors, including

- Patient’s characteristics
- Disease/Pathology presented
- Treatment volume

Treatment planning encompasses:

- Identifying the cancer type - different malignancies need different doses
- Locate tumor position - the size and the shape of the tumor often changes during treatment
- Evaluate other treatments - identify whether the patient has had or will have other treatments such as surgery or chemotherapy
- Evaluate the general health of the patient - determine the patient’s fitness level for treatment
- Obtain biological information – genetics, Family history, as well as hypoxic tumor status, proliferation activity, and metabolic activity prior to and throughout the treatment process

Types of Radiation Therapies:

- Image-guided radiation therapy
- proton therapy

- brachytherapy
- stereotactic body radiation therapy
- electron beam
- 3D conformal radiation therapy
- external beam therapy
- Linear accelerator
- Particle therapy
- Cone beamed computed tomography (CBCT)
- Surface-guided radiation therapy (SGRT

UNIT 1: HISTORY OF RADIATION SAFETY

Learning Objectives:

Upon completion of this unit, the student will be able to understand and explain the history of the radiologic sciences and the significance of:

- Wilhelm Conrad Rontgen
- Marie and Pierre Curie
- Henri Becquerel
- Radiographic History in the U.S.
- The American Society of Radiologic Technologists (ASRT)
- Preparation for the American Registry of Radiologic Technologists (ARRT) Certification Exam
- Sneak Preview: ALARA, Math, Time-Distance-shielding

Photo of Wilhelm Conrad Röntgen by Life Photo Archive is Public Domain. CC by J. S. Ballard

Wilhelm Conrad Roentgen was a German engineer and physicist credited with the discovery of X-ray in 1895. Roentgen discovered X-rays emanating from a Crookes tube. A Crookes tube aka Crookes–Hittorf tube is an early electrical discharge tube with partial vacuum. Invented by English physicist William Crookes, cathode rays (stream of electrons) applied at a high voltage, travel from the cathode (negative charge) to an anode (positive). The tube was covered with black cardboard. He noticed that a nearby fluorescent screen glowed and realized there were invisible rays that passed through different materials. Rontgen's discovery is one of the greatest scientific discoveries leading to diagnostic advances in the medical industry and later in the field of non-destructive testing. Rontgen generated the first medical X-ray image of his wife's hand pictured below:

The first medical X-ray by Wilhelm Röntgen of his wife Anna Bertha Ludwig's hand is in the Public Domain. Adaptation Radiation Safety cc by J. S. Ballard

The following are links to articles and videos providing detailed information about Roentgen – the German engineer & Physicist credited with the discovery of X-ray in 1895.

- The Life of Wilhelm Conrad Roentgen (article from the American Journal of Roentgenology)
- Nov. 8, 1895: Roentgen Stumbles Upon X-Rays (article from Wired Magazine).
- Roentgen video biography https://youtu.be/XcjVRgthqvo?si=rBgKLVLUqXk2ryrb
- Another Roentgen video biography

https://encyclopedia.pub/video/video_detail/310

Photo of Emil Grubbe (1875 -1960) Adaptation Radiation Safety cc by J. S. Ballard

January 1896. Émil H. Grubbé learned of Röntgen's discovery of X-rays. Coincidentally, Grubbé had already been experimenting with Crookes tubes for several months. Grubbé owned a vacuum tube manufacturing company. He was placing his left hand in the path of the invisible beam and then measuring the output by visualizing the image of his hand on a fluorescent screen. This led to very painful dermatitis. It is said, Grubbe consulted Dr. J. P.Cobb, Dr. J.E. Gilman and Dr. R. Ludlum, faculty members at the Hahnemann Medical School in Chicago. Upon seeing the severe dermatitis of normal cells, they agreed using x-rays may offer possibilities for therapeutic treatment of abnormal tissues. Thus, the first therapeutic application began on one of Dr. Ludlum's patients who had breast cancer.

The following are links to articles and videos providing detailed information about E. H. Grubbé – a Chicago chemist and homeopathic physician named Émil Grubbé (1875-1960) credited with if not the first doctor to employ radiation therapy for cancer, he was, at least, among the first.

- https://www.pbs.org/newshour/health/emil-grubbe-first-use-radiation-treat-breast-cancer
- chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://jbuon.com/archive/14-2-339.pdf

The following are major contributors to the application of radiologic sciences. Namely, units of radiation measurements.

Marie & Pierre Curie

Marie Curie, one of the most honored scientists of all time, is credited for the discovery of radium and received the 1903 Nobel Prize in physics along with her husband Pierre and fellow physicist Henri Becquerel. In 1911, Curie received the Nobel Prize in chemistry for her scientific research and breakthroughs with radium and polonium, making her not only the first woman in history to receive the Nobel Prize but also the only person – man or woman – to ever receive the Nobel Prize in two separate disciplines. Her name lives on with “Curie”, (Ci) used as a unit of radioactivity.

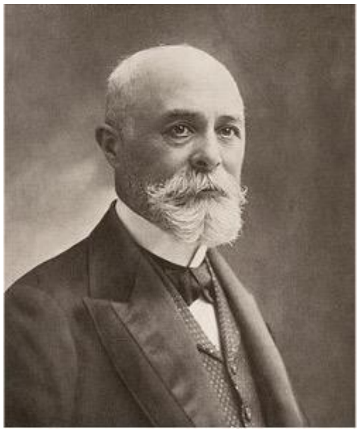
Marie Curie by Henri Manuel is in the Public Domain. Adaptation Radiation Safety cc by J. S. Ballard

Pierre Curie by Dujardin is in the Public Domain.

The following are links to a video and articles providing detailed information about Marie Curie and her tremendous contribution to science.

- Wikipedia article on Marie Curie
- Marie Curie video documentary https://youtu.be/XQ0ZIrP5-NY?si=Bi3V0VnhH27N8yMN

Antoine Henri Becquerel



Henri Becquerel by Paul Nadar is in the Public Domain. Adaptation Radiation Safety cc by J. S. Ballard

Henri Becquerel was a French physicist performing ground-breaking research at the same time as Wilhelm Rontgen and the Curies. His work in discovering "spontaneous radioactivity" earned him a share of the 1903 Physics Nobel Prize along with Marie and Pierre Curie. Similar to Curie, Becquerel has a unit named after him for radioactivity – the SI unit "Becquerel" (Bq)
The following are links to documents and videos on the life and scientific contributions made by Henri Becquerel.

- Becquerel biography (Nobel Prize Organization magazine article)
- Wikipedia biography of Becquerel
- Video biography of Becquerel
  https://youtu.be/GJz278yaKvw?si=Wld4vz4VGHcu1kmQ

Radiation History in the U.S.

In the late 1890s Thomas Edison learned of the recently discovered "X-rays" and began to research and experiment along with his research assistant Clarence Dally. Their lack of understanding of the hazards involved with X-radiation led to the painful, early death of Dally.

A shoe fluoroscope at the US National Museum of Health and Medicine. Public Domain. CC by J. S. Ballard

From the 1920s well into the 1950s, shoe companies used fluoroscopes like the one pictured above to “look” into the feet of potential customers to ensure a better shoe fit for the customer. While mostly a gimmick to generate sales, the fluoroscopes also generated dangerous levels of radiation and exposed thousands of people unnecessarily – all in the name of marketing and sales.

By the late 1940s, Scientists and health regulatory agencies around the world began to research and question the safety of these shoe-fitting fluoroscopes. By 1953, the US FDA recommended not using the machines on children, and in 1957, Pennsylvania was the first state to ban the use of the machines altogether. The last recorded shoe-fitting X-ray machine still in use was in Boston in the early 1970’s.

For more information, see the following videos:

- Shoe store fluoroscope video
- X-ray shoe fit check 1920s
- Read more about Clarence Dally at Smithsonian.com.

History of the American Society of Radiologic Technologists

The American Society of Radiologic Technologists (ASRT) is the membership association for medical imaging technologists and radiation therapists. (“ASRT History”) It is the largest and oldest radiologic sciences professional organization. The ASRT was founded in 1920 and now has more than 156,000 members. The ASRT is responsible for establishing standards of practice (scope of practice) and developing the radiologic sciences educational curricula. The society offers members educational opportunities and promotes radiologic technology as a professional career. The ASRT also monitors state and federal legislation related to the profession. There are 54 state and local societies affiliated with the ASRT; however, they operate independently of the national organization. The ASRT provides guidance and assistance upon request from the affiliate societies. As of the date of this publication, the ASRT business office is located in Albuquerque, N.M.

Early ASRT History

Many of the earlier operators of X-ray machines did not have medical Professional backgrounds as demonstrated by our earlier discussion on the shoe companies that used fluoroscopy to fit shoes. At the time radiography was considered a form of photography. Professional photographers were among the first to purchase and operate the equipment billed as “Roentgen Photography”. Most medical X-ray equipment in the 1900s was owned and operated by private businessmen, which included chemists, engineers, and electricians. However, it soon became apparent there was a more serious application for X-rays, to diagnose and treat pathologies.

Some of the earlier physicians would send their patients to these independent operators. Around the 1910s, more physicians started purchasing X-ray equipment to install in their medical offices. Some of these physicians who operated the X-ray equipment themselves began to specialize as radiologists. With the growth of equipment and technique, many of the physicians found themselves spending less time on direct patient care and began hiring assistants to handle the time-consuming task of operating X-ray equipment and developing films. At first, receptionists, secretaries, or office assistants with no knowledge of human anatomy or illnesses operated the equipment. Fortunately, hospitals, medical clinics, and physicians began to employ nurses for at least they had medical training.

Most of the medically trained assistants were women. According to the ASRT, these Pioneer Technicians not only performed routine procedures but were also responsible for machine maintenance while working in an environment that did not include radiation safety practices. The death toll amongst them was high. It wasn’t until the 1920s an x-ray technician named Eddy C. Jerman organized and created an education legitimacy for technicians. He served several terms as president of the *American Roentgen Ray Society* (ARRS) becoming president emeritus in 1930. In October 1920, he established the first national society, *the American Association of Radiological Technicians* (AART), and served as the examiner for the first 1,000 candidates for credentialing.

Ed C. Jerman, D.Sc. https://doi.org/10.1148/27.4.509

ALARA

Learning Objective:

- Define ALARA
- Explain ALARA both Pros & Cons
- List steps to ensure the practice of ALARA
- Differentiate the practice of ALARA in the various radiologic sciences modalities

The term ALARA (pronounced ah-lar-uh) is an acronym for the radiation protection practice of "as low as reasonably achievable." The ALARA principle practiced by technologists is a safety measure designed to minimize radiation exposure that does not have a direct benefit. The Nuclear Regulatory Commission (NRC) as defined in Title 10, Section 20.1003, of the Code of Federal Regulations (10 CFR 20.1003), means every reasonable effort should be made to limit the amount of ionizing radiation exposure keeping it far below the prescribed dose limits (Effective Dose Limits will be covered in Unit 8).

A stable professional practice, ALARA focuses on the cardinal rule of time, distance, and shielding. The practice of radiation protection has been widespread since the 1950s. More specifically, using lead shielding of the male and female reproductive organs (gonads) was required in radiation safety guidelines and regulatory standards. However, over the past several years there has been significant discussion in the regulatory agencies on whether to shield during diagnostic procedures. The American Association of Physicists in Medicine (AAPM) was the first to publish a recommendation on the validity of gonadal shielding. In 2019 AAPM adopted a policy to no longer support shielding patients' reproductive organs and fetuses during imaging studies. (AAPM Position Statements, Policies and Procedures - Details, n.d.)

Listed below are a few of the organizations that support and endorse the AAPM position statement.

- The National Council on Radiation Protection and Measurements (NCRP) recommends ending routine gonadal shielding during abdominal and pelvic radiography.
- The American Society of Radiologic Technologists (ASRT) supports the elimination of gonadal and fetal shielding specifically during abdominal and pelvic radiography examinations performed by registered radiologic technologists.
- The International Society of Radiographers and Radiologic Technologists (ISRRT) endorses the change in practice based on the latest scientific research and risk-benefit assessment. (Yumpu.com, n.d.)

Other Agencies

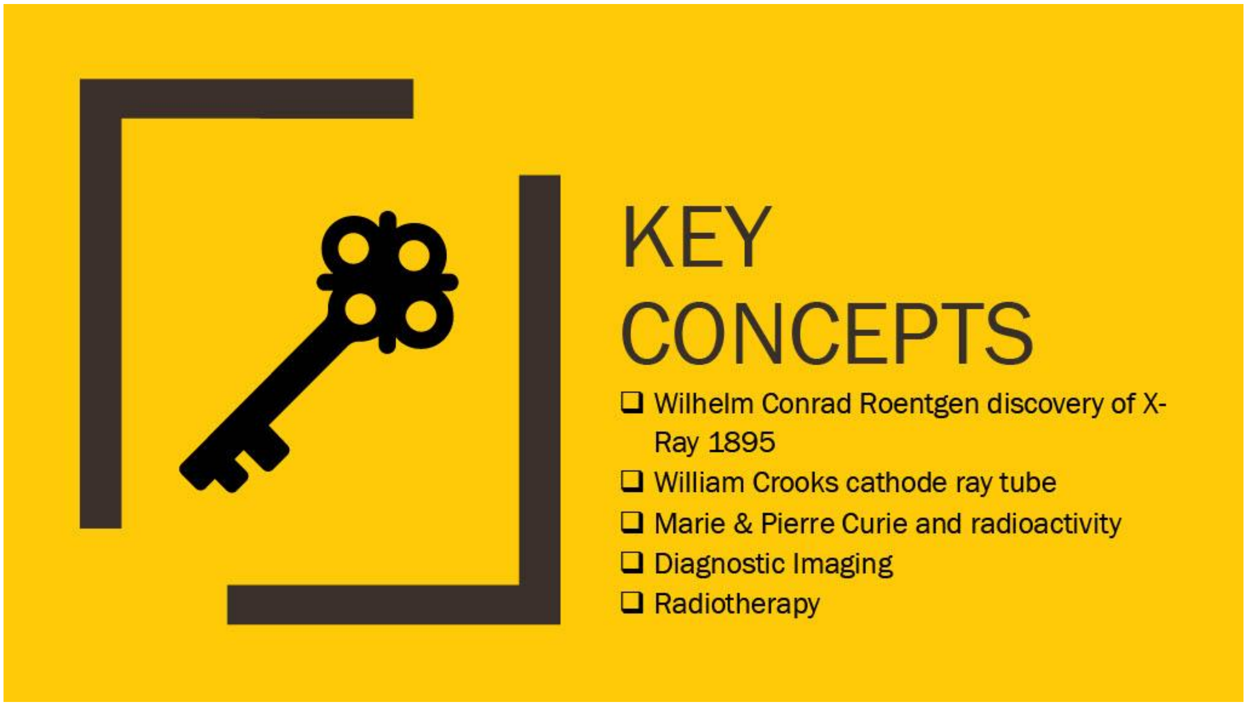
Protection and Safety in Radiation Therapy

Radiation therapists are also responsible for practicing ALARA. Radiation therapy has been used as a treatment for more than 100 years. The application of radiation for diagnosis and treatment is still misunderstood when it comes to exposure to medical radiation. People worry about the safety of radiation. Whether it is the patient or health care provider it is important to communicate effectively. Therapists should be knowledgeable of the various types of energies and absorption factors (discussed later in this unit). The fundamentals of the Radiation Sciences should be understood in that you can communicate to patients in layman's terms.

As previously mentioned, the cardinal principle of ALARA is time distance and shielding. In radiation therapy, ALARA may only be applied to the type of radiation therapy equipment in which radiation at the diagnostic range is the primary contributing factor. The equipment used in the radiation oncology departments includes fluoroscopy, CT simulators, PET scans, and linear accelerators all producing diagnostic range energy. During the treatment planning process, patients routinely receive CT scans or portal images. It has been the required practice of radiologic technologists to shield patients having diagnostic procedures. This has not been the practice in radiation therapy. It is important to consider safety concerns are very different and depend upon the types of treatments such as chemotherapy, targeted therapy, hormone therapy, and immunotherapy.

Cornerstone of ALARA

- Time: For people who are exposed to radiation in addition to natural background radiation, limiting or minimizing the exposure time reduces the dose from the radiation source.
- Distance: Just as the heat from a fire is less intense the further away you are, so the intensity and dose of radiation decrease dramatically as you increase your distance from the source.
- Shielding: Barriers of lead, concrete, or water protect from penetrating radiation such as gamma rays and neutrons. This is why certain radioactive materials are stored under water or in concrete or lead-lined rooms, and why dentists place a lead blanket on patients receiving x-rays of their teeth. Similarly, special plastic shields stop beta particles, and the air stops alpha particles. ("Minimize Your Exposure | NRC.gov") Therefore, inserting the proper shield between you and a radiation source will greatly reduce or eliminate the dose you receive.



KEY CONCEPTS

☐ Wilhelm Conrad Roentgen discovery of X-Ray 1895
☐ William Crooks cathode ray tube
☐ Marie & Pierre Curie and radioactivity
☐ Diagnostic Imaging
☐ Radiotherapy

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Unit #1 Glossary of Terms

Curie: (Ci) is the unit of measurement of the amount of radioactivity of a substance, named after Marie and Pierre Curie. 1 Ci = 3.7×1010 disintegrations per second (rate of decay)

Fluoroscope – an imaging technique that uses X-rays to obtain real-time images of the inside of an object. This technology was abused in the 1950's by shoe companies to "fit" an individual's foot to a specific shoe.

Marie Curie: Curie was the first woman awarded the Nobel Prize for her discovery of the radioactive elements Polonium and Radon. Curie is the only person – male or female – to win the Nobel Prize twice.

Pierre Curie: husband, research partner and co-Nobel Prize recipient of Marie Curie.

Becquerel (Bq) – Si unit for measuring radioactivity.

Henri Becquerel – French physicist that shared the 1903 Nobel Prize with Marie and Pierre Curie for his discovery of "spontaneous radioactivity"

Radiation: Energy in transit. Either as particles or electromagnetic waves.

RSO – Radiation Safety Officer – required for any company, education, medical or research facility that uses any form of Gamma or X-ray radiation.

Radioactivity: The characteristic of various materials to emit ionizing radiation.

Roentgen (R) – is a unit of measurement to the exposure of ionizing radiation, specifically Gamma radiation and X- rays, named after the German physicist.

Roentgen – Wilhelm Conrad Roentgen discovered the X-ray while doing research in Germany on November 8th, 1895

X-ray – a type of ionizing radiation formed in a Cathode Ray Tube (CRT) when high velocity electrons flow from the cathode to the anode.

UNIT 2: IONIZING RADIATION & UNITS OF MEASUREMENT

Learning Objectives:

Upon completion of this unit, the student will be able to define, understand, and apply the following:

- Ionizing Radiation
- Radiation Intensity & Units
- Isotope vs. Radioisotope
  - Stable vs. Unstable atoms
  - Radioactive half-life
  - Radioactive Decay
- ALARA
- Time, Distance, Shielding
- Inverse Square Law

Ionization Defined

Ionizing radiation is radiation that carries enough energy to liberate electrons from atoms or molecules, thereby ionizing them. Ionizing radiation is made up of energetic subatomic particles, ions or atoms moving at high speeds (usually greater than 1% of the speed of light), and electromagnetic waves on the high-energy end of the electromagnetic spectrum.

Gamma rays, X-rays, and the higher ultraviolet part of the electromagnetic spectrum are ionizing, whereas the lower ultraviolet part of the electromagnetic spectrum, and the lower part of the spectrum below UV, including visible light (including nearly all types of laser light), infrared, microwaves, and radio waves are all considered non-ionizing radiation. The boundary between ionizing and non-ionizing electromagnetic radiation that occurs in the ultraviolet is not sharply defined, since different molecules and atoms ionize at different energies. Conventional definition places the boundary at a photon energy between 10 eV and 33 eV in the ultraviolet.

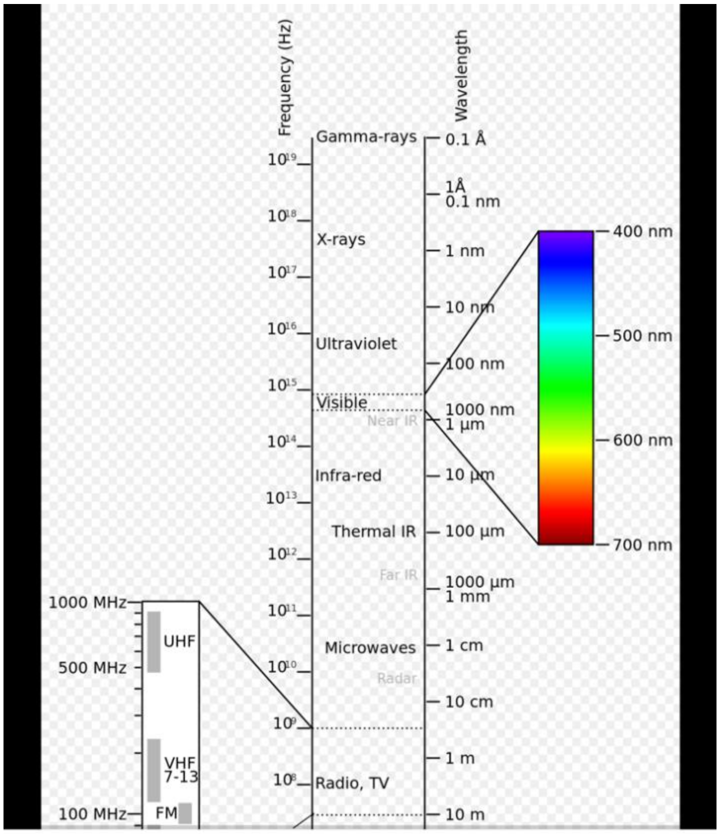
Table 2.1

The electromagnetic spectrum can be divided into two parts:

Ionizing radiation (x-rays, gamma rays, and high-energy ultraviolet radiation [energy higher than 10 eV]) can transfer sufficient energy to some orbital electrons to remove them from the atoms to which they were attached (the process of ionization, the foundation of the interaction of x-rays with human tissue).

Nonionizing radiation (ultraviolet radiation [energy less than 10 eV], visible light, infrared rays, microwaves, and radio waves) does not have sufficient kinetic energy to eject electrons from atoms.

Fig. 2.1 The Electromagnetic Spectrum

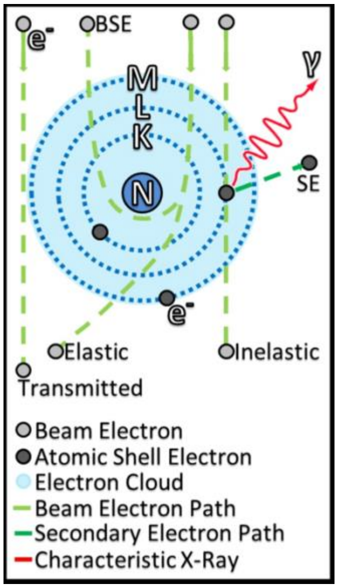


File:Electromagnetic-Spectrum.svg - Wikimedia Commons, 2012

Typical ionizing subatomic particles from radioactivity include alpha particles, beta particles, and neutrons. Almost all products of radioactive decay are ionizing because the energy of radioactive decay is typically far higher than that required to ionize. Other subatomic ionizing particles that occur naturally are muons, mesons, positrons, and other particles that constitute the secondary cosmic rays that are produced after primary cosmic rays interact with Earth’s atmosphere. Cosmic rays are generated by stars and certain celestial events such as supernova explosions. Cosmic rays may also produce radioisotopes on Earth (for example, carbon-14), which in turn decay and produce ionizing radiation. Cosmic rays and the decay of radioactive isotopes are the primary sources of natural ionizing radiation on Earth referred to as background radiation. Ionizing radiation can also be generated artificially using X-ray tubes, particle accelerators, and any of the various methods that produce radioisotopes artificially.

