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Cook, Jackie

From: nperrinn@icloud.com
Sent: Thursday, January 19, 2017 6:10 AM
To: 'Marty Anderson'; Adams Peter
Cc: 'Deirdre Gross'
Subject: RE: Rad Safety Curriculum

Good morning to all, below in my email signature is our Registered # by/for Texas. If I can be of further assistance, please feel free to contact me.

Thank you

Nelson J. Perrin
137 Mulberry Street
Lake Jackson, Texas
77566

RSO (RAD Safety Consultant/Training Instructor)

Texas Registered #R40118

ASNT IRRSP Certified ID #152184

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"Where there is no guidance the people fall, but in abundance of counselors there is victory."

From: Marty Anderson [mailto:MAnderson@gdiving.com]
Sent: Wednesday, January 18, 2017 8:28 PM
To: Adams Peter (Peter.Adams@enipetroleum.com) <Peter.Adams@enipetroleum.com>

Cc: Nelson Perrin (nperrinn@icloud.com) <nperrinn@icloud.com>; Deirdre Gross <dgross@gdiving.com>
Subject: Rad Safety Curriculum

Peter,
Attached is the curriculum you requested. If the NRC needs any further information, Nelson and I are both approved trainers by the State of Texas for radiation safety and we are both ASNT IRRSP certified. I also hold a Level III in RT from ASNT #72743. Shipping, receiving and transportation was covered by Chapter 9 in "Working Safely in Radiation", a former NRC book that is now issued by ASNT.

Would also like to schedule a time to speak with you concerning NDT and inspection needs as we offer all the services now. Look forward to working with you again.

Thank you,

Marty

907-252-7800

Student Workbook

Radiation Safety Training Series

Part 1: Radiation

Its Origin, Measurement, Effects and the Control of Dose

Rudarmel Enterprises, Inc.
Lake Oswego, Oregon

Contents

Foreword *iii*
Statement of Policy *iv*
Part 1 Outline *v*

Lesson 1 - Introduction to Radiation **1**

Lesson 2 - Radiation Properties and Sources **27**

Lesson 3 - Units of Measurement and Dose **47**

Lesson 4 - Radiation Hazards **65**

Lesson 5 - Controlling Radiation Dose **85**

Appendix A - Glossary of Terms **113**

Appendix B - Bibliography **121**

Foreword

This program has been developed by Quality Consulting Company, Inc. and is the first of a four part series. Each part of the series is designed for independent use which allows any single part to be used as a valuable training aid. The four parts of the Radiation Safety Training Series are: Part 1: Radiation - Its Origin, Measurement, Effects and the Control of Dose; Part 2: Radiation Detection - The Survey Instruments, Monitoring Devices and Survey Procedures; Part 3: Radiation Machines and Exposure Devices - The Operation, Inspection, Maintenance, Storage, Shipment, and Regulations. This program, Part 1, is divided into five lessons. It is recommended that the lessons be approximately 2 to 4 hours in length. Lesson 1 provides an introduction to radiation, what it is and where it comes from. Lesson 2 continues with the characteristics of radiation, ionization and industrial sources. Lesson 3 discusses the units of radiation measurement and radiation dose. Lesson 4 explains the hazards and biological effects of radiation. Lesson 5 deals with the methods of controlling radiation dose. This program consists of an instructor's package and student workbook.

The instructor's package contains a video tape, overhead transparencies, instruction manual, and text book. The text book titled, *Working Safely in Gamma Radiography*, was written by Dr. Stephen McGuire, a nuclear engineer with the U.S. Nuclear Regulatory Commission and is included in the instructor's package. The video, produced by Quality Consulting Company, Inc., brings into the classroom many elements that would otherwise be unobservable. The overhead transparencies add an extra dimension to the program and serve to reinforce the key concepts for the student as well as assisting the instructor in maintaining continuity from class to class. The instruction manual provides the instructor with an overview of the complete lesson and indicates the sequencing of visual aids. All materials included in the student workbooks are in the instruction manual. The textbook, *Working Safely in Gamma Radiography*, must be purchased separately for students.