Ionizing radiation is not detectable by human senses, so radiation detection instruments such as Geiger counters must be used to indicate its presence and measure it. However, high intensities can cause the emission of visible light upon interaction with matter, such as in Cherenkov radiation and radioluminescence. Ionizing radiation is used in a wide variety of fields such as medicine, nuclear power, research, manufacturing, construction, and many other areas, but presents a health hazard if proper measures against undesired exposure are not followed. Exposure to ionizing radiation causes damage to living tissue and can result in mutation, radiation sickness, cancer, and death.

Fig 2.2 Ionization



File:Electron-beam Interaction and Transmission With sample.jpg - Wikimedia Commons, 2013

- Video link of Ionization animation

Types of Radiation

There are two types of ionizing radiation presented on the electromagnetic spectrum. They have no mass, always travel at the speed of light, and are considered energy (E). The three electromagnetic ionizing radiation are:

- X-rays
- Gamma rays

When radiation is of a high frequency, it can transfer energy to an atom and remove some orbital electrons that were attached (ionization). The energy (specified in electron volts [eV]) is a product of the frequency (hertz [Hz] is the unit of measurement) of the photon multiplied by a constant called Planck's constant (h). E = hv

Table 2.2 demonstrates the calculation of the wavelength and energy of x-rays and gamma rays on the electromagnetic spectrum.

Use	Frequency	Wavelength	Energy
X-rays	100 PHz – 100EHz	3 nm – 3 am	0.4–400 keV
Gamma rays	100 EHz - infinity	3 – 0 am	400 keV–infinity

Electromagnetic values retrieved from Wikipedia contributors, 2024 is Public Domain

As previously mentioned, there are two basic physical forms of radiation. The first form (electromagnetic wave) comes from the electromagnetic spectrum also referred to as electromagnetic radiation. X-rays and gamma rays are pure energy and have no weight or mass. The second physical form is known as particle radiation. Particle radiation is fast-moving and has both energy and mass (weight). **Alpha**, **Beta**, and **Neutrons** are subatomic particles that are ejected from an atom at very high speeds. They possess kinetic energy that can cause ionization upon interacting directly or colliding with other atoms. Ionization does not occur when these particles are at rest (stable atom).

Uranium, thorium, and radium naturally emit alpha particles. This process is called radioactive decay. Man-made elements such as plutonium and americium Are also alpha emitters. Alpha particles lose energy quickly as they travel a short distance in biological matter (superficial layers of the skin). They have limited ability to penetrate therefore, they can be blocked by a sheet of paper. Therefore, external exposure to materials that emit alpha particles generally does not pose a danger. However, alpha particles are potentially dangerous if they are inhaled or ingested.

Beta particles are identical high-speed electrons except where they originate from. Beta rays are emitted by the decay of the neutron full nucleus while alpha rays are produced by the decay of the abundant proton nucleus. This process is called radioactive decay. Beta rays have a greater ability to penetrate the skin than alpha particles. Beta particles are approximately 8000 times lighter than alpha particles. Beta rays have one unit of electrical charge (-1) (negative charge) While alpha rays have two units of electrical charge (+2) (positive). Beta particles travel a few feet in the air that a thin sheet of metal, plastic, or could stop beta rays.

Neutrons are high-speed electrons that are not beta radiation. They are produced in a radiation oncology treatment machine called a linear accelerator. They are used to treat superficial skin lesions and small areas. They can deliver radiation boost treatments to breast tumors and add a tissue depth usually not exceeding 5 - 6 cm. Radiation protection for these high-speed electrons requires a certain number of millimeters of lead or lead equivalent such as aluminum, wood, or concrete. Neutrons are the electrically neutral components of an atom.

Isotope vs. Radioisotope

Isotopes are atoms of the same element. In other words, if two atoms have the same number of protons (atomic number or Z number) but have a different number of neutrons in their nuclei (mass) are stable isotopes and do not emit radiation. If one of these isotopes (atoms) has an excess combination of neutrons or protons it is considered unstable while the other one is considered stable. The unstable nuclei are referred to as a radioisotope. To become stable, the atom releases the excess nuclear energy in the form of positively charged alpha particles, negatively charged beta particles, gamma rays, or x-rays (radioactive decay). Practicing radiation safety and protection for radioisotopes is based on the loss of radioactivity over time. This is referred to as the half-life of a radioactive material. Each unstable atom gradually loses radioactivity in half-lives which means the time it takes 1/2 of the radioisotope to decay (lose energy). The time of radioactive decay is dependent on the individual radioisotope, for example, radon-222 takes fractions of a second while thorium 232 takes millions of years.

- Video link of Types of Radiation.

ALARA

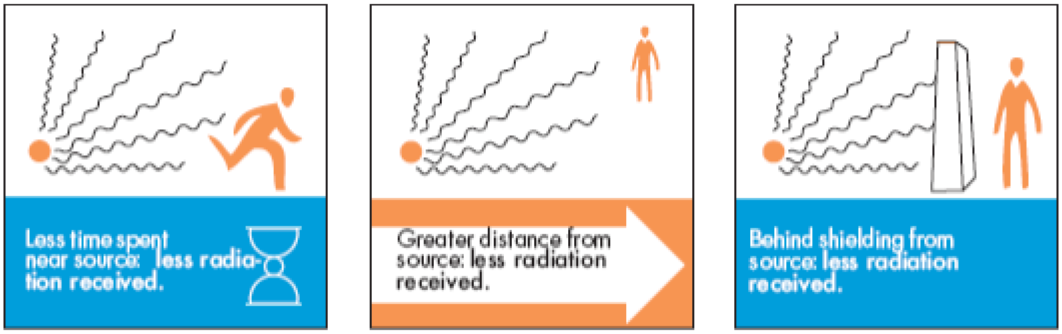
ALARA: As Low As is Reasonably Achievable

The ALARA Acronym comes out of the NRC (Nuclear Regulatory Commission) Code of Federal Regulations, Title 10, Section 20.1003. ALARA means, “To make every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken." The NRC Code goes on to explain what the practical limits might entail and the importance and practicality of taking extreme measures to keep both radiation workers and the general public safe.

Time, Distance, and Shielding

Radiation Safety is accomplished through a variety of strategies and is pertinent to several high-risk career areas. Radiation safety protocol will look different for an airline pilot than it does for a gamma radiation therapist and likewise, a radiologic technologist has yet a different set of constraints (patients, the public). The concept of Time Distance and Shielding to achieve ALARA is relevant to all exposure-risk careers, but our primary focus here is radiologic sciences. The goal is to understand the concept and real-world application of Time, Distance, and Shielding as it pertains to Radiation Safety.

The NRC states time, distance, and shielding measures minimize exposure to radiation in much the same way as protecting against overexposure to the sun (as illustrated in the figure below):



Time, distance, and shielding from NRC.gov is in the Public Domain.

Time- is an ALARA method to reduce or limit the length of time being exposed to ionizing radiation. For patients, time (in seconds) is one of the technical factors in the production of X-rays. The direct exposure technique is adjusted to the smallest radiation exposure time that produces a quality image (exposure technical factors will be discussed in Unit 4). For the technologists practicing ALARA, the method is to limit the length of time in an area that could potentially expose them to ionizing radiation.

Distance- the distance from the source of ionizing radiation to the patient is most often inherent based on the recommended equipment manufacturer technical guide. Techniques to produce quality images include a pre-set distance, referred to as the source-image-distance (SID) in Imaging and target-to-image receptor distance (TD) in radiation therapy. Radiation exposure can be affected by changes in the distance. This relationship follows the inverse square law states the intensity of radiation exposure is inversely proportional to the square of the distance. In other words, if the technologists double the space from the source of radiation, the exposure dose is lower (reduced by one-fourth).

Shielding- technologists use personal protection apparel (lead aprons or lead gloves) when placed in the direct path of the primary radiation beam. Shielding incorporates a variety of applications to protect patients, technologists, and the general population. Shielding is applied in the structural design of radiation facilities. Portions of the floor, ceiling, and side walls will generally receive the primary beam and are considered primary barriers. The amount of shielding required is determined by the level of radiation activity in that room. The design of protective barriers will be further discussed in Unit 9. Unit 9 also includes how shielding in the form of lead equivalent filters is intrinsic to the design of the machines. Modifying devices such as custom shielding blocks are used in radiation therapy.

Inverse Square Law

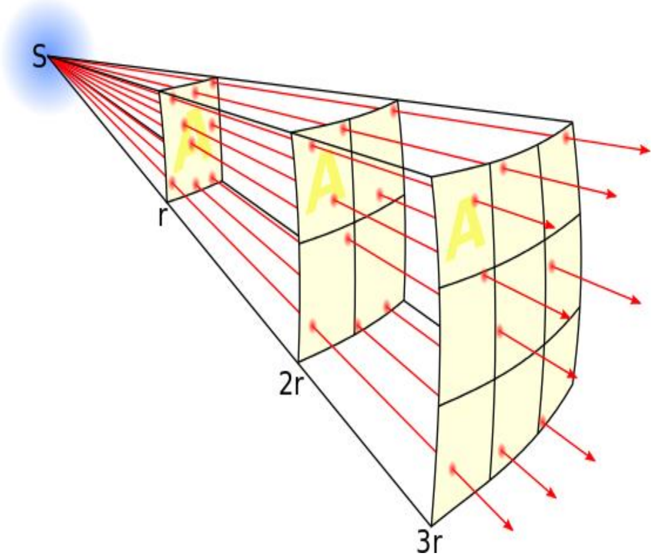
Learning Objective:

- Understand the application of the Inverse Square Law as it pertains to Radiation Safety
- Apply the Inverse Square law to create safe distances, times, or radiation amounts.

Inverse Square law: The radiation Intensity is inversely proportional to the square of the distance. Notice in the diagram that as the distance doubles, the area quadruples, and thus, the initial radiation amount is spread over that entire area and is therefore reduced, proportionately.

Imagine we are trying to expose an image receptor (IR) and we move the x-ray source twice as far away on the second image, will the image be overexposed or underexposed? Therefore, while the inverse square law pertains to radiation safety, it also helps us to determine source-to-image distances (SID or TID), time of x-ray exposure, and the intensity (KV) of our x-ray tube.

$$\frac{I_1}{I_2} = \frac{D_2^2}{D_1^2}$$



Inverse Square Law by Borb is CC BY-SA 3.0

I_1 = Intensity with a distance measured as (R/hr or mR/hr)
D_1 = Distance with an intensity (usually measured in feet) **I_2** = Intensity without a Distance
D_2 = Distance without Intensity

Solving for intensity (I_2) means that we want to know the radiation intensity at a given second location or known distance (D_2). To solve for Intensity, use the following formula:

$$I_2 = \frac{I_1 \text{ x } (D_2)^2}{(D_2)^2}$$

$$(D_2) = \frac{I_1 \text{ x } (D_1)^2}{(I_2)}$$

To solve for a safe distance (D2), we are D22calculating how far away from the radiation source (gamma or X-ray) is needed to achieve either 2mR/hr or 5mR/hr. **To solve for a safe distance, use the formula on the left**

Radiation Intensity & Units

REM, RAD, Roentgen, Curie, Becquerel, Sieverts – Why are there so many different units to measure radiation? This link provides an article that simplifies an explanation as to why.
The glossary of terms in unit one lists several physical quantities of radiation measurements that are named after the discoverer of radiation. The units of radiation measurement are inherently complicated. These units have seen several changes due to the evolving concepts of radiation dose. The Systemé International (SI) was adopted by the International Commission on Radiologic Protection (ICRP) In the 1990s. Today, the SI units are widely used universally and the US Scientific community. For example, the conventional unit Roentgen (Wilhelm Conrad Roentgen) is Air Kerma (Gray_a) or 2.58 $\times10^{-4}$ coulomb per kg) of air. Note: both Gray and Coulomb are scientists. US regulatory and engineering agencies have not fully embraced this change so it's important to know radiation quantities and units as well as their acronyms in both the conventional units and SI units.

There are 4 main units of radiation measurement. They are often confused but they are four different interrelated units. A good mnemonic to remember these units is R-E-A-D. ("Radiation Safety Manual | LSU CAMD")

Radioactivity refers to the amount of ionizing radiation released by a material. Whether it emits alpha or beta particles, gamma rays, x-rays, or neutrons, a quantity of radioactive material is expressed in terms of its radioactivity (or simply its activity), which represents how many atoms in the material decay in a given time. The units of measure for radioactivity are the *curie (Ci) and becquerel (Bq).*

Exposure describes the amount of radiation traveling through the air. Many radiation monitors measure exposure. The units for exposure are the *roentgen (R) and coulomb/kilogram (C/kg).*

Absorbed dose describes the amount of radiation absorbed by an object or person (that is, the amount of energy that radioactive sources deposit in materials through which they pass). The units for absorbed dose are the *radiation absorbed dose (rad) and gray (Gy).*

Dose equivalent (or effective dose) combines the amount of radiation absorbed and the medical effects of that type of radiation. For beta and gamma radiation, the dose equivalent is the same as the absorbed dose. By contrast, the dose equivalent is larger than the absorbed dose for alpha and neutron radiation, because these types of radiation are more damaging to the human body. Units for *dose equivalent are the roentgen equivalent man (rem) and sievert (Sv)*, and biological dose equivalents are commonly measured in 1/1000th of rem (known as a millirem or mrem).

Table 2.2

Roentgen(R): is a unit of measurement to the exposure of ionizing radiation in air, produced from X-rays and gamma rays. More specifically, it is *defined* as the electric charge freed by such radiation in a specified volume of air divided by the mass of that air. Named after German physicists Wilhelm Roentgen who is credited with the discovery of X-rays in 1895.

1 Roentgen is equal to 1,000 MilliRoentgens (mR)

Milli-Roentgen (mR): This is a smaller unit of measuring ionizing radiation.

1,000 mR = 1 R

The safe radiation exposure rate for the public is 2 mR/hour.

The safe radiation exposure rate for a certified radiographer is 5 mR/hr

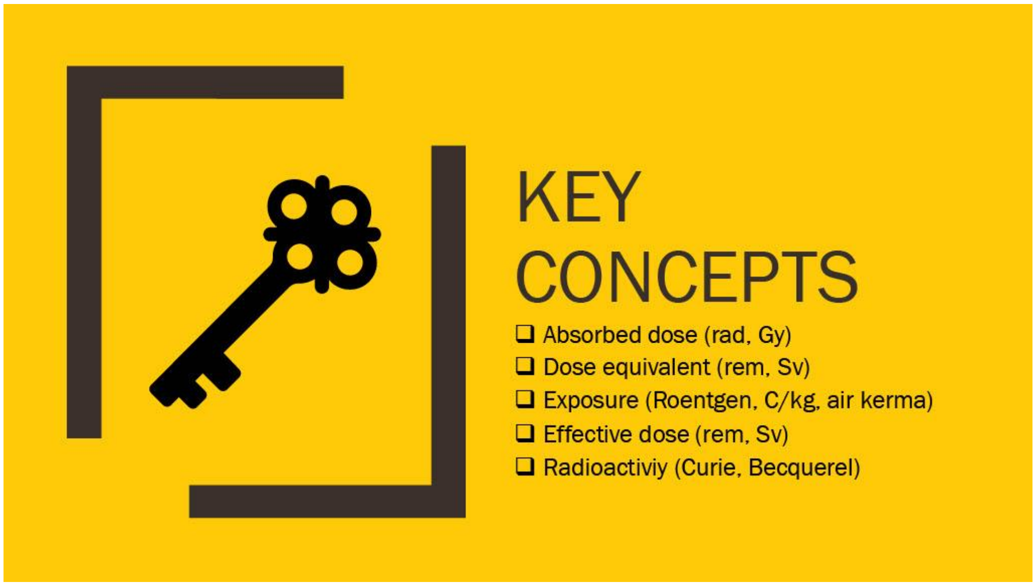
Sievert (SI): is the SI unit of measuring the radiation dose and therefore the effect on the body. 1 Sievert is equal to 100 REM's (Roentgen Equivalent Man)

Activity: The rate of decay of a radioactive material. In simple terms, the Activity (measured in ci or Bq) can be thought of as the amount of radiation Different gamma sources have different activity levels.

- **Curie (Ci):** the unit used to describe the rate of decay or **ACTIVITY** of a radioactive material in disintegrations per second.
  1 ci = 37,000,000,000 disintegration per second (That is, 37 Billion disintegrations per second) Or (3.7 x 10 10 dps)
- **Becquerel (Bq):** the **SI** unit to measure the activity in a radioactive material.
  1 Bq = 1 disintegration per second

Specific Activity: describes the activity per unit of mass of an isotope. Different isotopes have differing Specific Activities When performing gamma radiography, the Specific Activity can be factored in on how the source will behave – a smaller source physical size will have a smaller focal spot and thus may have better definition on the finished radiographs.

Radioactive Half-life: the amount of time required for ½ of the original number of radioactive atoms to decay or change into daughter atoms.



KEY CONCEPTS

☐ Absorbed dose (rad, Gy)
☐ Dose equivalent (rem, Sv)
☐ Exposure (Roentgen, C/kg, air kerma)
☐ Effective dose (rem, Sv)
☐ Radioactiviy (Curie, Becquerel)

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Unit #2 Glossary of Terms

ALARA: “As Low As Reasonably Achievable” Personnel working in the field are required to keep their radiation exposures ALARA.

Atom: The fundamental basic building block of matter is made up of three subatomic particles called protons, neutrons, and electrons. The basic unit of a chemical element of the periodic chart.

Curie: (Ci) is the unit of measurement of the amount of radioactivity of a substance, named after Marie and Pierre Curie. 1 Ci = 3.7×10^{10} disintegrations per second (rate of decay)

Becquerel (Bq) – Si unit for measuring radioactivity.

Electromagnetic spectrum: A continuum of electric and magnetic radiation encompassing all wavelengths.

Electron: a stable subatomic particle with a charge of negative electricity, found in all atoms.

Ion: an atom or molecule with a net electric charge due to the loss or gain of one or more electrons. A positively or negatively charged atom or molecule.

Ionization: The removal of electrons from an atom. The essential characteristic of high-energy radiation when interacting with matter.

Ionizing Radiation: a type of radiation that is able to disrupt atoms and molecules on which they pass through, giving rise to ions and free radicals.

Isotopes: atoms with the same atomic number and chemical properties as element atoms; the nucleus has the same number of protons but a different number of neutrons and thus, a different atomic mass.

Neutron: a subatomic particle with about the same mass as a proton but without an electric charge. Neutrons are present in all atoms except the Hydrogen atom.

Particulate (or particle) Radiation: is the radiation of energy by means of fast-moving subatomic particles. Alpha particles, Beta particles, neutrons, and positrons are examples of particulate radiation.

Photons: Discrete particles of light or electromagnetic radiation hypothesized to explain the corpuscular theory of radiant energy.

Proton: a subatomic particle present in all atomic nuclei, with a positive electric charge equal in magnitude to that of an electron, but of opposite sign.

Radiant energy (Qe): Energy transmitted through a medium by electromagnetic waves. Also known as radiation.

Radiation: Energy in transit. Either as particles or electromagnetic waves.

Radioactivity: The characteristic of various materials to emit ionizing radiation.

Roentgen (R) – is a unit of measurement to the exposure of ionizing radiation, specifically Gamma radiation and X-rays, named after the German physicist.

SI: The International System of units of measurement. Includes most of the base units formerly called metric.

X-ray – a type of ionizing radiation formed in a Cathode Ray Tube (CRT) when high-velocity electrons flow from the cathode to the anode

UNIT 3: BASIC ATOMIC THEORY & SCIENCE

Learning Objectives:

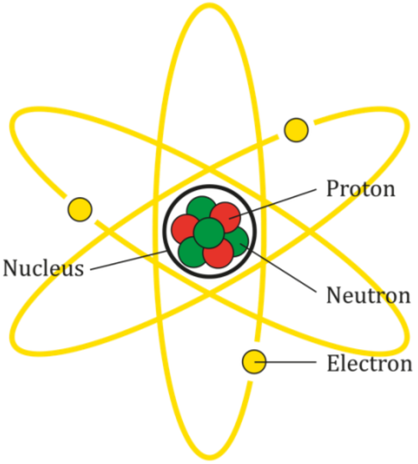
Upon completion of this unit, the student will be able to define and understand the following:

- Basic Atomic Theory
- Elements & Atoms
- Molecules & compounds
- Atomic Particles, number, weight, structure
  - Specific Activity
  - Fission
  - Fusion

Basic Atomic Theory

The atom is the smallest unit of an element. The atom retains the properties of the element and consists of electron shells and a nucleus with protons and neutrons. The protons, electrons, and neutrons are subatomic particles (Fig. 3.1). The three named subatomic particles are important in radiation therapy. Other subatomic particles of concern are positrons and photons. A subatomic particle at rest (not moving) is referred to as the mass (weight) of the particle. Note, that the mass of subatomic particles is measured by the atomic mass unit (amu).

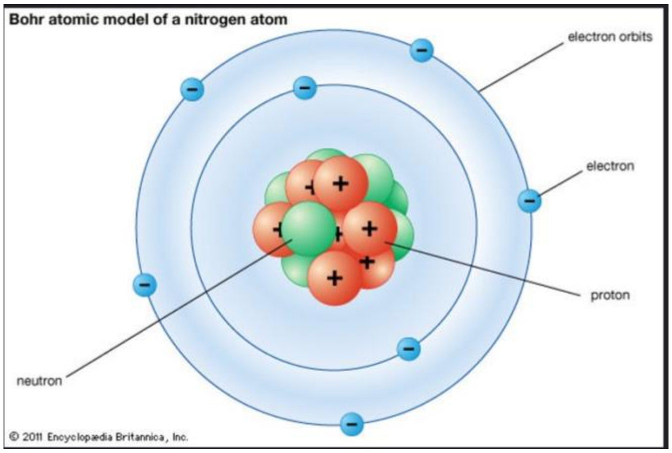
Fig. 3.1



(File:Atom diagram.svg - Wikimedia Commons, 2018)

In 1913, Neils Bohr combined the Rutherford atomic model with Einstein and Plank's quantum theories to explain radiation emitted from atoms (photons)[22]. The Bohr atom model provides a visual image of the atom's structure of the nucleus (central core) and the surrounding electrons bonded to orbital shells. The Bohr atom model posits electrons exist on the orbital shell only due to the binding energy. The closer the electron shell is to the nucleus, the higher the binding energy. Electrons do not lose energy while bonded to the orbital shell. However, when electrons are moved from a higher bond orbital shell to a lower orbital shell, the atom emits deficient energy in the form of radiation energy or photon.