The student workbook contains the key terms, reading assignments, quizzes and a lecture guide. It provides the student with ample space for recording notes and contains a hard copy of the overhead transparencies which is formatted for ease in adhering to an organized study program. The instruction sequencing of **READ** the outline, **LEARN** the key terms, **STUDY** the text, **COMPLETE** the quiz, **WATCH** the video tape, **FOLLOW** the lecture, and **REVIEW** the quiz keeps it simple for both the instructor and the student.

Statement of Policy for Use of this Training Program

This "Part 1: Radiation - Its Origin, Measurement, Effects and Control of Dose" training program has been developed by Quality Consulting Company, Inc. (QCC) of Portland, Oregon. The production of this video tape program is an independent project undertaken by QCC. The various companies and individuals who have contributed to this program do not accept any responsibility for the content of this program. QCC is solely responsible for its content.

The intent of this training program is to demonstrate the theory and practical application of Radiation Safety. It is the responsibility of the user of this training program to read, understand, and comply with any pertinent Federal or State regulations as well as the applicable procedures and specifications of their job assignment. Practical demonstrations and hands on training, used in conjunction with this course material, is required by most state and federal regulators. QCC does not accept any liability arising from the use of this training program. This program is now owned and distributed by Rudarmel Enterprises, Inc. and is formerly a product of Quality Consulting Company, Inc.

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This 1993 edition has been written to the regulations through 1993 and the 1994 New Part 20 regulations that become effective in 1994. The pages that are affected by New Part 20 and other regulation changes since 1989 are designated at the bottom of each page as "1994 Revision."

Rudarmel Enterprises, Inc.
Lake Oswego, Oregon

Program Outline

Part 1: Radiation - Its Origin, Measurement, Effects and the Control of Dose

I. Introduction to Radiation
   A. Discovery of Radiation
   B. Structure of Matter
      1. Atoms & Elements
      2. Molecules & Compound
      3. The Atom & Fundamental Particles
      4. Atomic Number & Weight
      5. Isotopes
      6. Periodic Table
   C. Origin and Types of Radiation
      1. X-Ray Generation
      2. Alpha, Beta, Gamma
      3. Activation
      4. Nuclear Decay

II. Characteristics of Radiation, Ionization, and Industrial Sources
   A. Characteristics of Radiation
      1. Electromagnetic Radiation
      2. Electromagnetic Spectrum
      3. Radiation Characteristics
      4. Particle, Gamma & X-Radiation
      B. Ionization and Ions
      1. Photoelectric Effect
      2. Compton Scatter
      3. Pair Production
      4. Absorption
   C. Industrial Radiation Sources
      1. Gamma Ray
      2. X-Ray

III. Radiation Measurement Units and Radiation Dose
   A. Units of Measurement
      1. Roentgen
      2. Radiation Absorbed Dose (rad)
      3. Relative Biological Effectiveness (RBE)
      4. Radiation Equivalent Man (rem)
   B. Theory of Allowable Dose - ALARA Philosophy
   C. Exposure Limits and Banking Concept

Part 1 Outline - Continued

IV. Radiation Hazards and Biological Effects
  A. "Natural" Background Radiation
  B. The Difference Between Radiation and Contamination
  C. Radiation Damage
  D. Radiation Exposure Effects
    1. Somatic
    2. Genetic
  E. An Exposure Case History

V. Methods of Controlling Radiation Dose
  A. Complying with ALARA
  B. Time - Formula for Dose
  C. Dispersion of Radiation
    1. Distance Calculations
  D. Attenuation of X-Rays and Gamma Rays
    1. Shielding Calculations
  E. Course Examination

About the Authors

The individuals who have contributed to the training series are recognized experts in their fields. The contributors to "Part 1: Radiation" are:

Lee Garrison, Don Hereford, and Michael Rudarmel of Quality Consulting Company, Inc. All hold Nondestructive Testing Level III certifications in Radiography having successfully completed the American Society for Nondestructive Testing Level III examinations for Radiographic Testing. They have been active as nondestructive testing instructors for many years providing industry and college classroom training courses on radiography and radiation safety. They have also developed specialized nondestructive testing training programs currently in use by colleges, technical training institutes and companies throughout the world.