Fig 3.2



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The Bohr atom model (Fig 3.2) led to the understanding of the quantum physics of the atom. Bohr's model established that electrons going around the nucleus in an angular motion can only have a given amount of binding energy. Bohr's model of the atom is used to calculate and predict quantitatively the binding energies of the electron assigned to its orbital shell. These energies are derived by Neils Bohr's application of the Planck constant to the energy value equation.

Whereas the quantum energy of a photon is equal to the frequency multiplied by Planck's constant ($E = hf\ [\gamma]$).[23]

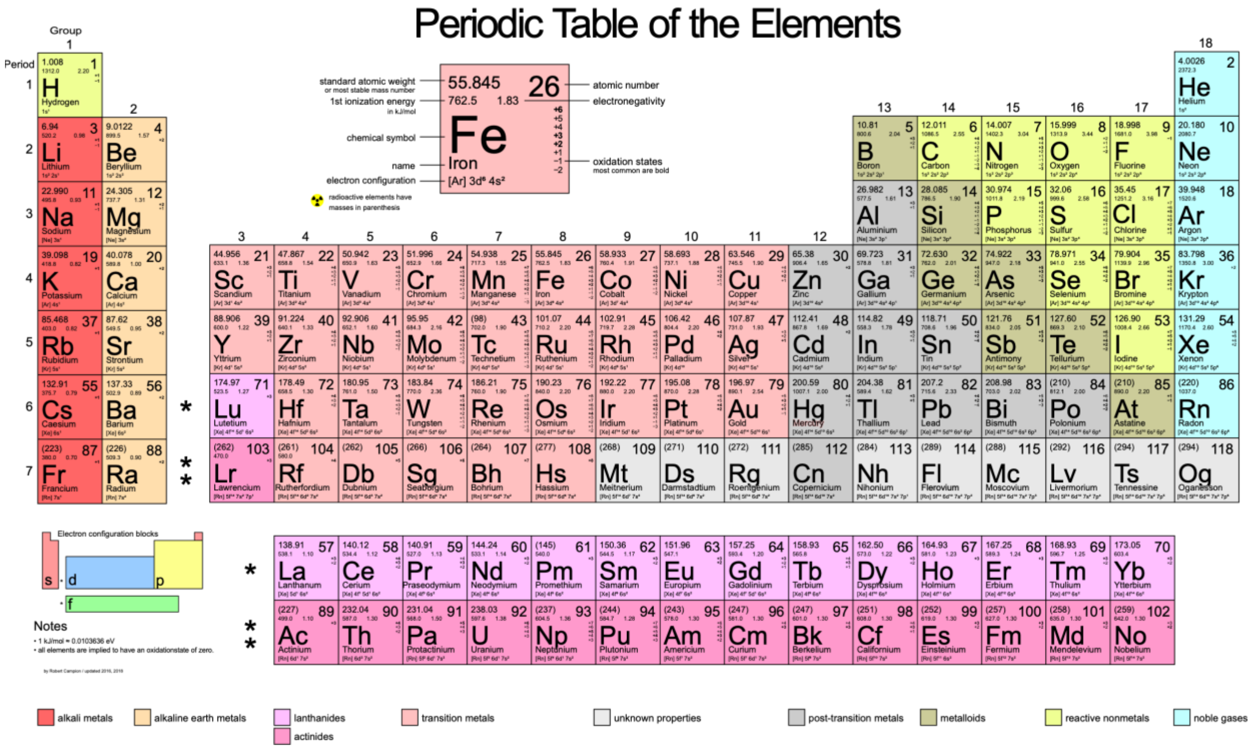
But first, the frequency (γ) of the photon must be solved. In the radiologic sciences, Plank's constant relates the ionizing radiation energy of the photon of the electromagnetic energy. As previously discussed in Unit 1, there are two types of ionizing radiation presented on the electromagnetic spectrum, x-rays and gamma rays. They have no mass and always travel at the speed of light (figure 2.1). The speed of light (c) is also a constant based on a published data sheet at $3.0 \times 10^8\ ms^{-1}$.[23] To solve for the frequency (γ) in Planck's constant, the speed of light (c) divided by the wavelength (λ) equals the frequency (γ) $c/\lambda = \gamma$.[23]

Similar to the speed of light (c), Plank's constant (h) 6.626×10^{-34} Js is listed as a physical fundamental constant also referred to as a universal constant on the scientific published data sheet. [23] The energy of the photon is fundamental in radiation protection and safety. The atomic theory is the key element in the production of photon energy to photon interaction with matter. Basic chemistry is integral in the production of photon energy and photon interactions with matter. The energy, matter, and the state of matter are considered, beginning with the atom. The strength of the photon energy increases as the electron bond increases such as an electron bonded closer to the nucleus creates a stronger energy level. Photon energy is directly related to any chemical structural changes such as when two atoms bond forming a molecule and when molecules sharing the same element bond forming compounds. Electromagnetic waves are the product of excitation of the molecules' chemical bonding leading to the formation of a new chemical or breaking the existing chemical bond.

The periodic table of elements (Fig 3.3) contains all elements which are the fundamental substance of matter. The arrangement of the chemical elements on the table is listed by increasing atomic number (Z). Several elements are specifically utilized in the radiologic sciences. In unit two we discussed ionization which is the removal of electrons from an atom. The ionizing energy must carry enough energy to liberate electrons from the atoms, molecules, or compounds. To produce useful photon energy (ionizing radiation) requires the main components (filament and anode [Unit 6]) of the X-ray tube to be constructed to have high melting points. This is important due to the amount of heat created when the fast-moving electron from the filament decelerates at the anode. The materials most often used for these components are:

- Tungsten (primary Z =74)
- Molybdenum (Z = 42)
- Rhodium (Z = 45)

Fig. 3.3 Periodic Table of the Elements



File:Periodic Table large.svg - Wikimedia Commons, 2009 public domain

Note: Tungsten is a natural earth compound and is listed on the periodical chart aside from the heavy metals.

Specific Activity

As a radiation therapist, having a general understanding of the scientific principles, terminology, and mathematical formulas is critical to your personal safety as well as the safety of others (patients, co-workers, general public). Once we have a solid foundation of the science, we can then safely learn the intricacies of practicing ALARA in both diagnostic and therapeutic applications. The radiation therapist is trained for the treatment of cancers using high energy sources (gamma, beta rays, alpha rays, and other heavily charged particles) and providing quality radiographic images for treatment plans using a diagnostic range of x-ray energies.

The fundamentals of ionization thus far have focused on the atom and the binding energy of the electron shell. The diagnostic range of energy is emitted when an electron's binding energy on a shell close to the nucleus is excited and releases excessive energy in the form of photon energy. The binding energy is dependent on the number of positive charges in the nucleus. The more positively charged nucleus the greater the electron binding energy. Let's look at what happens if that excitation occurs in the nucleus of an atom.

The nucleus of an atom contains protons which are positively charged and neutrons with no charge are bound together creating a nuclear force. The content within the nucleus (the number of protons and neutrons) represents the chemical and physical characteristics of an atom. As previously stated, the strength of the photon energy increases as the electron bond increases. Imagine the increase from a nuclear bond. In fact, the unit of measurement for photon energy emitted from the electron bond is the keV (kilo–electron–volts). Whereas the nuclear binding energy is measured in MeV (mega-electron-volts) and the energy emitted is in the form of electromagnetic wave (Gamma) or radioactive particles (Beta/Alpha).

- Video link of Radiotherapy photon interactions (change the playback speed to 0.75)

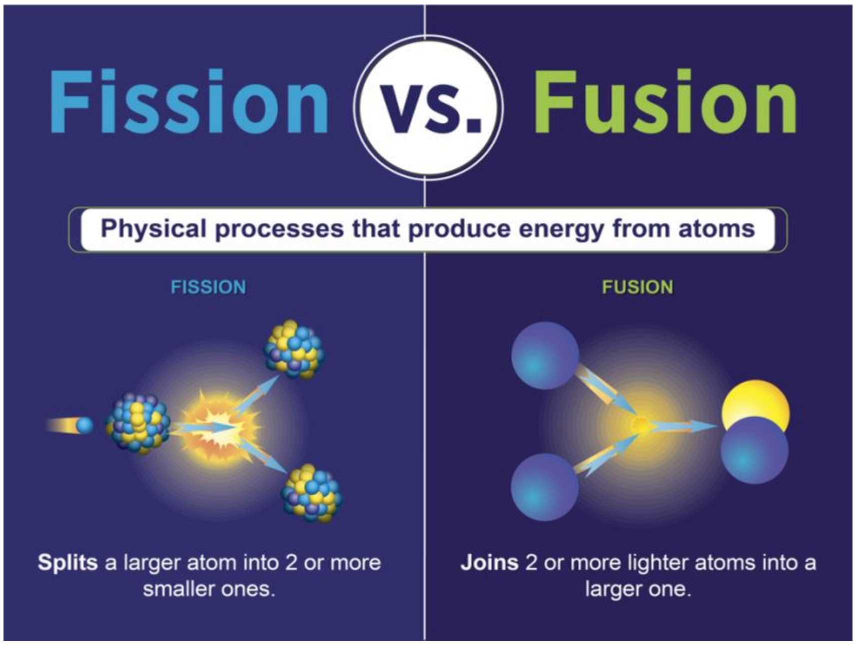
Gamma Rays are used widely in Radiation Therapy (wave and particle form). Gamma radiation is also known as wave-particle duality. When the nucleus of the high Z material is used to produce photon energy, both neutrons and gamma rays are emitted. Producing this level of photon energy (Gamma) is also dependent on the electron energy, which is usually 10 MeV or higher. Unfortunately, the process of creating the gamma sources (radioactive activation) and disposing of spent or decayed sources is costly and potentially hazardous. To reiterate the earlier statement, it is critical for therapists to have a solid understanding of the sources and processes they are working with.

- **Nuclear Fission**: When the nucleus of a stable atom splits upon impact of another particle and splits into 2 smaller parts. The resulting atoms are not the same element as the parent atom and are considered unstable and radioactive. This is the process by which Industrial isotopes (Cobalt 60, Iridium 192, Cesium 137) are created. Fig. 3.2

- **Nuclear Fusion**: This is what scientists claim powers the sun and could be the answer to all of mankind's energy needs. In this chemical reaction, two or more atomic nuclei are combined to form one (or more) different atomic nuclei. Fig. 3.2

- **Half-Life**: the amount of time required for ½ of the original number of radioactive atoms to decay or change into daughter atoms. The original term was "half-life period" coined by physicist Ernest Rutherford when he discovered the principle in 1907. Rutherford went on to receive the 1908 Nobel Prize in Chemistry. For more information, read this historical profile of Rutherford from sciencehistory.org.

Fig. 3.4

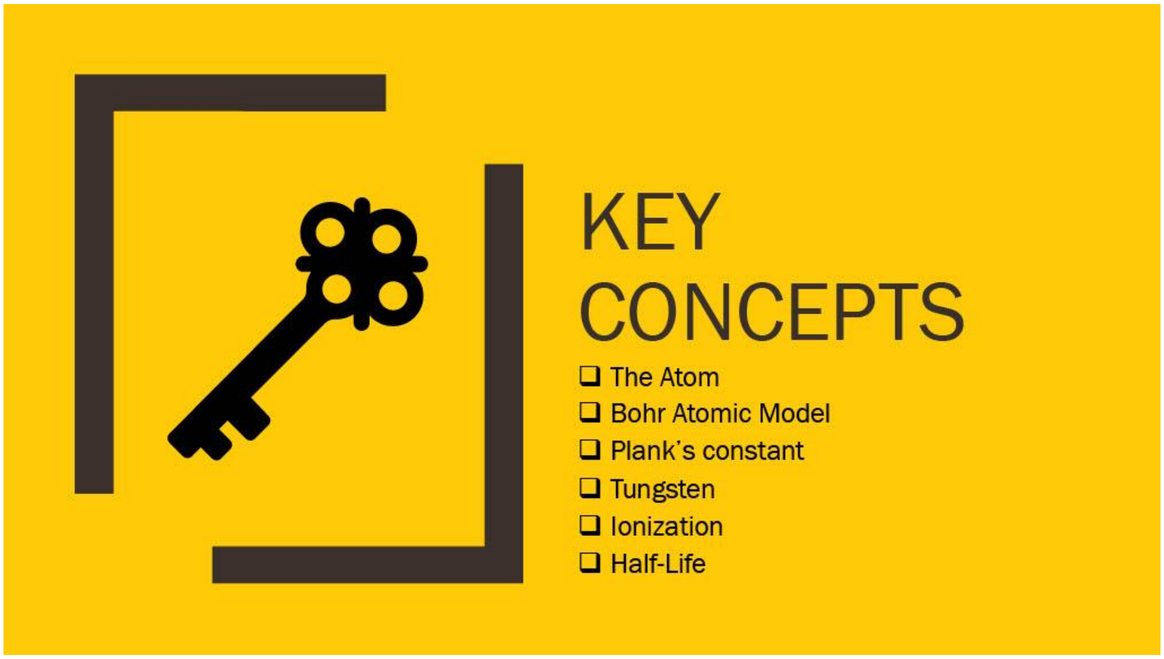


Graphic by Sarah Harman | U.S. Department of Energy (Infographic: Fission Vs. Fusion: What's the Difference) Public domain

Common isotopes and their respective half-life values:

ISOTOPE	**½ LIFE**
Uranium 238	4.5 Billion Years
Potassium 40	450 Million Years
Radium 226	1600 years
Iodine 128	25 minutes
Cobalt 60	5.27 Years

- Iridium 192: 73.83 Days
- Cesium 137 30 years
- Thulium 170 128.6 Days



KEY CONCEPTS

☐ The Atom
☐ Bohr Atomic Model
☐ Plank’s constant
☐ Tungsten
☐ Ionization
☐ Half-Life

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Unit #3 Glossary of Terms

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Alpha Particle: A positive electrically charged particle of radiation consisting of two protons and two neutrons (same as a helium nucleus). It is emitted from the nucleus of many radioactive materials during radioactive decay. Alpha particles have a very low kinetic energy and therefore can be stopped by a sheet of paper or clothing. However, if ingested, alpha particles have a Quality Factor (QF) of 20 times that of straight gamma or X-ray radiation, making them dangerously toxic if inhaled or ingested.

Daughter isotope: The compound remaining after the parent isotope (original isotope) has undergone decay.

Disintegration (Decay): The transformation of radioactive atoms into a stable state resulting in energy (radiation) and particle emission.

Gamma Rays: High energy, short wavelength electromagnetic radiation emitted during radioactive decay.

Gamma Radiography: Radiographs (film, DDA plates, CR, CT) are exposed using a gamma ray camera or radiograph shooting machine which can be portable, fixed in a cabinet or located in a vault.

Gamma Source (source): Industrial gamma radiography typically uses a man-made (activated) radiation source (Cobalt-60, Iridium-192, and Cesium-137). These sources are typically created for specific purposes and applications.

Half-Life: the amount of time required for ½ of the original number of radioactive atoms to decay or change into daughter atoms.

Half-Life Ir 192: 74 days

Half-Life Co 60: 5.3 years

Half-Life Cs 137: 30.17 years

Inverse Square Law: A law of nature which describes the relationship of radiation intensity to distance from the source of radiation, stated mathematically as "the intensity of radiation is inversely proportional to the square of its distance from the source". Radiographers use this mathematical principal to calculate safe distances and radiation dose rates for known distances while exposing radiographs with either X-ray or Gamma radiation.

Nuclear Fission: The process by which the nucleus of a stable atom splits upon impact of another particle and splits into 2 smaller parts. The resulting atoms are not the same element as the parent atom and are considered unstable and radioactive. This is the process by which Industrial isotopes (Cobalt 60, Iridium 192, Cesium 137) are created.

Nuclear Fusion: a nuclear reaction in which atomic nuclei of a lower atomic number fuse to form a heavier nucleus with the release of energy. The sun is an example of this process.

Radioactive: A state in which atoms have excess energy and are unstable. The nucleus disintegrates or decays in the process of becoming stable. This disintegration results in the emission of radiation and we measure this with the Curie (Ci)

UNIT 4: Specific Activity, Half-Life, & Half Value Layers

Learning Objectives:

Upon completion of this unit, the student will be able to define and understand the following:

- Specific Activity
- Common Radioisotopes
  - Ir-192
  - Co-60
  - CS-137
- Half-Life
- Half Value Layer (HVL)
- One-tenth Value Layer (TVL)

Activity: Named after Nobel Prize recipient Marie Curie, the curie (ci) is the unit used to describe the rate of decay, or activity, of a radioactive material in disintegrations per second. One curie equals 37,000,000,000 (37 billion) disintegrations per second. In the SI system, the Becquerel (Bq) is the unit of activity, which is equal to one disintegration per second (Unit 1). ("NDT Encyclopedia: Radiographic Testing")

Specific Activity: The specific activity of an isotope is used to describe the activity per unit of mass or weight (i.e. Curies per gram or Becquerels per gram)

Nuclear Radiation derives from an atom's nuclear constitution (value of the atomic number [Z] and the atomic mass [A]). Referred to as a nuclide. Isotopes are nuclides of different atomic masses. Isotones have the same number of neutrons. Except for fluorine, isotopes are man-made radioactive energy. Remember, unstable atoms give off radioactive energy as the atom stabilizes. A Radioisotope is an isotope that is unstable containing high levels of nuclear energy.

Alpha particles are large unstable atoms emitting alpha rays (α) from the elimination of the protons and neutrons in the nucleus (radioactive decay). Alpha particles are large, heavy radioactive energy that does not penetrate matter. Alpha rays can be deadly if ingested or inhaled. They are basically:

- a Helium atom with a +2 charge,
- can travel only a few centimeters,
- can be stopped by a sheet of paper, and

- are generally not considered as dangerous as gamma radiation or Beta particles UNLESS they get inside the body – then they are easily absorbed by the cells, and this is a dangerous condition.

Beta particles are ionizing radiation with almost zero mass (about 8,000 times smaller than Alpha particles), travel several meters in the air, and travel at high velocity approaching the speed of light. They are also referred to as Particulate Radiation. Beta rays carry a negative electrical charge and are known as Beta-minus Decay (β^-). The nuclear decay of neutrons in the nucleus emits electrons and protons. Most isotopes emitting β^- decay also emits gamma radiation from the remaining nuclide left over from radioactive decay. This is also known as daughter product, daughter isotope, radio-daughter, or daughter nuclide. Beta rays are less damaging than alpha rays and are more penetrating. Alpha particles can be absorbed by internal structures (irradiate)creating an internal radiation source as it decays (daughter isotopes). Whereas Beta particles have enough energy to travel further and penetrate matter creating less interaction internally. Positron Decay (β^+) occurs when the nuclei emit a positively charged electron and a neutrino during disintegration. Gamma radiation also occurs during β^+ due to the annihilation of an atomic electron (atomic electron shell vacancy). Radiation protection and safety practices with β^+ must include gamma recommended practices as well. Although Beta rays travel further than Alpha rays, they can be filtered (shield) by a thin layer of lead or its equivalent (aluminum), plastic (Lucite), or Acrylic.

Practicing radiation protection and safety from radioisotopes is based on radioactive decay of the radionuclide, the heaviness of the element, distance and shielding (Unit 2). ALARA!

One phenomenon technologists and therapists (RT) deal with is how rapidly the rate of decay affects the usefulness and associated hazards of a radioactive isotope. To help define and quantify this dilemma, the radioactive Half-Life is as follows:

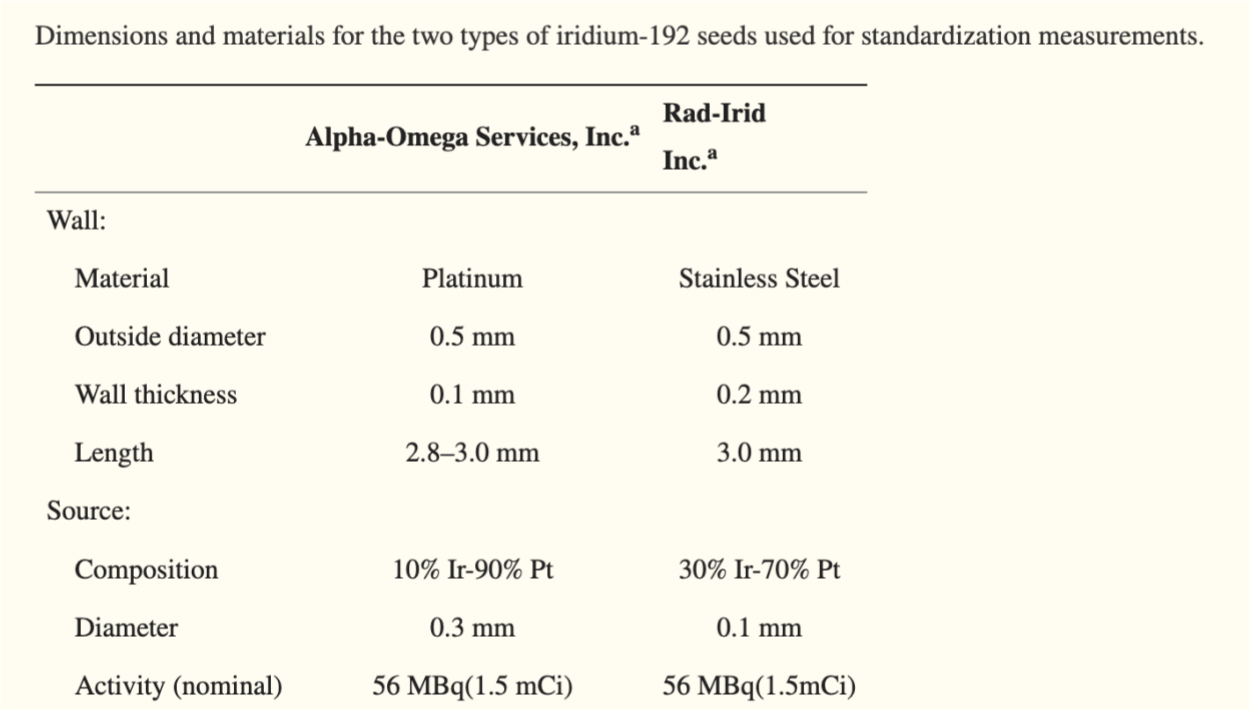
Half-life (symbol t1⁄2) is the time required for a quantity of an isotope to reduce to half its initial value. The term is commonly used in nuclear physics to describe how quickly unstable atoms undergo, or how long stable atoms survive radioactive decay. The term is also used more generally to characterize any type of exponential or non-exponential decay. For example, the medical sciences refer to the biological half-life of drugs and other chemicals in the human body.

The original term *half-life period* dating to Ernest Rutherford's discovery of the principle in 1907, was shortened to *half-life* in the early 1950s. Rutherford applied the principle of a radioactive element's half-life to studies of the age determination of rocks by measuring the decay period of radium to lead-206. ("Half-life - Wikipedia") Dr. Rutherford, a New Zealand Physicist is considered the "father of nuclear physics". ("Ernest Rutherford Biography | Biography Online") (A Force of Nature, n.d.)

So why does the RT care about half-life? There are two reasons:

1. Radiation safety protocols are dependent on calculating safe distances (Inverse Square Law Formula) and known radiation emissivity at any given distance from the gamma source. This can only be accomplished if the number of curies of the source is known. For example, if a patient has a 100-curie (ci) source of Iridium – 192 for interstitial radiotherapy (IRT), the standardized measurement of 5.2 R/h (Table 4.1) is emitted for each ci at 1 foot; therefore, a little math tells us that 100ci source multiplied by 5.2 R/h/ci has a total of 520 R/h. Appropriate shielding and safe distances (ALARA) will be calculated based on these calculated numbers.

Table 4.1



Dimensions and materials for the two types of iridium-192 seeds used for standardization measurements.

	Alpha-Omega Services, Inc.[a]	Rad-Irid Inc.[a]
Wall:		
Material	Platinum	Stainless Steel
Outside diameter	0.5 mm	0.5 mm
Wall thickness	0.1 mm	0.2 mm
Length	2.8–3.0 mm	3.0 mm
Source:		
Composition	10% Ir-90% Pt	30% Ir-70% Pt
Diameter	0.3 mm	0.1 mm
Activity (nominal)	56 MBq(1.5 mCi)	56 MBq(1.5mCi)

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6756240/table/T1/?report=objectonly public domain

2. Medical images (radiographs) are taken for diagnostic purposes or radiation therapy simulation. As in the safety protocols in item #1 above, a calculation of exposure times (how long to expose for a quality image and DDA's to the gamma radiation) must be

made. In keeping ALARA, the lowest amount of exposure time yields the lowest exposure dose.

Now, let's just fast forward to the scenarios above 74.3 days (the half-life of Ir-192), and our 100 ci source has decayed to 50 ci from the original 100 ci source, and all the safety protocols and exposure times have changed. Less shielding and distance are needed but more exposure time is needed to take the same image. Unit 6 explains the technical factors (techniques) used to produce quality images (radiographs).

ALARA: maintaining personal radiation exposure to "As Low As is Reasonably Achievable" involves the principles of Time, Distance, and Shielding. As has been demonstrated throughout this radiation protection and safety textbook, scientific and mathematical principles are the tools we use to determine what exactly is a safe Time or Distance as it relates to radiation exposure. Likewise, we use mathematical tools to determine the value of our radiation shielding to determine the Half-Value Layers (HVL).

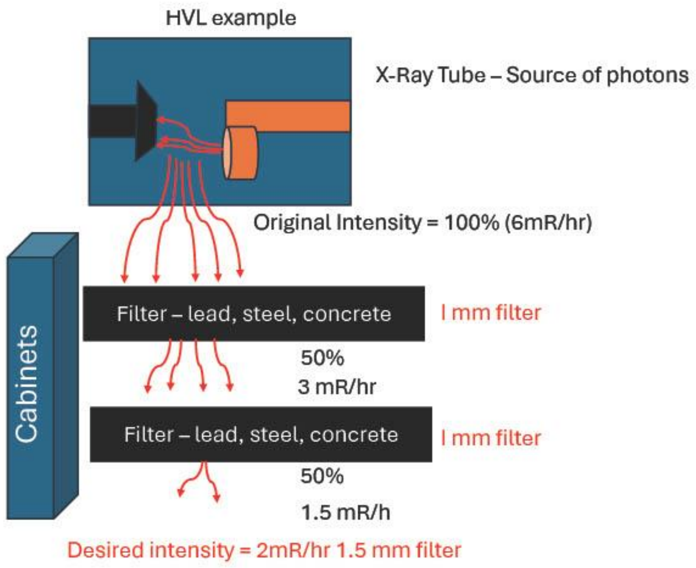
HVL (Half Value Layer): The amount (thickness) of a given shielding material needed to reduce the radiation emissivity by one-half its value. We use the following math formula to determine how thick of material it will take to reduce the radiation to a safe rate of emissivity.

HVL Formula: Io = Original Intensity   Id = Desired intensity

$$Log[\frac{Io}{Id}]/$$

What the HVL formula above accomplishes is how many HVLs are needed to reduce an **original intensity** to a **desired intensity**. For instance, in an imaging room, the lead lining in the 300 KV X-ray cabinets was calculated to a thickness that would provide an emissivity of 2mR/hr or less at one inch from any exterior point on the cabinet. However, how do we know how much lead, steel, or concrete to use? The most simplistic method would be to graph the original intensity down to the desired intensity. Note: The efficiency of a filter depends upon the type of material used, the energy of the beam, and the type of energy.

Fig. 4.1



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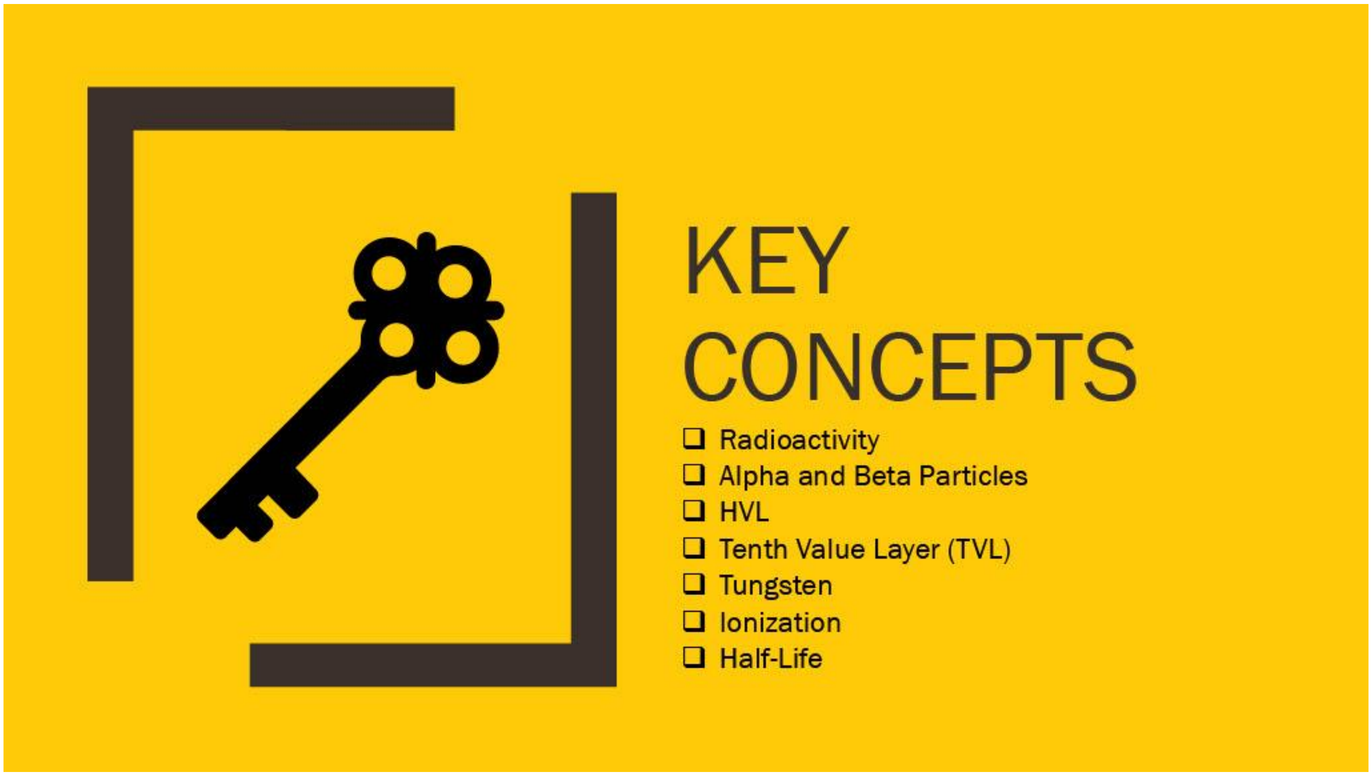
The table below shows approximately how thick the shielding material needs to be to reduce the radiation emissivity by one-half. It is important to note that different gamma sources require differing thicknesses of shielding to achieve the HVL. Also, note the most common shielding used is lead, iron, and concrete, but a few others are included as they are the preferred shielding in some applications. Tungsten and depleted uranium shield the isotopes used in portable gamma radiograph “cameras” and water, which are shielding materials of choice in nuclear reactors.

Table 4.2 Approximate Half Value Layers in cm (TVL in parentheses)

Energy (MeV)	Uranium	Tungsten	Lead	Iron	Concrete	Water
0.5			0.51	1.0	3.30	
1.0			0.76	1.52	4.57	
1.5			1.27	1.78	5.84	
2.0			1.52	2.03	6.60	
Ir-192	0.28	0.33	0.48	1.27	4.5	
Cs-137			0.65 (2.16)	1.6 (5.3)	4.8 (15.7)	
Co-60			1.2 (4.0)	2.1 (6.9)	6.2 (20.6)	
Ra-226			1.66 (5.5)	2.2 (7.4)	6.9 (23.4)	

Values retrieved from Wikipedia contributors. (2023). Half-value layer. Wikipedia. https://en.wikipedia.org/wiki/Half-value_layer public domain



KEY CONCEPTS

- ☐ Radioactivity
- ☐ Alpha and Beta Particles
- ☐ HVL
- ☐ Tenth Value Layer (TVL)
- ☐ Tungsten
- ☐ Ionization
- ☐ Half-Life

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Unit #4 Glossary of Terms

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Alpha Particles: Ionizing, particulate radiation, which can be deadly if ingested or inhaled. They are basically a Helium atom with a +2 charge, can travel only a few centimeters, can be stopped by a sheet of paper, and generally are not considered as dangerous as gamma radiation or Beta particles UNLESS they get inside the body – then they are easily absorbed by the cells and this is a dangerous condition.

Atom: The fundamental basic building block of matter made up of three subatomic particles called protons, neutrons, and electrons. The basic unit of a chemical element of the periodic chart.

Curie: (Ci) is the unit of measurement of the amount of radioactivity of a substance, named after Marie and Pierre Curie. $1\ \text{Ci} = 3.7\times10^{10}$ disintegrations per second (rate of decay)

Beta Particles: Ionizing, particulate radiation with almost zero mass (about 8,000 times smaller than Alpha particles) Travels several meters in air and travels at high velocity approaching the speed of light.

Electron: a stable subatomic particle with a charge of negative electricity, found in all atoms.

Gamma Radiation: is a penetrating, ionizing, electromagnetic radiation arising from the radioactive decay of atomic nuclei, containing the shortest wavelength of the electromagnetic spectrum.

Half-Life: the amount of time required for ½ of the original number of radioactive atoms to decay or change into daughter atoms.

Half-Life Ir 192: 74 days

Half-Life Co 60: 5.3 years

Half-Life Cs 137: 30.17 years

Ion: an atom or molecule with a net electric charge due to the loss or gain of one or more electrons. A positively or negatively charged atom or molecule.

Ionization: The removal of electrons from an atom. The essential characteristic of high-energy radiations when interacting with matter.

Ionizing Radiation: a type of radiation that is able to disrupt atoms and molecules through which it passes, giving rise to ions and free radicals.

Isotopes: atoms with same atomic number and chemical properties as element atoms; the nucleus has same number of protons but a different number of neutrons and thus, a different atomic mass and unlike radioisotopes can be relatively stable.

Daughter isotopes: In nuclear physics, a decay product (also known as a daughter product, daughter isotope, radio- daughter, or daughter nuclide) is the remaining nuclide left over from radioactive decay.

Neutron: a subatomic particle with about the same mass as a proton but without an electric charge. Neutrons are present in all atoms except the Hydrogen atom.

Nuclear Fission: The process by which the nucleus of a stable atom splits upon impact of another particle into 2 smaller parts. The resulting atoms are not the same element as the parent atom and are considered unstable and radioactive. This is the process by which Industrial isotopes (Cobalt 60, Iridium 192, Cesium 137) are created.

Nuclear Fusion: a nuclear reaction in which atomic nuclei of a lower atomic number fuse to form a heavier nucleus with the release of energy. The sun is an example of this process.

Particulate (or particle) Radiation is the radiation of energy by means of fast-moving subatomic particles. Alpha particles, Beta particles, neutrons, and positrons are examples of particulate radiation.

Photons: Discrete particles of light or electromagnetic radiation hypothesized to explain the corpuscular theory of radiant energy.

Proton: a subatomic particle present in all atomic nuclei, with a positive electric charge equal in magnitude to that of an electron, but of opposite sign.

Radiation: Energy in transit. Either as particles or electromagnetic waves.

Radioactivity: The characteristic of various materials to emit ionizing radiation.

Radioisotope: an isotope by nature that is always unstable, containing high levels of nuclear energy.

Roentgen (R) – is a unit of measurement to the exposure of ionizing radiation, specifically Gamma radiation and X- rays, named after the German physicist Wilhelm Conrad Röntgen.

milli-Roentgen (mR): One thousandth of a Roentgen (1/1000)

SI: The International System of units of measurement. Includes most of the base units formerly called metric.

X-ray – a type of ionizing radiation formed in a Cathode Ray Tube (CRT) when high velocity electrons flow from the cathode to the anode.

UNIT 5: X-RAY PRODUCTION

Learning Objectives:

Upon completion of this unit, the student will be able to define and understand the following:

- Describe the general design of an x-ray tube.
- Discuss the cathode and filament currents.
- Describe the parts of the anode
- Explain x-ray production
- List the main technical factors in creating photon energy, and
- What part of the X-ray beam do they control

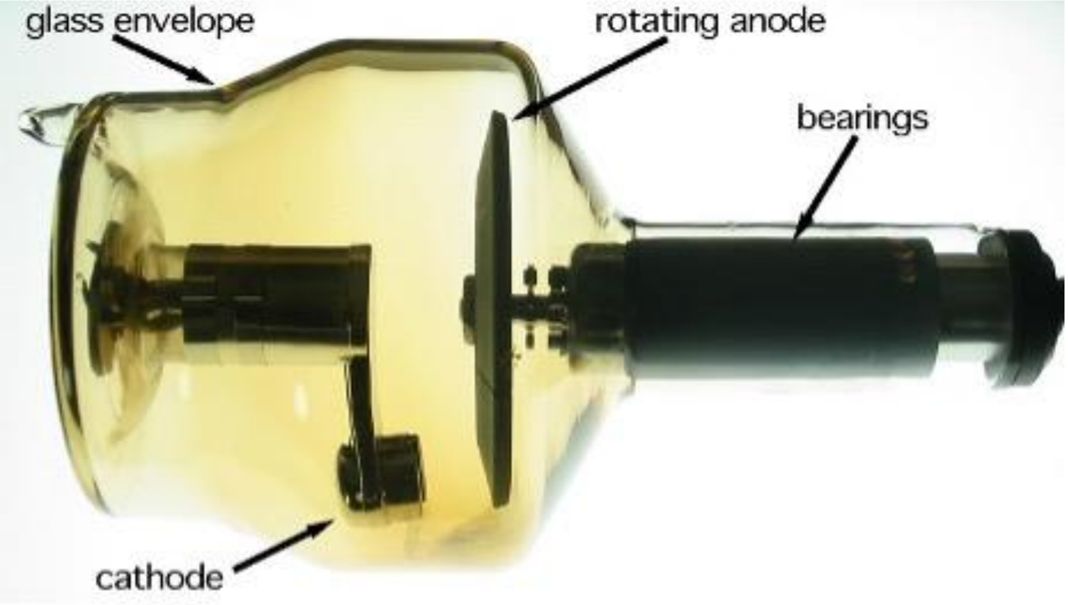
The X-ray Tube

X-Ray: X-ray, discovered by Wilhelm Conrad Roentgen in 1895 is widely used today both in the medical and industrial radiography fields. X-rays or x-ray photons are generated when a high electrical voltage is introduced in a special vacuum tube via a hot cathode. The high-energy electrons are directed towards a metal Anode – usually a tungsten target – and when the electrons collide with the anode x-ray photons are generated and aimed in a specific direction and pattern.

The resulting X-ray photons are non-particulate, ionizing radiation with the ability to penetrate matter. X-rays of the same energy level will be absorbed more readily by dense material as compared to less dense material. This is the reason lead, tungsten, and concrete are used for shielding radiation. But since the x-rays (and gamma rays) are invisible, and have no smell or no taste, how do we know if we're being exposed to ionizing radiation? Often, people think X-rays are continuously on because they do not know X-rays, and gamma rays have to be produced in an X-ray system.

The core of an X-ray system and the source of the ionizing radiation production is the X-ray tube (a large diode). X-rays (photons) are emitted when a high-speed electron hits a metal target called the anode. Only 1% of the energy in the electron beam is converted to photons the rest is converted to heat. This creates a lot of heat inside the vacuum which is problematic whereas the tube can overheat and 'crack'. A large anode, usually made of Rhenium-alloyed tungsten or molybdenum is used to absorb the heat. To increase the heat capacity, X-ray tubes have rotating tungsten disk that helps to dissipate the heat over a larger target area. As the anode rotates through 360°, that spot of the anode being bombarded by the high energy electron stream has a chance to cool down. So, where do these high-energy, fast-moving electrons come from within the vacuum glass tube?

The Cathode is the other terminal inside of the vacuum glass tube. A diode has two terminals the anode which is the positive semiconductor and the cathode which is the negative semiconductor. The cathode is also referred to as cathode assembly because it consists of two parts: the filament and the focusing cup. the cathode (filament) is heated to cause the release of electrons these are accelerated by a high voltage towards the anode. Thermionic emission is dependent on the current used to heat the filament and boil off electrons which stay station around the filament (space charge) until they are accelerated by a high voltage towards the anode.



Typical rotating anode x-ray tube by Daniel W. Rickey is CC BY-SA 3.0

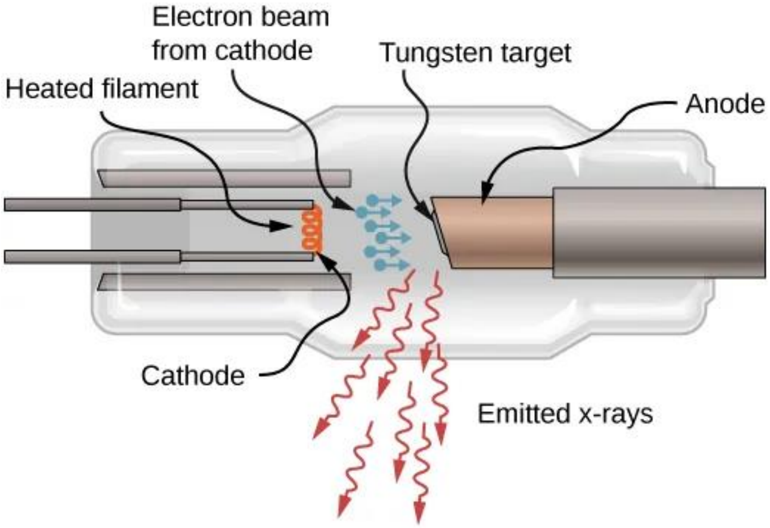
In Radiation Therapy, the linear accelerator produces ionizing radiation of either electrons or very high-energy X-rays. How the X-ray beam is generated is very similar to an X-ray tube in that it is a diode (positive target and negative cathode). The beam is generated when radio frequency waves are pulsed into the waveguide by the magnetron. This is synchronized with the injection of electrons into the waveguide by the electron gun. The radio frequency waves accelerate the electrons along the waveguide to a speed approaching the speed of light. The X-ray beam is created when the electrons hit and interact with a tungsten target at the opposite end. The magnetron controls the power and frequency of the radiofrequency waves which determine the energy of the X-rays produced. The accelerator uses a diode-type electron gun situated at the end of the waveguide. The electrons are produced by heating the tungsten filament within the cathode and are then injected into the waveguide. The number of electrons injected is controlled by the temperature of the filament. The electrons are accelerated along the waveguide toward the target, similar to how the focusing cup of the cathode assembly operates.

This is a video link How a Linear Accelerator Works

X-Ray Production

X-ray production requires three things to occur:

⇒ a source of electrons that's thermionic emission (cathode)
⇒ a means of accelerating the electrons that's the (KVP)
⇒ the means of decelerating the electrons that happen (anode)



File:OpenStax UPhysicsV3 8.21 X-ray Tube sketch.webp - Wikimedia Commons, 2016 public domain

The number of X-rays and the energy of X-rays are controlled by the operator. The X-ray beam of exposure can be adjusted with these three key primary factors:

1. The KVP or the kilovoltage peak sometimes referred to as KV for convenience
2. The mA, which is the tube current in milliamps
3. Time in seconds, how long the process is applied. The current and time are multiplied together to give the mAs (how much for how long)

The application of a given mA, KVP, and exposure time produces the photon energy. Increasing the mA or the tube current increases the number of electrons produced in the X-ray tube. Increasing the number of electrons increases the number of photons this is the idea of intensity or quantity. The effect of changing the kVp is slightly different. Increasing the kVp increases the tube's potential (I often refer to the kVp as kilovoltage potential instead of kilovoltage peak to remember the tube's potential is based on the voltage). The energy of electrons produced in the X-ray tube moves faster and harder with higher voltage. The increased electron energy results in increased photon energy. This is referred to as the beam quality. Increased electron energy also increases the total number of X-rays produced. This occurs mainly because high-energy electrons are more likely to be converted into photons. Furthermore, increasing kVp increases both the number and energy of X-rays (photons) created. Increasing the exposure time also increases the total number of X-ray photons. The exposure time is just the amount of time that electrons are flowing through the tube, bombarding the target (anode) where the photon energy is being created.

mA and exposure time in seconds influence the total number of X-rays created (quantity). KVP influences both the number (quantity) and the energy of it (quality).

This is a video link Production of X-rays

Production and ALARA

ALARA is how the technical parameters can be manipulated to reduce exposure while maintaining quality images or for Radiation Therapy, protect unaffected tissues (normal tissues). First, it is important to have a clear understanding of the different parameters that are typically set on the console of the equipment. These are the ones that affect the X-ray generation and the duration of time that those X-rays are on. We learned that x-rays are produced in the vacuum tube by applying the kVp, the mA, and the time. All of these should be considered as one. The exposure or the intensity of X-rays that are created and measured (Unit of measurements Unit 2) are related to these technical parameters, and X-ray production cannot occur without all three.

Things you need to know about how the different technical factors are related to X-ray exposure. The factors are listed in the order of importance to ALARA.

Exposure Time – calculated in seconds to determine photon energy (quantity). Selecting the time on the equipment console is usually provided in milli-seconds (msec). Exposure time is linearly related to exposure dose. Decreasing time would:

Decrease the number of electrons ‘boiled’ off the cathode – decreased quantity
Decrease the amount of time the electron stream interactions with the target – decrease quantity and quality
Decrease the amount of time the patient is exposed to the beam – decrease quantity

Decrease the amount of time in the vicinity of an X-ray source - decrease quantity and quality
Note: Radioisotopes (Nuclear Medicine) and some treatment units still operating in the United States where the source of the energy is never ‘off’. It stands to reason the less time in or around the unit, the less exposure dose.

Kilovoltage potential (kVp) – is one of the two primary controls that the technologist controls in the production of x-rays and beam quality and quantity (photon energy). The X-ray tube and equipment are parts of the X-ray circuits where the potential between the cathode and the anode is applied. The electrons coming off the cathode (space charge) have potential energy and when an electrical charge (voltage) is applied, those electrons are driven from the cathode to the anode. As the electron stream travels from the cathode with high energy (kVp), its energies are converted from potential energy to kinetic energy. As previously noted, radiation therapy units operate at mV (much higher energy).