Roy Wysnewski, the Technical Manager for FUJI NDT Systems, a division of FUJI Medical Systems, USA, Inc. Mr. Wysnewski holds a Bachelor of Science degree in Physics from the University of Cincinnati. He is renowned for his work in the film manufacturing process and for his work in the field of Radiography.

Lesson 1

Lesson 1
Introduction to Radiation

Read

The Outline

I. Introduction to Radiation
   A. Discovery of Radiation
   B. Structure of Matter
      1. Atoms and Elements
      2. Molecules and Compounds
      3. The Atom and Fundamental Particles
      4. Atomic Number and Weight
      5. Isotopes
      6. Periodic Table
   C. Origin and Types of Radiation
      1. X-Ray Generation
      2. Alpha, Beta, Gamma
      3. Activation
      4. Nuclear Decay

Learn

The Key Terms

activation — The process of bombarding stable atoms with neutrons to make them radioactive.

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.

atom — A unit of matter consisting of a nucleus (made up of neutrons and protons) and electrons that surround the nucleus. The smallest part of an element that retains the properties of the element.

atomic mass unit (A.M.U.) — The unit of measure for the weight of an atom. This unit is based on one sixteenth the weight of an Oxygen-16 atom. One neutron or one proton weighs approximately one A.M.U.

atomic number	The total number of protons in an atom. The atomic number determines the element and its chemical properties.
atomic weight	The total mass of an atom. It is approximately equal to the total number of protons and neutrons in the nucleus of an atom and measured in Atomic Mass Units (A.M.U.).
bremsstrahlung	The electromagnetic radiation produced when an electrically charged particle, such as an electron, is subjected to a change in velocity. It is the German word meaning "braking radiation".
beta particle	An electrically charged particle of radiation emitted from the nucleus of many radioactive materials during radioactive decay. A beta particle is a fast-moving electron, sometimes moving close to the speed of light.
compound	A chemical combination of elements.
disintegration	The transformation of radioactive atoms into a stable state resulting in energy (radiation) and particle emission.
element	A basic type of matter. Each element has distinct chemical properties, and cannot be divided into simpler substances by chemical means.
electrons	An elementary particle with a unit negative electrical charge and a mass approximately equal to 1/1840th that of a proton.
electron volt (eV)	A unit of energy equal to the amount of kinetic energy gained by an electron when it is accelerated through a voltage difference of 1 volt in a vacuum. MeV equals 1 million electron volts.
gamma rays	High energy, short wavelength electromagnetic radiation emitted during radioactive decay.

isotope	Atoms having the same number of protons but a different number of neutrons in the nuclei. Atoms with the same atomic number (the same chemical element) but different atomic weights.
molecule	The simplest structural unit that displays the characteristic physical and chemical properties of a compound.
neutron	An uncharged elementary particle with a mass nearly equal to that of a proton. A neutron is stable when bound in an atomic nucleus and has a mass approximately equal to 1840 times that of an electron, or 1 A.M.U.
nucleus	The positively charged central region of an atom, made up of protons and neutrons.
proton	A positively charged elementary particle with a mass approximately equal to 1840 times that of an electron, or 1 A.M.U.
radiation	The emission or propagation of waves (x-rays, gamma rays, ultraviolet, etc.) or fast moving particles (Alpha or beta particles, neutrons, etc.) through matter or space.
radioactive	A state in which atoms have excess energy and are unstable. The nucleus disintegrates in the process of becoming stable. This disintegration results in the emission of radiation.
radioisotope	An unstable isotope of an element that disintegrates spontaneously, emitting radiation.

Study The Text

Working Safely in Gamma Radiography

Preface	Page iv
Chapter 1	Pages 3 through 5
Chapter 2	Pages 9 through 1st paragraph on page 10
	Pages 13d through 16
Chapter 3	Pages 19 through 20a
Chapter 4	Page 27 through 1st paragraph on page 28

Complete The Quiz

Complete the quiz at the end of this lesson.

Watch The Video Tape

Lesson 1 - Introduction to Radiation

Follow The Lecture

Introduction to Radiation

Discovery of Radiation

Wilhelm Conrad Roentgen (1845-1923)

Wilhem Roentgen was elected rector of the University of Wuerzburg, Germany in 1895 and was considered one of the world's leading physicists. Roentgen's most important contribution to science was the discovery of x-rays in 1895.