Changes in kVp (such as increasing energy to mV) have important effects on just about everything. Changes in kVp affect the beam quality (strength of the photon), and the energy of the beam quantity (the intensity or number of photons), and it also affects the patient dose as well as the occupational or public dose. When the kVp is increased, it creates a larger voltage difference across the X-ray tube. This causes the electrons to move more quickly which then gives them more energy and produces a higher energy X-ray beam. When we decrease the kVp a smaller voltage difference across the tube is created and therefore the electrons move more slowly through the X-ray tube they have less energy than the X-ray beam. Only the kVp can change the x-ray beam energy, not mA, time, or distance.

The kVp is mathematically equal to the maximum beam energy. For example: if the KVP is set to 100 the maximum energy photons in the beam are going to be 100 keV (not all photons in the beam will have 100 keV but some will).
100 kVp = 100 keV
100 mV = 100 MeV

keV is an acronym for kilo-electron volts and MeV is the acronym for mega-electron volts which are the unit of measure for quantifying the energy of X-ray photons. Changes in kVp also influence the patient dose. Increasing the kVp increases the dose to the patient. This is because increasing kVp creates more X-ray photons which means more photons are striking the patient. The reverse is also true in that if the kVp is decreased, the patient dose will also decrease! 😕 You might think the above statement is untrue, but it is not! The above statement refers to the quantity created in the X-ray beam with increased kVp. The above statement can be confusing. You might ask “Doesn't an increase in kVp increase penetration through the patient?” Yes, that is correct. Increasing KVP increases the number of photons passing through the patient and it increases the number of photons absorbed in patients. This happens because increasing kVp increases both the energy and intensity of the beam. Therefore, when practicing **ALARA**, the recommendation is to utilize a high kVp (appropriate for the image) with low mAs (mA, time, and mAs are discussed next).

Milliamperage (mA), Time (seconds), and milliamperage per sec – X-rays are produced when electrons travel from the cathode filaments and interact with atoms in the anode target. This movement of electrons is what’s called the tube current. The tube current is measured in units of milliamperes which is abbreviated mA. So, simply the movement or flow of electrons in the X-ray tube is the tube’s current. I like to use the flow of water in a river as an analogy for an X-ray tube current. Imagine standing on the bank of a river watching the water flow downstream. The water is a little rough and fast moving like a water rapid. If the mA is increased at the x-ray control console, this results in an increase in the tube’s current (increased rapid) which is simply an increase in the rate of electrons flowing through the tube, and this in the end increases the total number of X-rays produced. Now imagine standing on the bank of a river. This river is calm and there is a slow flow of water traveling downstream. So, conversely, if we decrease the mA of the X-ray control console, this decreases the tube current which is by definition a decrease in the rate of electrons flowing through the X-ray tube and this finally decreases the number of X-rays produced. It is easy to see how aggressively the surging, churning, and crashing rapids can relate to the increased number of electrons bombarding the target producing increased energy turbulence.

Time – is described as the actual time the X-ray tube is on during. On the X-ray machine console, the operator selects the exposure factors (kVp, mA, and time). The exposure time is selected based on the overall exposure (mAs) needed to produce a quality image. In other words, mA creates the quantity (number) of electrons (how much) while the time in seconds indicates how long. Exposure time and mA are inversely proportional to the overall exposure. Let’s use water as an analogy again. This time, a sink has been plugged in and needs to be filled with water (1/2 full). If the facet was turned on using the spay nozzle (low mA). It would take a long time to reach the halfway mark. As opposed to opening the facet at full strength (high mA), the time it would take to fill the sink to the halfway mark would be much faster.

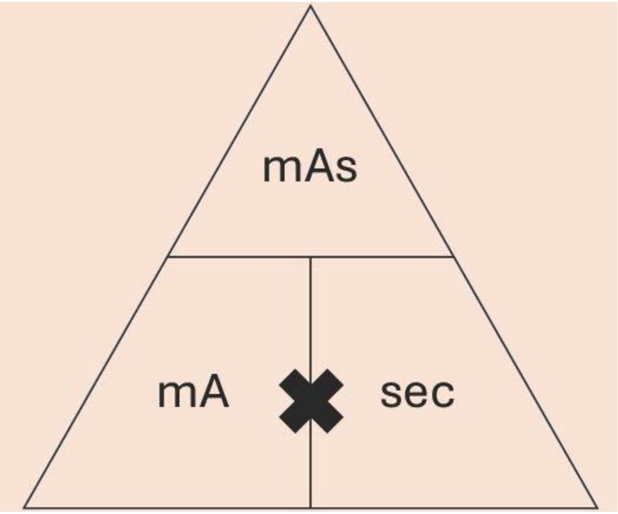
Let’s look at the following mathematical formula solving for exposure dose (mAs).

mAs = tube current (mA) x time in seconds

mAs = How much for How long

mA = mAs divided by sec (mA/sec)

Time (s) = mAs divided by mA (mAs/mA)



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Modern Imaging Equipment

Radiographic imaging has seen remarkable technical development in the last 40 years. Digital imaging is now the standard across the modalities since it was introduced for clinical use in computed tomography (CT) in the 1970s. CT was the first imaging modality to add a computer application to ionizing radiation equipment. Over the past twenty years, computer applications have been applied to all modalities. The first version of the digital imaging system was the computed radiography (CR) system in 1983.

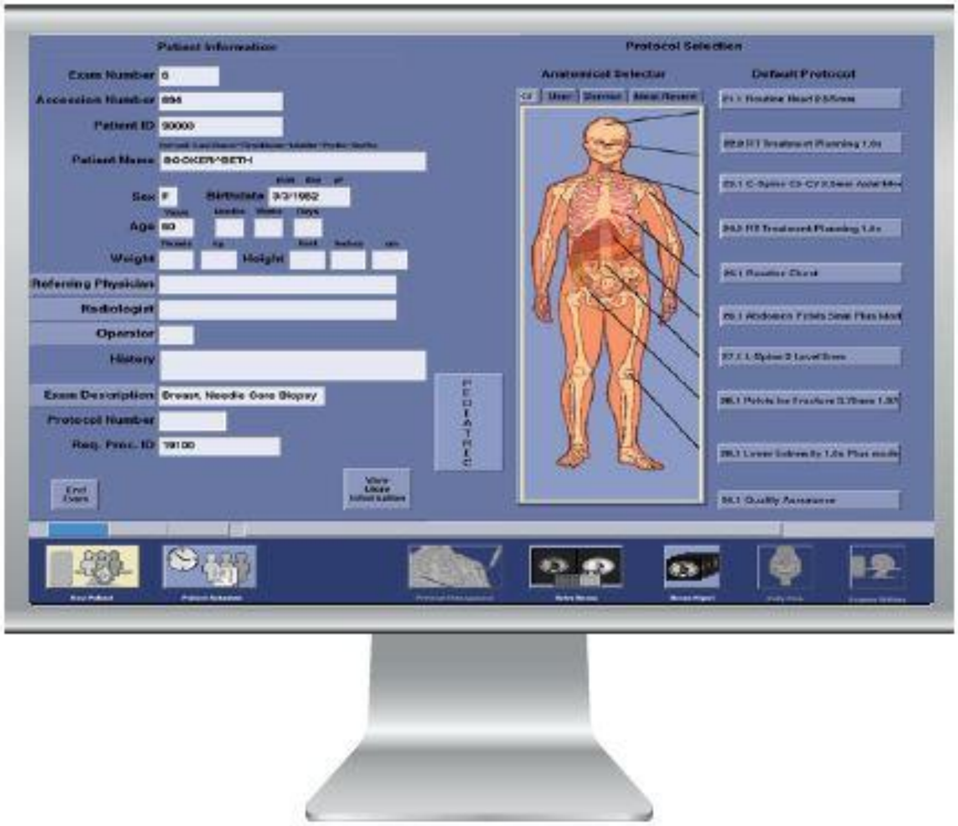
The advent of digital technology has significantly impacted the practice of ALARA (as low as reasonably achievable). ALARA, derived from the Linear No Threshold Hypothesis (LNT), is a principle that acknowledges radiation risks increase linearly with dose and that no safe dose exists. Not only is ALARA considered a rule of thumb, but it is also a legal requirement in various regulatory agencies such as the US Federal 'Code of Federal Regulations,' the Nuclear Regulatory Commission (NRC), and the National Council on Radiation Protection and Measurements (NCRP). With digital imaging, technical factors are conveniently preprogrammed, eliminating the need to manually select parameters like KVp, MA, time, or MAs. These precalculated factors are either displayed by the image itself or by the name of the procedure being performed. Regardless, it remains important to limit exposure to only what is necessary.

Radiation exposure comes with certain risks, and even with more control of all the parameters using digital radiography (DR), it is still crucial to avoid unnecessary exposures. One such risk with DR is what is referred to as ‘dose creep.’ Dose creep is the process of selecting digital presets without consideration of any variations needed, leading to potential overexposure of patients. This practice can result in underexposed images if the preset is too low, which cannot be digitally corrected and must be repeated.

In a fast-food restaurant, the role of a cashier is crucial in ensuring accurate transactions. This includes selecting the images of the items ordered, collecting the amount from customers, and ringing up the change. However, when the digital readout suddenly stops displaying the change, it creates an opportunity for errors to occur. This phenomenon is similar to dose creep in radiology. Technologists may become complacent in selecting presets and adjusting images without reviewing their choices. Unfortunately, this practice leads to an increase in radiation dose for patients as inappropriate high radiographic techniques are selected with the assumption that the image can be easily rescaled. To maintain the principles of ALARA (As Low As Reasonably Achievable), it's crucial for technologists to avoid dose creep by being mindful and thorough when selecting presets and adjusting images.

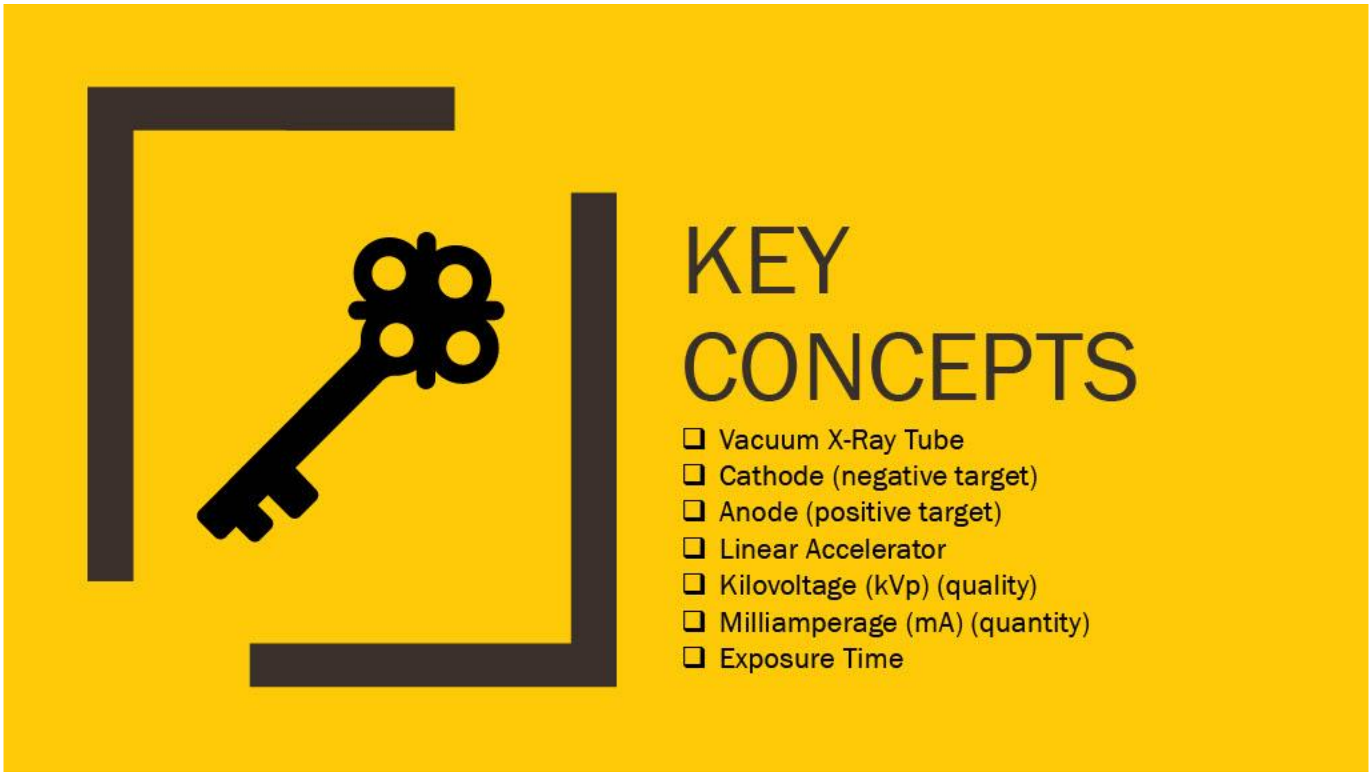
At a correctional facility health clinic, a recurring situation involved the weekly performance of chest X-rays for tuberculosis screening. It was protocol to use the preset settings for large patients, regardless of the patient's size or condition. This oversight in customization could potentially lead to inaccurate results and impact the overall effectiveness of tuberculosis screening within the facility. It was clear that a more individualized approach was needed to ensure accurate and reliable diagnoses for all patients while maintaining ALARA.

In the field of technology, it is essential for technologists to have a strong understanding of how to manually select the appropriate techniques. Just as the cashier needs to know how to process transactions manually in case of technical issues, a technologist must be able to navigate and troubleshoot various technologies without relying solely on automated processes. This level of expertise ensures that they can effectively address any challenges that may arise in their work.



Exam Number 6
Accession Number 894
Patient ID 90000
Patient Name BOOKER^SETH
Sex F Birthdate 3/3/1962
Age 60
Weight
Height
Referring Physician
Radiologist
Operator
History
Exam Description Breast, Needle Core Biopsy
Protocol Number
Req. Proc. ID 19100

Gulley, Brandy (GE Healthcare) https://images.app.goo.gl/7U9VFHGB7qwkFFxHA



KEY CONCEPTS

- ☐ Vacuum X-Ray Tube
- ☐ Cathode (negative target)
- ☐ Anode (positive target)
- ☐ Linear Accelerator
- ☐ Kilovoltage (kVp) (quality)
- ☐ Milliamperage (mA) (quantity)
- ☐ Exposure Time

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Unit #5 Glossary of Terms

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Coolidge Tube - An X-ray tube is a vacuum tube that converts electrical input power into X-rays.

Digital imaging (radiography) - Digital radiography is a form of radiography that uses x-ray–sensitive plates to directly capture data during the patient examination, immediately transferring it to a computer system

Diode - A diode is a two-terminal electronic component that conducts current primarily in one direction

Exposure Time - the amount of time required to produce the x-ray or photon energy

Kilovoltage potential - Peak kilovoltage (kVp) refers to the maximum high voltage applied across an X-ray tube to produce the X-rays. Potential refers to the stored energy or the ability of the x-ray tube to do work

Linear Non-threshold (LNT) - a dose-response model used in radiation protection to estimate stochastic health effects such as radiation-induced cancer, genetic mutations and teratogenic effects on the human body due to exposure to ionizing radiation.

Milliamperage (mA) - represents the amount of current passed through the X-ray tube.

Milliamperage per second (mAs) - Current and exposure time are often reported together in the following way: current (mA) x time (s) = mA-seconds (mAs). The product of mAs represents the total amount of radiation exposure.

Overexposure – represents of too much photon energy produced (high kVp and/or high mAs) resulting in an overexposed image (black) and increase radiation exposure to the patient, staff and public.

Quality – refers to the x-ray energy (photon) penetrating power in the primary beam.

Quantity – refers to the number of photons within the primary beam

Thermionic emission - is the emission of electrons from a heated metal (cathode). May be described as the discharge of negative particles (electrons) from the cathode of an x-ray tube.

Underexposure – represents not enough photon energy. An underexposed image appears light (white) and often deemed unacceptable same as overexposed images.

UNIT 6: X-RAY

Learning Objectives:

Upon completion of this unit, the student will be able to define and understand the following:

- List the major organizations responsible for evaluation, monitoring, establishing, and regulating medical radiation
- Identify the US regulatory agencies enforcing radiation protection and safety practices
- Explain the described methods for radiation protection initiatives

Several regulatory bodies oversee radiologic sciences, including federal agencies, international organizations, and other agencies:

Federal agencies

Agency	Role/Responsibility	Website
Nuclear Regulatory Commission (NRC)	Oversee the safe use of radioactive materials and protecting people and the environment. Regulating commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine. Ensures that facilities utilizing radioactive materials adhere to strict safety standards. This includes monitoring radiation levels, conducting regular inspections, and enforcing compliance	nrc.gov

	with regulatory requirements.	
Food and Drug Administration (FDA)	The FDA - Center for Devices and Radiological Health (CDRH) is entrusted with the vital responsibility of safeguarding public health by ensuring the timely availability of safe, effective, and high-quality medical devices, as well as safe radiation-emitting products that protect both the patients and healthcare providers.	fda.gov/radiation
Environmental Protection Agency (EPA)	Setting and enforcing environmental standards to protect human health and the environment from the use of radioactive materials by establishing protective limits on the radioactivity in soil, water and air that comes from human activities.	epa.gov/radiation
Occupational Safety and Health Administration (OSHA)	Sets and enforces protective workplace safety and health standards.	osha.gov/radiation
Department of Energy (DOE)	Environment, health, safety and security (EHSS) is a unit of the DOE responsible for developing and maintaining nuclear safety policies, requirements, and	energy.gov/radiation energy.gov/occupational-radiation-exposure

	guidance of hazards and accidents. EHSS maintains nuclear facility design, operations, maintenance, training, nuclear safety research and QA requirements.	
Department of Transportation (DOT)	Responsible for regulating and ensuring the safe and secure movement of hazardous materials to industry and consumers by all modes of transportation, including pipelines.	dot.gov/radiation Minimum Packaging Required for Radioactive Materials
States that Regulate (Agreement States)	*Licensure* - Permission granted by state to practice; states varying in terminology: license, certificate, permit. *Standard* - regulatory board has required some education and training to be allowed to practice. *Equipment* - regulation around the operation of specific equipment has operator requirements	asrt standards, regulations, and legislation

International organizations

Agency	Role/Responsibility	Website
International Commission for Radiation Protection (ICRP)	International organization that provides recommendations and guidance on all aspects of protection against ionizing radiation.	icrp.org

	Legislation in most countries adheres closely to ICRP recommendations and forms the basis of radiation protection and safety standards, legislation and practices worldwide.	
International Atomic Energy Agency (IAEA)	Provide the fundamental principles, requirements and recommendations to ensure nuclear safety of medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste.	iaea.org
National Council on Radiation Protection and Measurements (NCRP)	Disseminates information, guidance and recommendations on radiation protection and measurements, with a focus on radiation properties and effects measurement techniques employed and the quantities and units used to be comparable throughout the United States and the world. Recommendations of the Council are important to radiation users — medical, industrial and	ncrponline.org

	governmental; to the general public; and to other state, national and international groups.	
United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)	Collects and evaluates exposures to the human population worldwide from all natural and man-made sources of ionizing radiation. Reviews and reports on the current understanding of the biological effects of exposure to ionizing radiation at the molecular, cellular and tissue levels, as well as human health risks and effects on the natural environment. *does not develop policy or provide advice to governments or regional or international bodies.	unscear.org
National Academy of Sciences/National Research Council Committee on the Biological Effects of Ionizing Radiation (NAS/NRC-BEIR)	Provides independent, objective analysis and advice to the nation on issues related to science and technology. Published *Health Effects of Exposure to Low Levels of Ionizing Radiation*.	nasonline.org

Professional Organizations

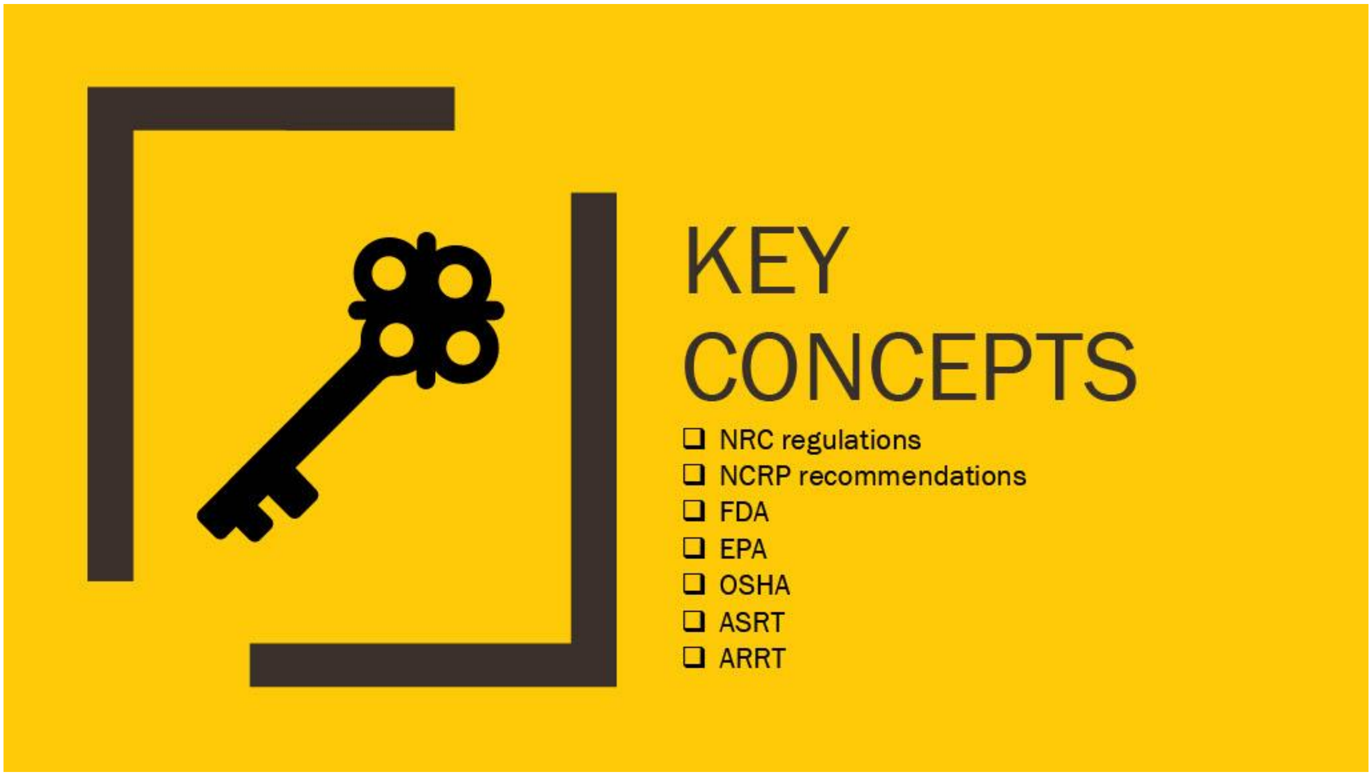
Agency	Role/Responsibility	Website
American Society of Radiologic Technologists (ASRT)	Premier professional association for the medical imaging and radiation therapy community. Governing body for professional scope of practice and development of the educational curricula.	asrt.org
American Registry of Radiologic Technologists (ARRT)	Leading credentialing organization for medical imaging, interventional procedures, and radiation therapy. Certify and register technologists in a range of disciplines by overseeing and administering education, ethics, and examination requirements.	arrt.org
American Association of Physicists in Medicine (AAPM)	Supports the Medical Physics community with a focus on advancing patient care through education, improving safety and efficacy of radiation oncology and medical imaging procedures through research, and the maintenance of professional standards.	aapm.org
American College of Radiology (ACR)	A professional medical society which provides accreditation in	acr.org

	Mammography, CT, MRI, Breast MRI, Nuclear Medicine and PET, Ultrasound, Breast Ultrasound and Stereotactic Breast Biopsy.	
Radiological Society of North America (RSNA)	Non-profit organization and an international society of radiologists, medical physicists and other medical imaging professionals representing 31 radiologic subspecialties from 145 countries around the world. It is one of the largest radiological societies in the world. Committed to excellence in patient care and healthcare delivery through education, research and technologic innovation.	rsna.org
Joint Review Committee on Education in Radiologic Technology (JRCERT)	Is the only organization recognized by the United States Department of Education (USDE) and the Council for Higher Education Accreditation (CHEA) for the accreditation of traditional and distance delivery educational programs in radiography, radiation therapy, magnetic resonance, and medical dosimetry.	jrcert.org

The Joint Commission	Is an organization that accredits US health care organizations and programs. It has been the gold standard for patient safety & care.	jointcommission.org

Joint Initiatives Radiation Protection and Safety Measures

Organization	Role	Website
Image Wisely	Raise awareness and provide up-to-date educational resources for radiology professionals and referring clinicians regarding the safe use of adult medical imaging. Improve safe and effective imaging care of children worldwide by raising awareness of the opportunities to lower radiation dose in the imaging of children.	imagewisely.org
Image Gently		imagegently.org
Background Equivalent Radiation Time (BERT)	a unit of measurement of ionizing radiation dosage amounting to one day worth of average human exposure to background radiation.	nrc daily radiation doses



KEY
CONCEPTS

- ☐ NRC regulations
- ☐ NCRP recommendations
- ☐ FDA
- ☐ EPA
- ☐ OSHA
- ☐ ASRT
- ☐ ARRT

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Unit #6 Glossary of Terms

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Accreditation - a formal, independent verification that a program or institution meets established quality standards resulting status; certification

Agency – an organization established to provide a specific service

Compliance – the act of meeting, adhering to, or practicing according to an established standard

Council – an advisory or legislative body of people selected to provide advice

Enforcing – to ensure observance or obedience to a set standard

Federal - a system of government that unites several states under a central government

Governing - having authority and responsibility for making and enforcing rules and laws.

Mandate - an official command or order to carry out a particular policy or task

Principles - a system of beliefs, behaviors, standards or rules to guide conduct

Recommendations – suggestions or advice for the best course of action

Regulating – to control, govern, or direct according to the rule

Society - an organization or group formed for a particular purpose or activity

Standards - applies to any definite rule, principle, or measure established by authority

UNIT 7: Biological Effects

Learning Objectives:

Upon completion of this unit, the student will be able to define and understand the following:

- The two general categories of biological impact of ionizing radiation.
- The units of measurement for radiation exposure.
- Solving for the radiation quality factor
- Biological effects based on exposure rates

Effects of Radiation

Radiation Symptoms occur because of overexposure to radiation. Most are familiar with the effects of spending too much time in direct sunlight on a hot summer's day – the result is a sunburn. Sunburns occur when an individual's skin is overexposed to the sun, and the medical community has gone to great lengths to educate people on the harmful effects of the sun's radiation. These harmful effects vary from uncomfortable red, inflamed skin to severe blistering demanding medical treatment. So, how does one prevent a sunburn? Spend less TIME in the sun. Cover your skin with clothes, shade, or sunscreen (SHIELDING). This sounds a lot like the ALARA principle of TIME, DISTANCE, and SHIELDING.

We can feel the gentle warmth of the sun's rays on our body, but the damage being done is slow, and the pain is a delayed response to the overexposure of sunlight. Likewise, the ionizing radiation of gamma and x-rays are invisible; they have no smell, but unlike the sun, they cannot be felt at all.

The biological effects of radiation fit into two general categories:

1. **Acute radiation exposure** is when an individual receives a high radiation dose over a relatively short period of time. Acute radiation exposure is also called Acute Radiation Syndrome (ARS). ARS results when an individual receives a whole-body exposure of 100 to 200 Rems or more (Roentgen

Equivalent Man) over 24 hours. The table below shows the likely symptoms associated with differing levels of exposure.

2. **Chronic radiation exposure** occurs over an extended or prolonged time, and the results vary depending on the dose of exposure, duration of exposure, and individual reaction to the over-exposure.

Roentgen (R), Radiation Absorbed Dose (RAD), Roentgen Equivalent Man (REM), and Quality Factor (QF) are units of radiation measurement, and the radiographer needs to discern between them.

Roentgen (R) is the unit used to measure radiation exposure in **AIR** for X-rays and gamma rays, which is based on the ionization produced in air. More specifically, the Roentgen is defined as “the radiation flux which will produce 2.083 x 109 ion pairs per cubic centimeter (one electrostatic unit of charge either positive or negative) at a standard temperature and standard pressure (0° C and 760 mm Hg). But for all practical purposes – commit to memory that Roentgens measure ionizing radiation in the air.

Radiation Absorbed Dose (RAD) is the accepted unit of measurement of absorbed dose in **tissue**. 1 RAD represents 100 ergs of energy imparted per gram of material at the place of exposure.

Quality Factor (QF) is a factor or multiplier of the actual biological effects or damage of the specific radiation type on the human tissue. In a sense, not all Roentgens impart equal damage to tissue, and therefore, we use a QF multiplier to calculate the Roentgen Equivalent Man (REM). Table 7A below will demonstrate the various QF values of differing ionizing radiation sources.

Roentgen Equivalent Man (REM) is defined as the quantity of ionizing radiation of any type which, when absorbed in a biological system, results in the same biological effects as one unit of absorbed dose in the form of low linear energy transfer (LET) radiation. More practically, REM is defined as the product of the RAD multiplied by the QF.

RAD x QF = REM

For example, an exposure to 1 R of gamma or X-rays is equal to 1 REM because the

QF of gamma and X-rays are 1. However, exposure to 1R of alpha particles is equal to 20 REM due to the QF of 20 for alpha particles. All things being equal, alpha particles are 20 times worse for human tissue than gamma or x-rays. It is critical for individuals working in nuclear facilities and performing gamma radiography to clearly understand the simple equation above and calculate the REM dose accurately.

The following data is compiled from the NRC and can be seen in an expanded format. nrc.gov

TABLE 7-1: Quality Factor (QF)

Types of Radiation	Quality Factor (QF)
X-Rays	1
Gamma Rays	1
Beta Particles	1
Neutron Radiation	10
High-Energy Protons	10
Alpha Particles	20

TABLE 7-2: Biological Effects Based on Exposure Rates

Dose	Summary of Biological Effects
<5 rad	No immediate observable effects
~5 to 50 rad	Slight blood changes may be detected by medical evaluations
~50 to 150 rad	Slight blood changes will be noted, and symptoms of nausea, fatigue, vomiting, etc., likely
~150 to 1,100 rad	Severe blood changes will be noted, and symptoms appear immediately. Approximately 2 weeks later, some of those exposed may die. At about 300 – 500 rad, up to one-half of the people

	exposed will die within 60 days without intensive medical attention. Death is due to the destruction of the blood forming organs. Without white blood cells, infection is likely. At the lower end of the dose range, isolation, antibiotics, and transfusions may provide the bone marrow time to generate new blood cells, and full recovery is possible. At the upper end of the dose range, a bone marrow transplant may be required to produce new blood cells.
~1,100 to 2,000 rad	The probability of death increases to 100% within one to two weeks. The initial symptoms appear immediately. A few days later, things get very bad, very quickly, since the gastrointestinal system is destroyed. Once the GI system ceases to function, nothing can be done, and medical care is for comfort only.
>2,000 rad	Death is a certainty. At doses above 5,000 rad, the central nervous system (brain and muscles) can no longer control body functions, including breathing and blood circulation. Everything happens very quickly. Nothing can be done, and medical care is for comfort only.

Week 7 Glossary of Terms

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Acute radiation exposure is when an individual receives a high radiation dose over a relatively short period of time. Acute radiation exposure also called Acute Radiation Syndrome (ARS). ARS results when an individual receives a whole-body exposure of 100 to 200 Rems or more (Roentgen Equivalent Man) over a 24-hour period of time.

Alpha Particle: A positive electrically charged particle of radiation consisting of two protons and two neutrons (same as a helium nucleus). It is emitted from the nucleus of many radioactive materials during radioactive decay. Alpha particles have a very low kinetic energy and therefore can be stopped by a sheet of paper or clothing. However, if ingested, alpha particles have a Quality Factor (QF) of 20 times that of straight gamma or X-ray radiation, making them dangerously toxic if inhaled or ingested.

Beta Particle: negatively charged particles having mass and charge equal in magnitude to that of an electron.

Biological half-life: the amount of time required for one half of a radioactive substance to be removed (from a human) by the natural biological processes (urination, sweating, bowel movements, vomiting)

Chronic radiation exposure occurs over an extended or prolonged period of time and the results are often varied depending on the dose of exposure, duration of exposure and individual reaction to the over-exposure.

Gamma Radiography: Radiographs (film, DDA plates, CR plates) are exposed using a gamma ray camera or radiograph shooting machine which can be portable, fixed in a cabinet or located in a vault.

Gamma Source (source): Industrial gamma radiography typically uses a man=made (activated) radiation source (Cobalt-60, Iridium-192, and Cesium-137). These sources are typically created for specific purposes and applications.

Gamma Radiation: is a penetrating, ionizing, electromagnetic radiation arising from the radioactive decay of atomic nuclei, containing the shortest wavelength of the electromagnetic spectrum.

Ionizing Radiation: a type of radiation that is able to disrupt atoms and molecules on which they pass through, giving rise to ions and free radicals.

Neutron: a subatomic particle with about the same mass as a proton but without an electric charge. Neutrons are present in all atoms except the Hydrogen atom.

Particulate (or particle) Radiation: is the radiation of energy by means of fast-moving subatomic particles. Alpha particles, Beta particles, neutrons, and positrons are examples of particulate radiation.

Photons: Discrete particles of light or electromagnetic radiation hypothesized to explain the corpuscular theory of radiant energy.

Roentgens (R), is the unit of measuring radiation exposure in **AIR** for X-rays and gamma rays, which is based on the ionization produced in air. More specifically, the Roentgen is defined as "the radiation flux which will produce 2.083 x 109 ion pairs per cubic centimeter (one electrostatic unit of charge either positive or negative) at a standard temperature and standard pressure (0° C and 760 mm Hg). Nevertheless, for all practical purposes – commit to memory that Roentgens are a measure of ionizing radiation in air.

Radiation Absorbed Dose (RAD) is the accepted unit of measurement of absorbed dose in **tissue**. 1 RAD represents 100 ergs of energy imparted per gram of material at the place of exposure.

Quality Factor (QF) is a factor or multiplier of the actual biological effects or damage of the specific radiation type on the human tissue. In a sense, not all Roentgens impart equal damage to tissue and therefore we use a QF multiplier to calculate for the Roentgen Equivalent Man (REM).

Roentgen Equivalent Man (REM) is defined as the quantity of ionizing radiation of any type which, when absorbed in a biological system, results in the same biological effects as one unit of absorbed dose in the form of low linear energy transfer (LET) radiation. More practically, REM is defined as the product of the RAD multiplied by the QF.

X-ray – a type of ionizing radiation formed in a Cathode Ray Tube (CRT) when high velocity electrons flow from the cathode to the anode.

UNIT 8: MORE BIOLOGICAL EFFECTS OF RADIATION

Learning Objectives:

Upon completion of this unit, the student will be able to define and understand the following:

- The biological factors affect radiation response.
- The correlation between radiation exposure and malignancy.
- Annual dose limits as established by the NRC
- Radiation dose ranges associated with each specific acute biological effects
- How to adjust the technical factors to reduce exposure

More Effects of Radiation

In previous units, the biological effects of radiation exposure on the body and the units used to measure these exposures were addressed. Unit 8 will review those units and expand into detail on the specifics of the biological effects of radiation exposure or *overexposure*.

The Biological Effects of radiation poisoning or overexposure to the whole body are divided into three general categories by the USNRC, and they are:

1. **Somatic Effects:** a person receiving somatic effects might exhibit **prompt** symptoms such as minor to severe skin burns, cataracts on the eyes, and even severe internal organ and blood damage. A person might also experience **delayed** (somatic effects) such as cancer due to damaged and mutating cells in the body.

2. **Genetic Effects:** a person can experience genetic mutations and changes in their DNA that can be passed on to their offspring, although in some radiation exposure cases, the victim becomes sterile and unable to reproduce.

3. **Teratogenic Effects:** this is when a developing embryo (baby) is exposed to radiation, and the result can be malformation of organs, including various levels of mental retardation.

   This effect differs from genetic effects in that the radiation caused damage to the baby after fertilization of the embryo as opposed to before to the parents' (mother or father) DNA.

   No question that ionizing radiation exposure must be kept to a minimum.

Radiographers and therapists must be fluent in "radiation safety," prepared to keep themselves and everyone safe, and practice ALARA.

The Median Lethal Dose (MLD) is that radiation dose expected to cause death to 50 percent of an exposed population within 30 days (MLD 50/30). Typically, the MLD 50/30 is in the range from 400 to 450 rem (4 to 5 Sieverts) received over a very short period. Table 8-1 displays the Annual Dose Limits as established by the NRC. It is interesting to note the different doses allowed based on age and body parts.

Table 8-1: similar to Table 7-2 in the previous unit, with a bit of variation in the biological effects of acute exposure on a human.

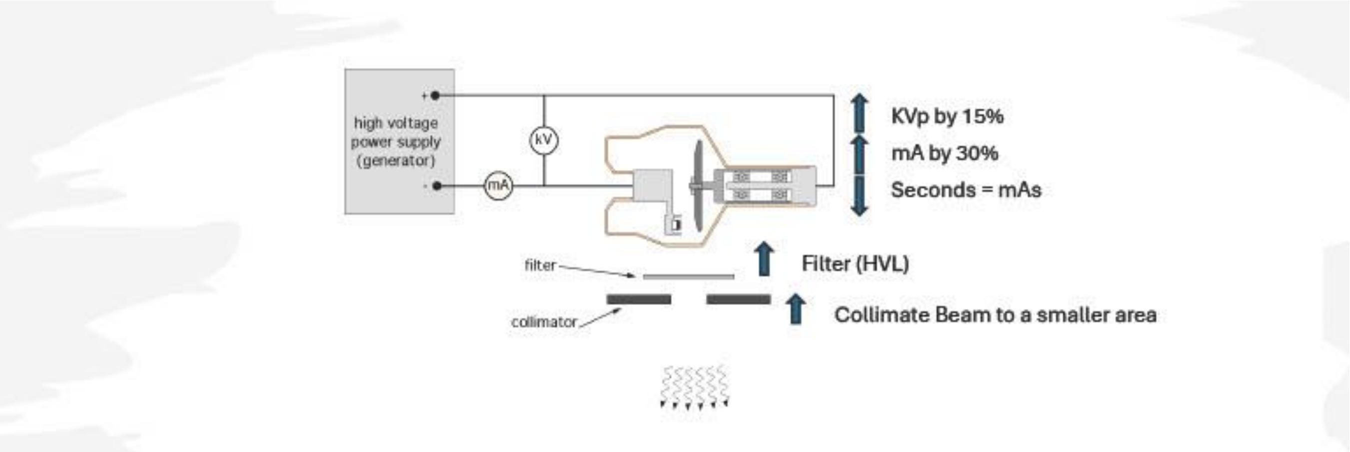
Dose (Rads*)	Effects
25-50	First sign of physical effects (drop in white blood cell count)
100	Threshold for vomiting (within a few hours of exposure)
320-360	~ 50% die within 60 days (with minimal supportive care)
480-540	~ 50% die within 60 days (with supportive medical care)
1,000	~ 100% die within 30 days

Patient Dose Management

Radiation safety from low-dose medical imaging that utilizes ionizing radiation is essential. The term safety is very subjective, and it often means absolute safety. It is rarely used when discussing ionizing radiation and the risk of biological effects. Safety relates to theory and reality; however, theory and reality are the same, but in reality, they are not. This is especially appropriate when discussing radiation safety and how and why we employ ionizing radiation in the medical industry. In theory, ionizing radiation should be standardized, and the licensure of people operating the equipment should be standardized. In reality, it is not standardized. In most cases, the benefits of the need for medical imaging will outweigh the relatively small excess cancer risk associated with the procedure. Patient management should not be altered based on radiation risk; however, for specific subsets of patients (i.e., fetuses, children, medically compromised, and elderly), radiation risk should be of more significant concern to the clinician. Damage from low- dose ionizing radiation should be taken into consideration, as well as the probability or likelihood of an event occurring that can damage the patient.

Medical imaging specialists are usually the 1st and often the only medical professional to interact with patients receiving a medical imaging examination. Radiographers and therapists are charged with a great deal of responsibility even before the examination begins. Being able to expose patients to ionizing radiation, the RT must be responsible and work safely, comply with radiation protection regulations, and report any unsafe procedures that occur. Modality operators must know what is expected of them, especially if the modality generates ionizing radiation. The RT is responsible for the exposure technique, which is the different parameters chosen to create the ionizing radiation exposure that will be used to create the medical image.

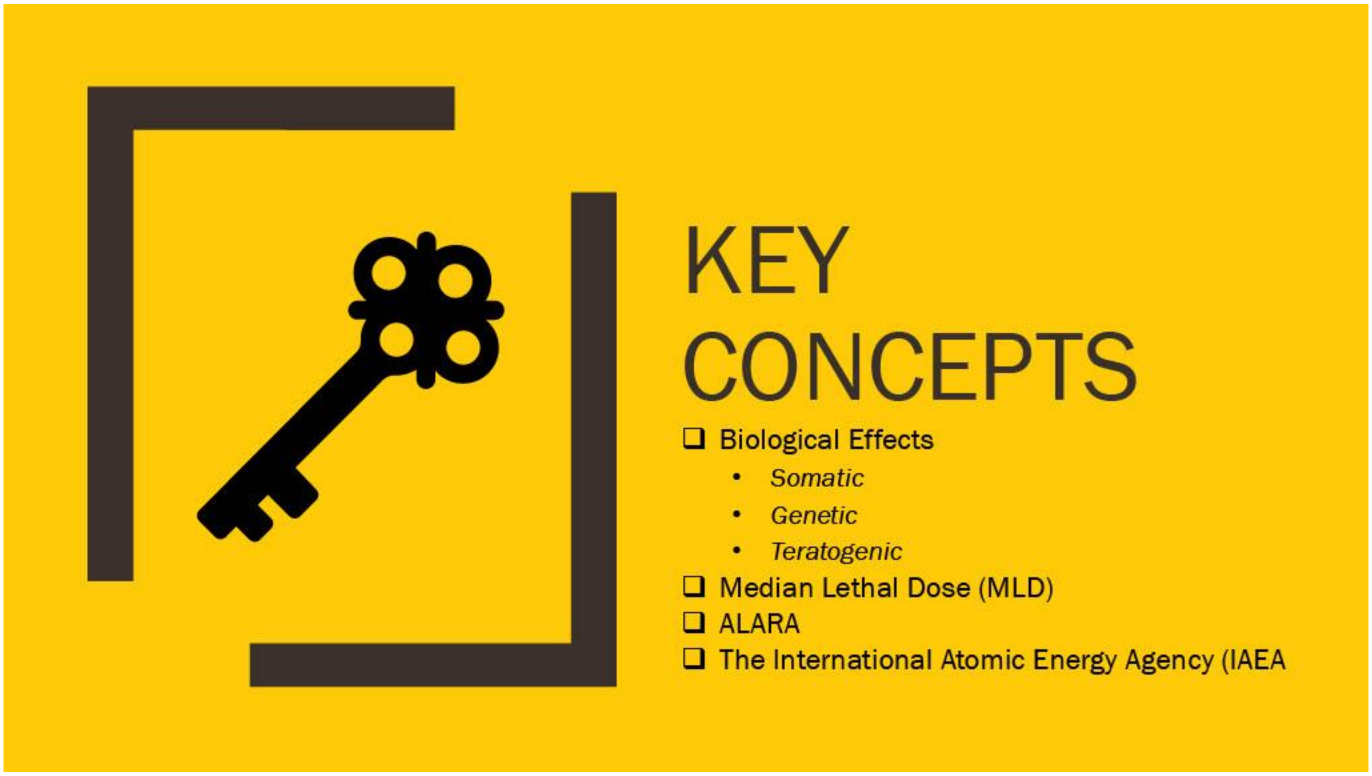
Again, ALARA is the fundamental principle for achieving a level of safety. ALARA, an acronym for as low as reasonably achievable, means every reasonable effort should be made to keep exposure to ionizing radiation minimal. Several factors must be considered. Most important is the exposure technique. The technique selection from the operator console is driven by the need to produce and provide appropriate penetration or signal value through the patient to receive an appropriate signal value at the image receptor. The figure below illustrates How to adjust the technical factors (discussed in Unit 5) when practicing patient dose management ALARA.



File:X-ray Tube schematic.png - Wikimedia Commons, 2011 Public Domain

Saving Lives with the Right Dose of Radiation

The correct amount of radiation is essential to kill cancer cells. Radiotherapy is an effective tool to treat cancer only if the proper dose is applied. If the dose is too high, it will harm the patient. If the dose is too low, the cancer cells will not be under control. Dosimetry is used to determine the necessary dose amount of radiation. Dosimetry is the science that measures the radiation absorbed by human tissue. The International Atomic Energy Agency (IAEA) ensures that patients receive the exact amount of radiation they need. IAEA provides calibration and audit services required for accurate dose measurements for radiotherapy centers. Dosimetry measurements are crucial to make sure radiation treatment is safe and effective. (International Atomic Energy Agency (IAEA), n.d.)



KEY CONCEPTS

- ☐ Biological Effects
  - *Somatic*
  - *Genetic*
  - *Teratogenic*
- ☐ Median Lethal Dose (MLD)
- ☐ ALARA
- ☐ The International Atomic Energy Agency (IAEA

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Unit 8 Glossary

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Acute radiation exposure is when an individual receives a high radiation dose over a relatively short period of time. Acute radiation exposure is also called Acute Radiation Syndrome (ARS). ARS results when an individual receives a whole-body exposure of 100 to 200 Rems or more (Roentgen Equivalent Man) over a 24-hour period. The table below shows the likely symptoms associated with differing levels of exposure.

Somatic Effects: a person receiving somatic effects might exhibit prompt symptoms such as minor to severe skin burns, cataracts on the eyes, and even severe internal organ and blood damage. A person might also experience delayed somatic effects such as cancer due to damaged and mutating cells in the body.

Genetic Effects: a person can experience genetic mutations and changes in their DNA that can be passed on to their offspring, although in some radiation exposure cases, the victim becomes sterile and unable to reproduce.