A phosphorescent glow on the surface of cathode ray tubes had been observed by other scientists of the times. Roentgen decide to experiment with the conduction of electricity in a vacuum tube and determine whether the cathode stream or the phosphorescent glow included ultra violet or any other form of invisible light. During preliminary tests he noticed a screen of barium platino-cyanide crystals that had been laid on a table nearby was glowing brightly although ten or twelve feet away. Further experiments with the vacuum tube, demonstrated that the fluorescence was caused by some kind of invisible rays. Although he named these invisible rays x-rays, in some countries they are referred to as Roentgen rays.

Roentgen found that x-rays were able to pass through materials that were opaque to ordinary light, that the penetrating power increased with the voltage applied to the tube and that they exposed photographic film. Within a year of the discovery of x-rays, he had made x-ray pictures of his wife's hand and many metal objects.

Within a few months of the announcement of Roentgen's discovery, hospitals were using x-ray pictures to aid in surgery. For his outstanding discovery, Roentgen received the first Nobel Prize in Physics (1901).

Henri Becquerel (1852-1908)

In 1896 Henri Becquerel, a French physicist, discovered that a completely sealed photographic plate was exposed by a uranium bearing mineral and when developed, the plate contained strange tracks as though it had been light struck. This discovery was overshadowed by Roentgen's x-rays, since Becquerel's rays lacked the intensity to give pictures of bones.

Marie and Pierre Curie (MC 1867-1934)(PC 1859-1906)

Henri Becquerel assigned the study of the radiation given off from uranium ore to Marie Curie. Madame Curie and her husband, Pierre, began their experiments by refining a ton of a uranium bearing ore called pitchblende. They were not very far into the process of refining when they realized that, although the uranium itself was giving off invisible rays, some other substance hidden within the ore was much more powerful. Their first discovery was the radioactive element polonium, which Marie named after her native country, Poland.

Discovery of Radiation

1895 - Wilhelm Roentgen; Discovered X-Rays

1896 - Henri Becquerel; Rays From Uranium

1898 - Marie & Pierre Curie; Work With Radium

1899 - E. Rutherford; Alpha,Beta & Gamma

1905 - Albert Einstein; Theory of Relativity

FUJI NDT Systems — Figure 1.1.1 — Quality Consulting Co. & Associates

There was evidence of a more powerful element yet. By 1898, they were able to separate a very small amount, about a quarter of a gram, of an element they named radium. Radium was given its name because of the great intensity of radiation it gave off. It was 30 years after its discovery before radium was available for use in industrial radiography, due to the extreme cost of refining.

Ernest Rutherford (1871-1937)

Rutherford was a British physicist and Nobel Prize winner whose work marked several important steps toward our present understanding of atomic structure. When the study of radioactive substances was new, he became interested in the properties of the particles and rays they emit. He named these emissions alpha and beta particles and gamma rays. His work did much to show their individual nature.

Albert Einstein (1879-1955)

Einstein, a German physicist, is the most well-known physicist of our time. His theory of relativity is one of the greatest additions ever made to science, and the formula, $E=mc^2$ is perhaps the most important equation in science. E stands for energy, m for mass and c^2 for the speed of light multiplied by itself. The formula showed that matter, if entirely changed to energy such as heat or light, produces an unbelievable amount of energy. $E=mc^2$ showed that the atomic bomb was possible.

Scientist Memorial (Hamburg, Germany 1922)

Radiation burns were noticed within a month of Roentgen's announcement of the discovery of x-rays. A couple of years later it was well known that x-rays were hazardous and that precautions needed to be taken when working with them. Some of the early workers with x-rays did not heed these warnings and failed to protect themselves.

Discovery of Radiation

1922 - Scientist Memorial; Hamburg, Germany

1922 - Watertown Laboratory; Industrial X-Ray

1929 - Naval Research Lab.; Gamma Radiography

1945 - Alamogordo, N.M.; 1st Atomic Bomb

1946 - Atomic Energy Commission Established

Fuji NDT Systems — Figure 1.1.2 — Quality Consulting Co. & Associates

The early scientists working with radioactive materials also suffered burns from radiation. Becquerel was burned by a sample of radium he carried in his pocket. Marie and Pierre Curie experienced radiation burns on their skin from radium. They also both developed leukemia, perhaps from exposure to radiation.