Teratogenic Effects: this is when a developing embryo (baby) is exposed to radiation, and the result can be malformation of organs, including various levels of mental retardation. This effect differs from genetic effects in that the radiation caused damage to the baby after fertilization of the embryo as opposed to before to the parent’s (mother or father) DNA

Annual Occupational Dose Limits: This is the maximum dose allowable by NRC for monitored radiographers and other occupations where radiation exposure occurs, such as nuclear medicine, medical radiography, nuclear power plant reactors, and research scientists.

Table 8-A: Annual Dose Limits

	Adults (≥ yrs)	Minors (<18 yrs)
Whole body	5000 mrem/yr	500 mrem/yr
Lens of eye	15000 mrem/yr	1500 mrem/yr
Extremities	50000 mrem/yr	5000 mrem/yr
Skin	50000 mrem/yr	5000 mrem/yr
Organ	50000 mrem/yr	5000 mrem/yr

Dosimetry - Measurement of radiation exposure from x-rays, gamma rays, or other types of radiation

Low-dose ionizing radiation - values below 100 mGy for acute low-dose exposures and below 5 mGy per hour for low-dose rate

Median Lethal Dose (MLD) is that radiation dose expected to cause death to 50 percent of an exposed population within 30 days (MLD 50/30). Typically, the MLD 50/30 is in the range from 400 to 450 rem (4 to 5 Sieverts) received over a very short period.

UNIT 9: CAUTION SIGNAGE AND DETECTION DEVICES

Learning Objectives:

Upon completion of this unit, the student will be able to define and understand the following:

- Equipment design
- Room design
- Safety Signage & Personnel Monitoring Equipment
  - Safety Signage
  - Safety Zones
  - Survey Meter
  - Geiger Counter
  - Area Monitor
- Occupational Dose Management
  - Radiation Limits
  - Film Badge
  - OSL
  - TLD
  - Pocket Ionization Chambers
- Effective Dose Limits

X-Ray Equipment Design

Understanding how an ionizing radiation machine's design helps us minimize exposure to ourselves and the patient is part of a radiation safety and protection plan. An overview of what will be discussed is the tube housing, the control panel, collimation, and filtration (calculate total filtration). The main objective of this learning section is to explain the technical aspects of equipment design as it relates to radiation safety. Maintaining the safety of equipment involves a radiation safety plan that includes quality assurance (QA) measures and quality control (QC) testing.

Each part of the equipment plays a role in reducing exposure. The production of ionizing radiation must be reproducible (consistent exposure quality and quantity). Exposures must be linear (a combination of technical factors produces the same quantity). The image receptor/detector must have a certain amount of sensitivity to radiation absorption.

The tube housing is lead-lined. It is lead-lined to minimize any leakage radiation (off-focus radiation). The whole encasing around the X-ray tube is very heavy. A small (port window)

window permits the photon (X-ray) beam to exit the tube. The X-rays emitted from the port are called the useful beam or primary beam. X-rays are produced isotopically. The photon energy goes out in all directions from the anode. In compliance with the NCRP recommendation for performance standard of leakage radiation from the tube housing, the exposure rate should not exceed one R/hr at 1m from the source (x-ray tube). Thus, based on the tube potential (kVp) and current (mA), the total filtration of an X-ray tube must be designed with at least 2.5 millimeters of lead equivalent (aluminum). The amount of filtration equivalency is based on the NCRP report #33 Section 3.2.2 (a) the operating kVp and the minimum total filtration that includes the recommended inherent filtration plus the added filtration table.

Operating kVp	Minimum Total Filter (Inherent plus added)
Below 50 kVp	0.5 mm aluminum
50 – 70 kVp	1.5 mm aluminum
Above 70 kVp	2.5 mm aluminum

The NCRP for X-ray therapy equipment design recommends a therapeutic-type machine (Contact therapy) that must meet additional requirements for tube leakage radiation at 2 inches (5 cm) from the source and not exceed 0.1 R/hr. The filter system must be arranged to minimize errors. The filter's construction must not allow radiation to escape from the slot to exceed 1R/h at 1m. Therapy machines are constructed to have a filter indication system using changeable filters.

According to NCRP Report No. 33, the design recommendation of a diagnostic-type X-ray tube is at least 12 inches (30cm) from the tube to the tabletop (SOD) and not less than 15 inches (38 cm) (SID). Note the greater the SOD, the lower the skin entrance dose (SED). Meanwhile, beam monitoring devices are fixed on therapeutic machines, indicating errors due to incorrect filtration, tube potential/ current, or uniformity variations.

Room Design

The control room panel or console is crucial to any ionizing radiation equipment. It is where technical factors such as mA, time (mAs), and KVP are selected and visually displayed for the operator. The control room must be located behind a suitable barrier, which serves as a secondary layer of protection (secondary barrier). In addition to the primary and secondary barriers, there are also "controlled" and "uncontrolled" areas. The controlled area is limited to authorized personnel and includes the treatment and control rooms. Maintaining strict access in these areas ensures that only trained professionals can access ionizing radiation equipment. This protects staff from unnecessary exposure and minimizes the risk to patients and visitors. Overall, the control room and its associated controlled area are vital in maintaining safety within ionizing radiation equipment facilities. The general population location is the “uncontrolled area.” This includes patient waiting room areas, visitors, and non-occupational employees such as the receptionist, admissions, and billing services areas.

Room shielding prevents radiation transmission through the room walls and is required for all ionizing radiation rooms. Shielding protects against primary, secondary, and scatter radiation. The amount of shielding (thickness) depends on:

- The distance from the source of the ionizing radiation.
- The room workload
- Room uses on the other side of the wall
- Amount of time the primary beam is directed at the wall.

The NCRP recommends that the primary barrier (wall) thickness in the direct path of the useful X-ray beams (primary beam) up to 7 feet is 1/16th inch of lead or lead equivalent. No added shielding is needed if the floor and ceiling are concrete based. Secondary radiation comprises scatter and leakage radiation; a secondary barrier is adequate. The wall above 7 feet is considered a secondary barrier, typically 1/32nd inch of lead or lead equivalent. The NCRP Statement No. 16 recommends assessing safety, quality, and reliability in a radiation therapy practice. Structural shielding design and evaluation of ionizing radiation machines up to 10 MeV publications is also reported by the American Association of Physicists in Medicine (AAPM). The National Council on Radiation Protection and Measurements (NCRP), Structural Shielding Design and Evaluation for Megavoltage X- and Gamma Ray Radiotherapy Facilities Report 151 address rooms design with greater than 10MeV. Sample values of shielding guidelines for 0.1 -100 Mev particle accelerators recommend 6 -9 shielding thickness (concrete in feet) for 6 MeV. As previously mentioned, the amount of shielding depends upon the factors listed above. The workload (W) is the most critical factor in determining the higher energy mode used in radiation therapy. There are several other NCRP reports (No. 51, No. 79, and No. 144) that address shielding designs for the higher energies that are used for total body radiation, intensity-modulated radiation therapy, stereotactic radiosurgery, stereotactic radiotherapy, and inoperative radiotherapy.

Protective barrier considerations include:

Distance (D): shielding coverage is proportional to the distance from the primary radiation source

Occupancy (T): Controlled area (<100 mR/wk) and uncontrolled area (2 mR/wk)

Workload (W): The thickness of the barrier is proportional to the workload of the

room (mA-min/wk)
Use (U): Amount of time the X-ray beam is directed at a barrier. NCRP Primary barrier factor equals ¼, and secondary factor equals one (always present)
HVL: Amount of shielding required to reduce radiation intensity to half (1/2) original value
TVL: Amount of shielding required to reduce radiation intensity to 1/10th the original value

Caution Signage and Labels

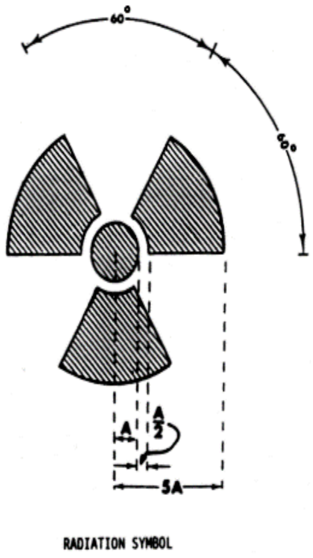
The NRC provides detailed information on the signage to be used for every level and type of radiation safety situation. It is the radiographer's responsibility to recognize and understand the significance of the variety of signs. The NRC dictates the color, wording, size, and geometric shape of Radiation Caution signs in NRC Part 20.1901 as follows:

(a) *Standard radiation symbol*. Unless otherwise authorized by the Commission, the symbol prescribed by this part shall use the colors magenta, purple, or black on a yellow background. The symbol prescribed by this part is the three-bladed design:

(1) The cross-hatched area is to be magenta, or purple, or black, and the background is to be yellow.

(b) *Exception to color requirements for standard radiation symbol*. Notwithstanding the requirements of paragraph (a) of this section, licensees are authorized to label sources, source holders, or device components containing sources of licensed materials that are subjected to high temperatures, with conspicuously etched or stamped radiation caution symbols, and without a color requirement.

(c) *Additional information on signs and labels*. In addition to the contents of signs and labels prescribed in this part, the licensee may provide, on or near the required signs and labels, additional information, as appropriate, to make individuals aware of potential radiation exposures and to minimize the exposures



Radiation Symbol from NRC is Public Domain.

Warning sign from NRC is Public Domain

Radiation Caution Signs are divided into the categories of Radiation Area and Radioactive Material

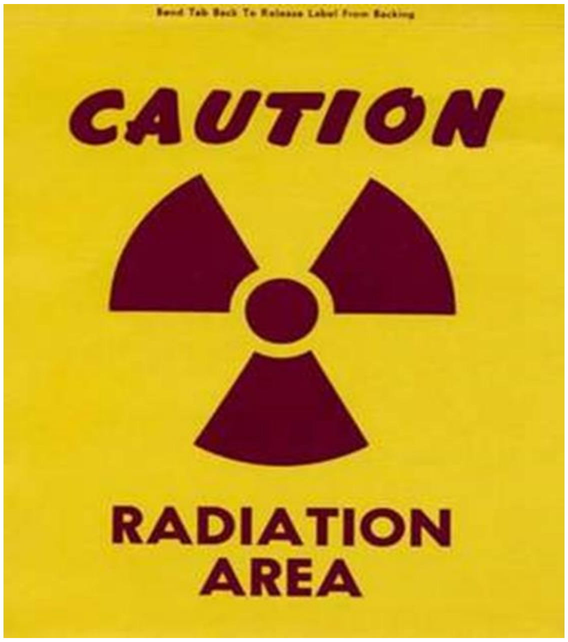
Radiation Areas are covered in NRC Part 20.1003 and defined as follows:

Radiation area means 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 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

Furthermore, a designation of “High Radiation Area” is spelled out in NRC Part 20.1003 as follows:

High radiation area means an area, accessible to individuals, in which radiation levels from radiation sources external to the body could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in 1 hour at 30 centimeters from the radiation source or 30 centimeters from any surface that the radiation penetrates.

Caution sign from NRC is Public Domain.



Caution sign from NRC is Public Domain.

Radioactive Material container signage and labeling are specified in NRC Part 20.1904:

a) The licensee shall ensure that each container of licensed material bears a durable, clearly visible label bearing the radiation symbol and the words "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL." The label must also provide sufficient information (such as the radionuclide(s) present, an estimate of the quantity of radioactivity, the date for which the activity is estimated, radiation levels, kinds of materials, and mass enrichment) to permit individuals handling or using the containers, or working in the vicinity of the containers, to take precautions to avoid or minimize exposures.

b) Each licensee shall, prior to removal or disposal of empty uncontaminated containers to unrestricted areas, remove or deface the radioactive material label or otherwise clearly indicate that the container no longer contains radioactive materials.

The NRC divides Radioactive Signage (including shipping labels) into the following categories:

Radioactive White – I Label – radiation level at package surface is less than or equal to 0.5 mR/hr.

Radioactive I sign from NRC is Public Domain.

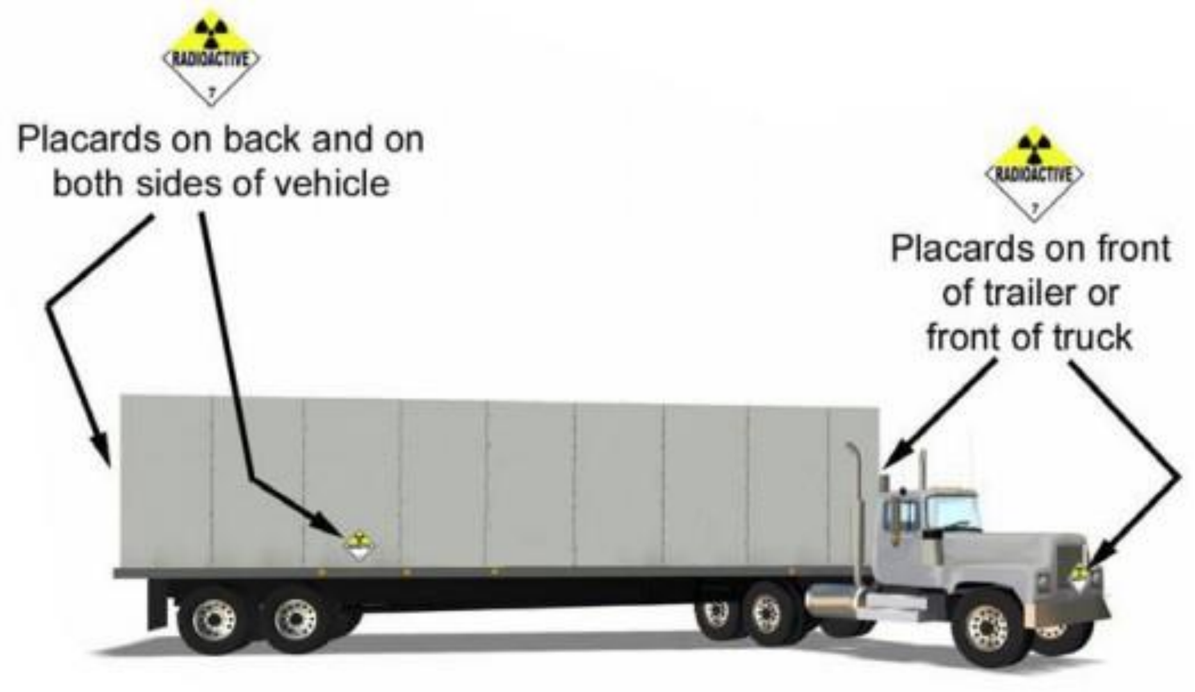
Radioactive Yellow – II Label – radiation level at package surface is greater than 0.5 mR/hr but is less than or equal to 50.0 mR/hr

Radioactive II sign from NRC is Public Domain.

Radioactive Yellow – III Label – radiation level at package surface is greater than 50 mR/hr but is less than or equal to 200.0 mR/hr

Radioactive III sign from NRC is Public Domain

Placards must be displayed on both sides, and both ends of motor vehicles, freight containers, and rail cars when used for transporting radioactive materials bearing a "**RADIOACTIVE YELLOW III"** label as shown below (more info at NRC – Shipping Requirements):



Placard placement graphic from NRC is Public Domain.

Monitoring and Detection Devices

In the spirit of ALARA the field of radiography has developed safety protocols that have evolved over the years, and as the safety standards have improved the devices and tools used for monitoring radiation emission and dosage to personnel have progressed as well. In this final section, we will look at the required detection instruments required for a radiographer including the regulations associated with the operation and calibration of these devices. The following is a list of the detection instruments for radiographers:

- Survey Meters
- Area rate Alarm
- Pocket Dosimeter
- Film Badge
- TLD (Thermoluminescent Dosimeter)
- OSL (Optically Stimulated Luminescent Dosimeter)

The **Survey Meter** is probably the radiographer's most important safety tool. When surveying the vast number of industrial radiation over-exposure incidents, many of them occurred because a radiographer did not use his or her survey meter or the survey meter was not calibrated and functioning properly. NRC requires that all survey meters be calibrated by a certified calibration agency every 6 months. This is the best insurance a radiographer has to protect against radiation over-exposure incidents.

Survey Meter by Scott Ballard is CC-BY 4.0

The **two types of Survey Meters** used in industry are the ion chamber and the Geiger-Muller (Geiger Counter).

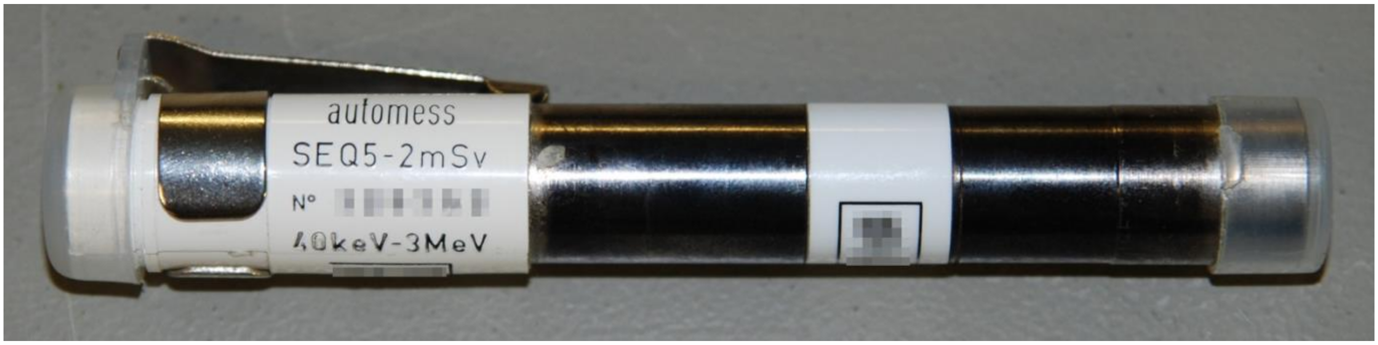
The I**on Chamber** uses an electric field (battery-operated) which is applied across a volume of gas, between two electrodes. The ion chamber is capable of measuring all forms of ionizing radiation (x-ray, gamma, alpha, and beta particles) and is considered more reliable with X-ray.

The Geiger Muller (Geiger Counter) uses a gas-filled tube (cathode) surrounding a central electrode (anode) made of a fine tungsten wire. The counter detects individual particles or ions, however, too many ions will saturate the counter and it will lose accuracy. Although more sensitive than an ion chamber survey meter – Geiger counters are typically used to detect low to medium levels of radiation but will lose accuracy in measuring higher levels. For this reason, most industrial radiographers use the ion chamber survey meter.

Area Rate Alarms are just that – an alarm that sounds when the pre-set exposure rate is exceeded. The NRC requires that rate alarms be pre-set to 500 mR/hr, must be calibrated and tested annually, and be +/- 20% of the true radiation dose rate to be considered calibrated and acceptable.

Area Rate Alarm by Scott Ballard is CC BY 4.0

Pocket Dosimeters provide an immediate indication of accumulated dose and have a 0-200 mR range value required by NRC. Dosimeters must be calibrated (zeroed) at the beginning of each shift. A pocket dosimeter serves a similar purpose to the radiographer's film badge except a film badge records the dosage over a longer period (quarterly or annually). Radiographers can look at the dosimeter throughout the day, monitoring the dose they receive, further protecting themselves from over-exposure. Below is a cutaway view of a traditional dosimeter. They are also more user-friendly electronic dosimeters with digital readouts and built-in alarms.



File:Direct-reading dosimeter.jpg - Wikimedia Commons. (2007). https://commons.wikimedia.org/wiki/File:Direct-reading_dosimeter.jpg Public Domain

Personal Monitoring Devices

Each worker who is expecting to receive more than 10% of the applicable annual dose limit (NRC) or more than 25% of the quarterly dose limit (OSHA) is required to wear a personal monitoring device or dosimeter. As required by OSHA In 29 CFR 1910.1096 (OSHA 2014a) and the NRC in 10 CFR 20 (USNRC 2014d) There must be a process for assigning, exchanging, monitoring, and reporting personal monitoring devices (PMD). For OSHA requirements on personnel monitoring, see OSHA's Ionizing Radiation Standard (29 CFR 1910.1096).

The monitoring device typically referred to as a "**Film Badge**" is the radiographer's personal dosimetry (PMD)**.** The purpose of the film badge is to keep a detailed record of quarterly, annual, and lifetime radiation doses received by the radiographer. The film badges are sent (mailed) to a private monitoring company monthly, quarterly, or annually depending upon the radiation safety program policy. The company sends reports to the radiation safety officer or designee. Most companies today are web-based and occupational workers can retrieve their reports online. A few do's and don'ts with personal dosimetry:

- Always wear it at work
- Do not wear away from work (home, lunch, parts store run)
- Do not wear when receiving a medical X-ray, MRI, CT scan, etc…
- Wear a dosimetry badge outside of lead aprons

Film badge Wikipedia contributors, 2024 public domain

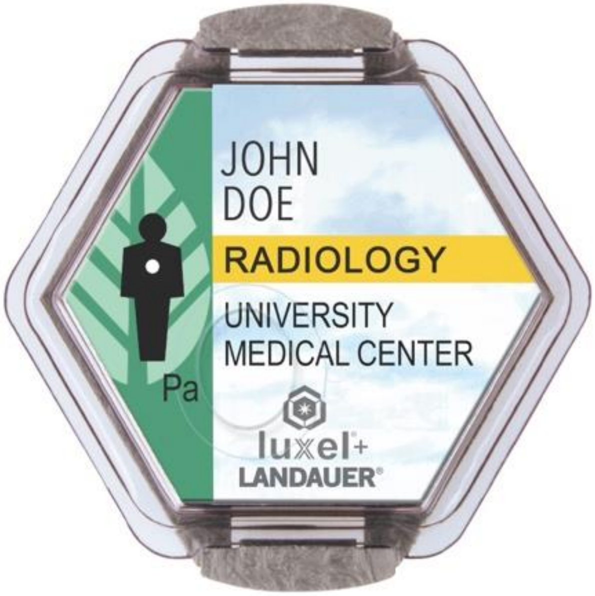
"**Film badge**" is a term we use almost generically but is not the same as a TLD or OSLD. Film badges contain an actual film that is "exposed", and we read the exposure like we might read a radiograph that's been exposed. After use, the film is removed from a packet that protects it from light exposure and developed to measure exposure. The film badge is used to measure and record radiation exposure due to gamma rays, X-rays, and beta particles. (Wikipedia)

A **TLD**, or thermoluminescent dosimeter is not a film badge but is worn like one and serves the same purpose of storing an individual's radiation dose over a period of months or even a year. TLDs can be re-set and reused. Calcium fluoride and lithium fluorite are the two most common types of thermoluminescent (thermo-heat and luminescent–light) dosimeters.

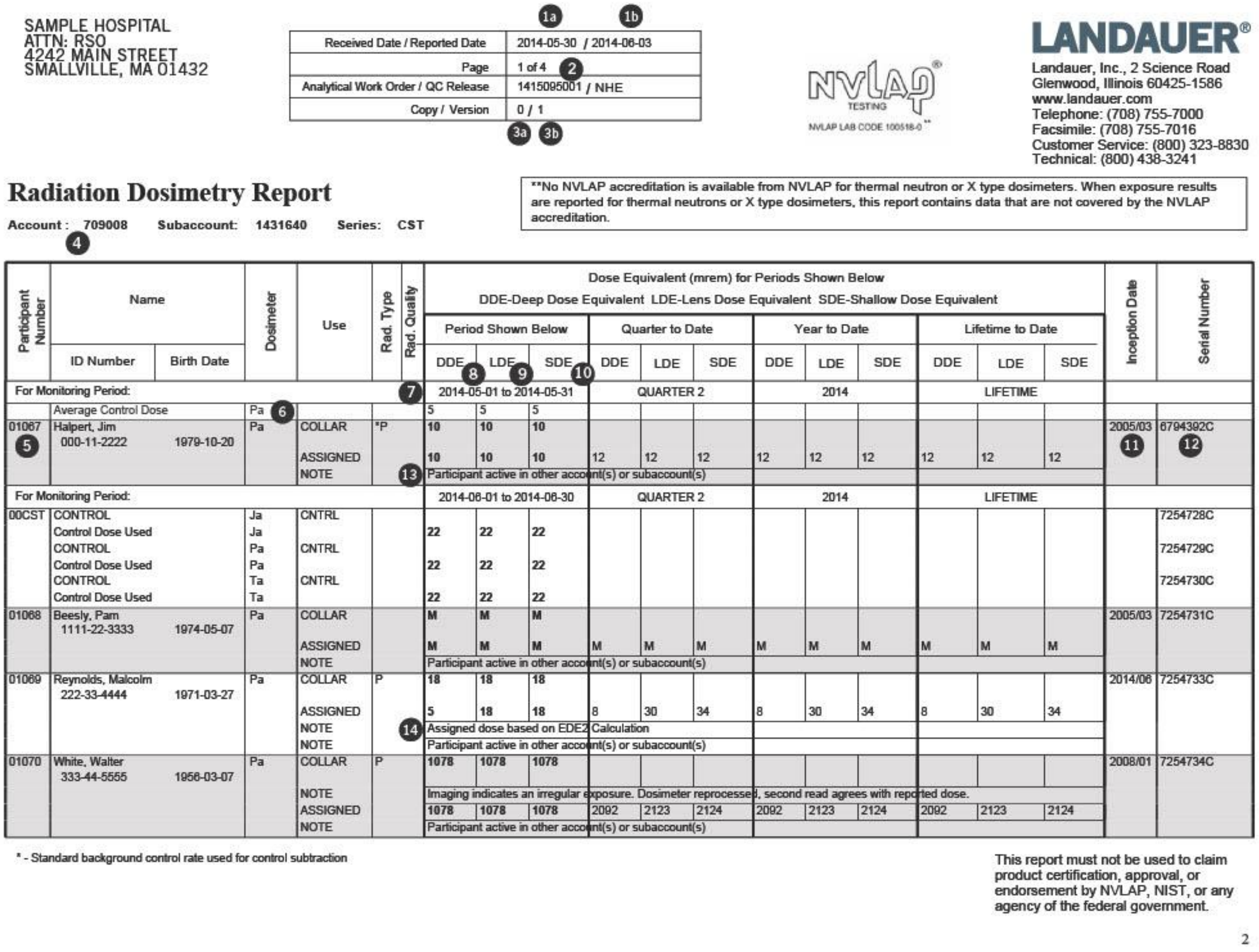
(TLD ring Wikipedia contributors, 2024 public domain Thermoluminescence dosimeter in the form of a finger ring for measuring radiation exposure to fingers and hands

An Optically stimulated luminescence Dosimeter **(OSL)** is a device that operates on the process in which a pre-irradiated (exposed to ionizing radiation) material when subjected to an appropriate optical stimulation, emits a light signal proportional to the absorbed dose. The wavelength of the emitted light is the characteristic of the OSL material (Wikipedia). According to Le Xu et al., The Crop Journal 2023, the range of energies the OSL responds to is anywhere from 5 keV to

40 MeV for photons and beta radiation from 150 keV to 10 MeV.



File:Direct-reading dosimeter.jpg - Wikimedia Commons. (2007). https://commons.wikimedia.org/wiki/File:Direct-reading_dosimeter.jpg Public Domain



SAMPLE HOSPITAL
ATTN: RSO
4242 MAIN STREET
SMALLVILLE, MA 01432

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Page	1 of 4 ②	
Analytical Work Order / QC Release	1415095001	/ NHE
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NVLAP LAB CODE 100518-0 **

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Technical: (800) 438-3241

Radiation Dosimetry Report

Account : 709008 ④ **Subaccount: 1431640** **Series: CST**

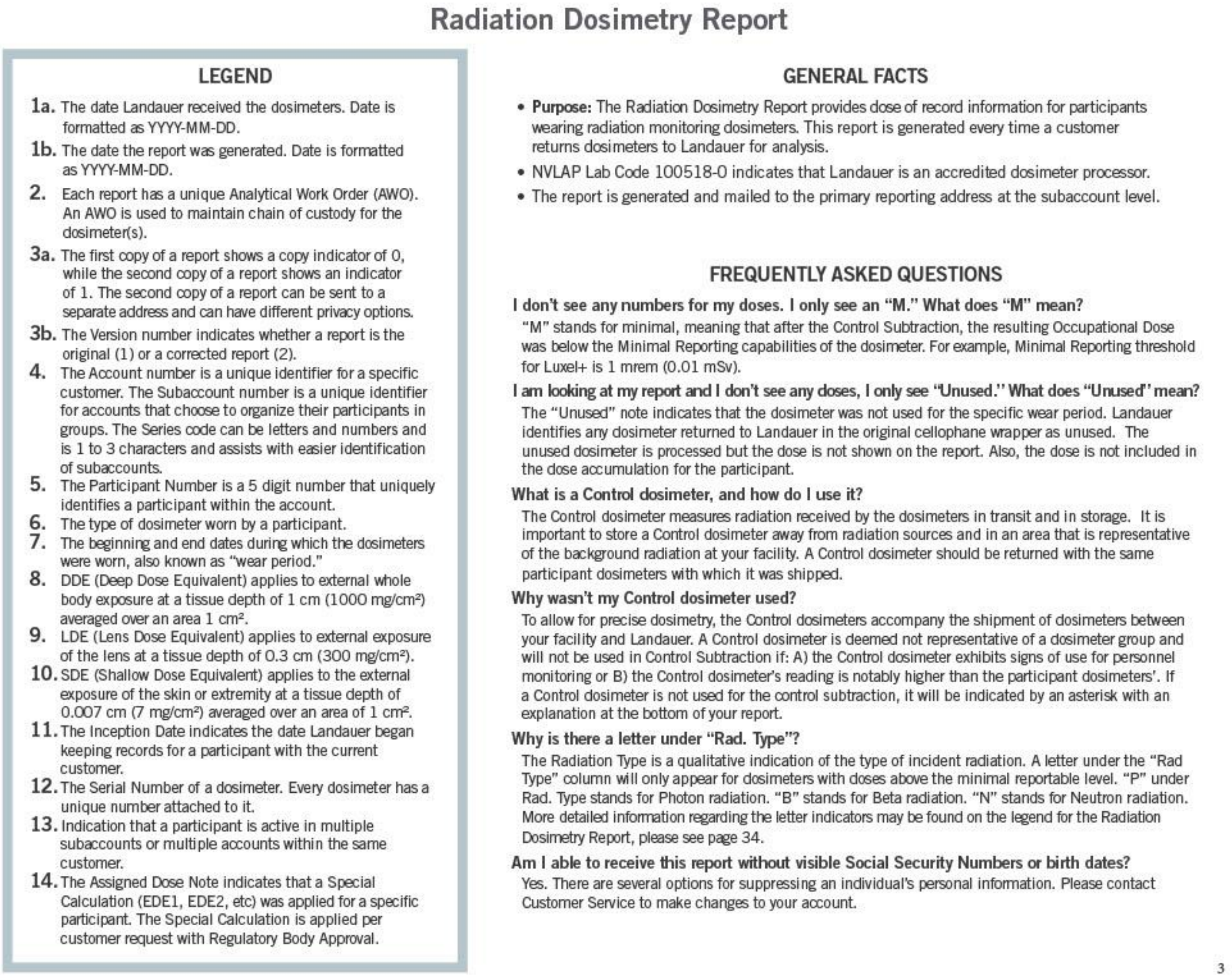
**No NVLAP accreditation is available from NVLAP for thermal neutron or X type dosimeters. When exposure results are reported for thermal neutrons or X type dosimeters, this report contains data that are not covered by the NVLAP accreditation.

Participant Number	Name		Dosimeter	Use	Rad. Type	Rad. Quality	Dose Equivalent (mrem) for Periods Shown Below DDE-Deep Dose Equivalent LDE-Lens Dose Equivalent SDE-Shallow Dose Equivalent												Inception Date	Serial Number
							Period Shown Below			Quarter to Date			Year to Date			Lifetime to Date				
	ID Number	Birth Date					DDE ⑧	LDE ⑨	SDE ⑩	DDE	LDE	SDE	DDE	LDE	SDE	DDE	LDE	SDE		
For Monitoring Period:						⑦	2014-05-01 to 2014-05-31			QUARTER 2			2014			LIFETIME				
	Average Control Dose		Pa ⑥				5	5	5											
01067	Halpert, Jim		Pa	COLLAR	*P		10	10	10										2005/03	6794392C
⑤	000-11-2222	1979-10-20		ASSIGNED			10	10	10	12	12	12	12	12	12	12	12	12	⑪	⑫
				NOTE		⑬	Participant active in other account(s) or subaccount(s)													
For Monitoring Period:							2014-06-01 to 2014-06-30			QUARTER 2			2014			LIFETIME				
00CST	CONTROL		Ja	CNTRL																7254728C
	Control Dose Used		Ja				22	22	22											
	CONTROL		Pa	CNTRL																7254729C
	Control Dose Used		Pa				22	22	22											
	CONTROL		Ta	CNTRL																7254730C
	Control Dose Used		Ta				22	22	22											
01068	Beesly, Pam		Pa	COLLAR			M	M	M										2005/03	7254731C
	1111-22-3333	1974-05-07		ASSIGNED			M	M	M	M	M	M	M	M	M	M	M	M		
				NOTE			Participant active in other account(s) or subaccount(s)													
01069	Reynolds, Malcolm		Pa	COLLAR	P		18	18	18										2014/06	7254733C
	222-33-4444	1971-03-27		ASSIGNED			5	18	18	8	30	34	8	30	34	8	30	34		
				NOTE		⑭	Assigned dose based on EDE2 Calculation													
				NOTE			Participant active in other account(s) or subaccount(s)													
01070	White, Walter		Pa	COLLAR	P		1078	1078	1078										2008/01	7254734C
	333-44-5555	1956-03-07		NOTE			Imaging indicates an irregular exposure. Dosimeter reprocessed, second read agrees with reported dose.													
				ASSIGNED			1078	1078	1078	2092	2123	2124	2092	2123	2124	2092	2123	2124		
				NOTE			Participant active in other account(s) or subaccount(s)													

* - Standard background control rate used for control subtraction

This report must not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

2



Radiation Dosimetry Report

LEGEND

1a. The date Landauer received the dosimeters. Date is formatted as YYYY-MM-DD.

1b. The date the report was generated. Date is formatted as YYYY-MM-DD.

2. Each report has a unique Analytical Work Order (AWO). An AWO is used to maintain chain of custody for the dosimeter(s).

3a. The first copy of a report shows a copy indicator of 0, while the second copy of a report shows an indicator of 1. The second copy of a report can be sent to a separate address and can have different privacy options.

3b. The Version number indicates whether a report is the original (1) or a corrected report (2).

4. The Account number is a unique identifier for a specific customer. The Subaccount number is a unique identifier for accounts that choose to organize their participants in groups. The Series code can be letters and numbers and is 1 to 3 characters and assists with easier identification of subaccounts.

5. The Participant Number is a 5 digit number that uniquely identifies a participant within the account.

6. The type of dosimeter worn by a participant.

7. The beginning and end dates during which the dosimeters were worn, also known as "wear period."

8. DDE (Deep Dose Equivalent) applies to external whole body exposure at a tissue depth of 1 cm (1000 mg/cm^2) averaged over an area 1 cm^2.

9. LDE (Lens Dose Equivalent) applies to external exposure of the lens at a tissue depth of 0.3 cm (300 mg/cm^2).

10. SDE (Shallow Dose Equivalent) applies to the external exposure of the skin or extremity at a tissue depth of 0.007 cm (7 mg/cm^2) averaged over an area of 1 cm^2.

11. The Inception Date indicates the date Landauer began keeping records for a participant with the current customer.

12. The Serial Number of a dosimeter. Every dosimeter has a unique number attached to it.

13. Indication that a participant is active in multiple subaccounts or multiple accounts within the same customer.

14. The Assigned Dose Note indicates that a Special Calculation (EDE1, EDE2, etc) was applied for a specific participant. The Special Calculation is applied per customer request with Regulatory Body Approval.

GENERAL FACTS

- **Purpose:** The Radiation Dosimetry Report provides dose of record information for participants wearing radiation monitoring dosimeters. This report is generated every time a customer returns dosimeters to Landauer for analysis.
- NVLAP Lab Code 100518-0 indicates that Landauer is an accredited dosimeter processor.
- The report is generated and mailed to the primary reporting address at the subaccount level.

FREQUENTLY ASKED QUESTIONS

I don't see any numbers for my doses. I only see an "M." What does "M" mean?

"M" stands for minimal, meaning that after the Control Subtraction, the resulting Occupational Dose was below the Minimal Reporting capabilities of the dosimeter. For example, Minimal Reporting threshold for Luxel+ is 1 mrem (0.01 mSv).

I am looking at my report and I don't see any doses, I only see "Unused." What does "Unused" mean?

The "Unused" note indicates that the dosimeter was not used for the specific wear period. Landauer identifies any dosimeter returned to Landauer in the original cellophane wrapper as unused. The unused dosimeter is processed but the dose is not shown on the report. Also, the dose is not included in the dose accumulation for the participant.

What is a Control dosimeter, and how do I use it?

The Control dosimeter measures radiation received by the dosimeters in transit and in storage. It is important to store a Control dosimeter away from radiation sources and in an area that is representative of the background radiation at your facility. A Control dosimeter should be returned with the same participant dosimeters with which it was shipped.

Why wasn't my Control dosimeter used?

To allow for precise dosimetry, the Control dosimeters accompany the shipment of dosimeters between your facility and Landauer. A Control dosimeter is deemed not representative of a dosimeter group and will not be used in Control Subtraction if: A) the Control dosimeter exhibits signs of use for personnel monitoring or B) the Control dosimeter's reading is notably higher than the participant dosimeters'. If a Control dosimeter is not used for the control subtraction, it will be indicated by an asterisk with an explanation at the bottom of your report.

Why is there a letter under "Rad. Type"?

The Radiation Type is a qualitative indication of the type of incident radiation. A letter under the "Rad Type" column will only appear for dosimeters with doses above the minimal reportable level. "P" under Rad. Type stands for Photon radiation. "B" stands for Beta radiation. "N" stands for Neutron radiation. More detailed information regarding the letter indicators may be found on the legend for the Radiation Dosimetry Report, please see page 34.

Am I able to receive this report without visible Social Security Numbers or birth dates?

Yes. There are several options for suppressing an individual's personal information. Please contact Customer Service to make changes to your account.

3

Images courtesy of Landaur, Inc. https://www.landauer.com/product/radiation-dosimetry-report

Effective Dose Limits

The NCRP limitation of exposure to ionizing radiation recommendations is in Report No. 116. Because there's no amount of radiation exposure so small that some form of mutation couldn't occur at some. Point mutation could occur at a very small amount of radiation exposure. The exposed populations are listed into two basic groups:

1. Occupational - working around radiation in some way shape or form, required to wear PMD, and comply with specific dose limitations to their occupational exposure.
2. Non-occupational – members of the public

Dosimetry is used in monitoring the dose of healthcare workers who work with ionizing radiation. Dosimetry measures and calculates the amount of ionizing radiation exposure to the:

- Whole body
- Area
- Extremities
- Fetus, and
- Detection of leakage

Occupational dosimetry is necessary because United States federal law limits the amount of radiation that can be received by a healthcare worker during the year. The annual effective dose limit to the whole body is 50 millisieverts. The purpose of this limit is to minimize the probability of stochastic effects like cancer. The limit to the lens of the eye is 150 millisieverts for the year. The purpose of this limit is to prevent radiation-induced cataracts. This dose limit is much higher than the whole-body dose limit because cataract formation only takes place at much higher doses. The annual skin and extremity dose limit is even higher at 500 millisieverts. The purpose of this limit is to prevent deterministic effects which are only possible at very high doses.

Table 8-1: Annual Dose Limits

	Adults (≥ yrs)	Minors (<18 yrs)
Whole body	5000 mrem/yr	500 mrem/yr

Lens of eye	15000 mrem/yr	1500 mrem/yr
Extremities	50000 mrem/yr	5000 mrem/yr
Skin	50000 mrem/yr	5000 mrem/yr
Organ	50000 mrem/yr	5000 mrem/yr

Quick exercise: Convert the Annual Dose Limits table to the International System of Units (SI).

For members of the public, the dose limits are 10% of the occupational dose limit, so the annual effective dose limit for members of the public:

Table 8-2: Public Exposure Dose Limits

Whole body	
infrequently exposed members of the public like visitors	5 mSv/yr
frequently exposed members of the public like clerical staff and others that work near radiation	1 mSv/yr
Lens of eye	15 mSv/yr
Extremities	50 mSv/yr
Skin	50mSv/yr
Fetus/Embryo	0.5 mSv/month
Gestational period	5.0 mSv/entire pregnancy
Negligible Individual Dose (NID)	0.01 mSv/yr

Unit 9 Glossary

cc by Theresa Hollaway created with PowerPoint

Area Rate Alarms: an alarm that sounds when the pre-set exposure rate is exceeded. The NRC requires that rate alarms be pre-set to 500 mR/hr, must be calibrated and tested annually and be +/- 20% of the true radiation dose rate to be considered calibrated and acceptable.

Film Badge: The purpose of the film badge is to keep a detailed record of quarterly, annual, and lifetime radiation doses received by the radiographer. Film badges contain an actual film that is "exposed" and we read the exposure like we might read a radiograph that's been exposed. After use, the film is removed from a packet that protects it from light exposure and developed to measure exposure

The Geiger Muller (Geiger Counter) uses a gas-filled tube (cathode) surrounding a central electrode (anode) made of a fine tungsten wire. The counter detects individual particles or ions, however, too many ions will saturate the counter and it will lose accuracy.

OSLD Optically stimulated luminescence Dosimeter is used like a film badge to keep a detailed record of quarterly, annual, and lifetime radiation doses received by the radiographer. The device that operates on the process in which a pre-irradiated (exposed to ionizing radiation) material when subjected to an appropriate optical stimulation, emits a light signal proportional to the absorbed dose.

Pocket Dosimeters provide immediate indication of accumulated dose and have a 0-200 mR range value required by NRC. Dosimeters must be calibrated (zeroed) at the beginning of each shift. A pocket dosimeter serves a similar purpose to the radiographer’s film badge except a film badge records the dosage over a longer period (quarterly or annually).

RSO – Radiation Safety Officer – required for any company, education, medical or research facility that uses any form of Gamma or X-ray radiation.

Survey Meter: a device (ion chamber or Geiger-Muller counter) used to take a real time reading of ionizing radiation emissivity.

TLD, or thermoluminescent dosimeter is used like a film badge to keep a detailed record of quarterly, annual, and lifetime radiation doses received by the radiographer. TLD’s can be re-set and reused.

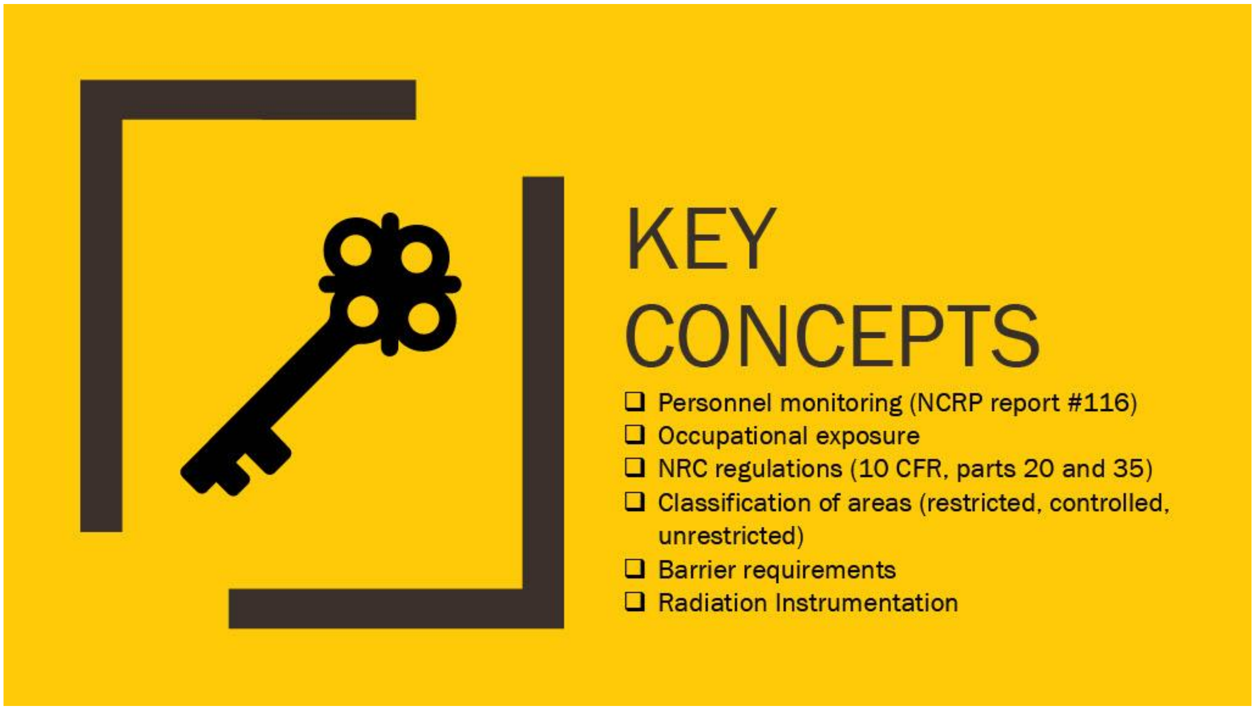
Annual Dose Limits

	Adults (≥ yrs)	**Minors (<18 yrs)**
Whole body	5000 mrem/yr	500 mrem/yr
Lens of eye	15000 mrem/yr	1500 mrem/yr
Extremities	50000 mrem/yr	5000 mrem/yr
Skin	50000 mrem/yr	5000 mrem/yr
Organ	50000 mrem/yr	5000 mrem/yr

Public Exposure Dose Limits

Whole body **infrequently** exposed members of the public like visitors	5 mSv/yr
frequently exposed members of the public like	

clerical staff and others that work near radiation	1 mSv/yr
Lens of eye	15 mSv/yr
Extremities	50 mSv/yr
Skin	50mSv/yr
Fetus/Embryo	0.5 mSv/month
Gestational period	5.0 mSv/entire pregnancy
Negligible Individual Dose (NID)	0.01 mSv/yr



KEY CONCEPTS

- ☐ Personnel monitoring (NCRP report #116)
- ☐ Occupational exposure
- ☐ NRC regulations (10 CFR, parts 20 and 35)
- ☐ Classification of areas (restricted, controlled, unrestricted)
- ☐ Barrier requirements
- ☐ Radiation Instrumentation

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