By 1905 the hazards of exposure to radiation were well understood and it was known that radiation exposure could cause cancer. A memorial was dedicated in Hamburg, Germany, in 1922, to 169 pioneering scientists who died as a result of exposure to radiation.

Watertown Laboratory (1922)

Between 1912 and 1922, industrial radiography was limited because the maximum energy x-ray available was 125kv. In 1922, a Coolidge tube capable of 200kv at 5Ma was introduced and installed at the U.S. Government Arsenal at Watertown, Massachusetts. The 200kv tube marked the beginning of real accomplishments in industrial radiography.

Naval Research Laboratory (1929)

X-ray equipment in 1929 had a practical limit of 3" of steel and the Navy was looking for a way to radiograph 10 to 12 inches of steel. With radium, the Navy found that they could penetrate these thicknesses. The use of radium by the Navy at the Boston Navy Shipyard in 1929 marked the beginning of gamma radiography.

Alamogordo, New Mexico (1945)

The first atomic bomb was exploded on the White Sands Proving Ground marking the beginning of the Atomic Age.

Atomic Energy Commission (1946)

Congress established the Atomic Energy Commission in 1946 and gave it responsibility for directing government work with atomic material for war and peace.

Structure of Matter

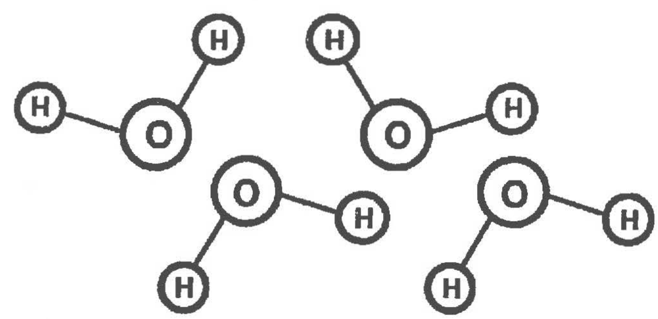
Matter is composed of numerous tiny particles known as atoms. Substances such as aluminum, calcium, cobalt, iron, and many others are composed wholly of identical atoms. These substances are known as elements. Elements cannot be chemically reduced into smaller particles.

Structure of Matter

Elements

Aluminum	Al	Iron	Fe
Beryllium	Be	Neon	Ne
Calcium	Ca	Nitrogen	N
Carbon	C	Oxygen	O
Cobalt	Co	Silver	Ag

Molecules & Compounds



H_2O - Water Molecules

FUJI NDT Systems   Figure 1.1.3   Quality Consulting Co. & Associates

Materials such as water, salt, oil and an infinite variety of others are made up of combinations of elements. These are known as compounds. Compounds can be chemically reduced into the elements of which they are composed.

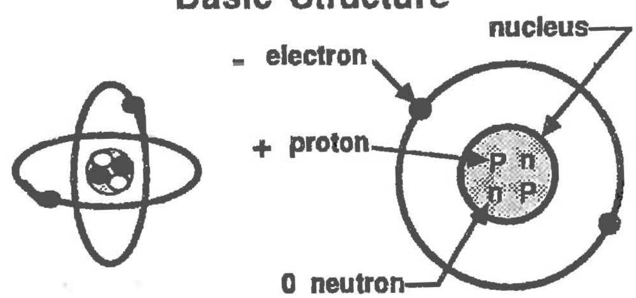
A molecule is the simplest structural unit that displays the characteristic physical and chemical properties of a compound. Molecules are a stable configuration of elements bound together by electrostatic and electromagnetic forces. A water molecule is a combination of one oxygen atom and two hydrogen atoms.

The Atom and Fundamental Particles

It was discovered that the atom, once thought to be the smallest division of matter, was itself made up of tinier particles. The fundamental particles that are of interest are shown in Figure 1.1.4.

The Atom

Basic Structure



Fundamental Particles

Proton - a unit of positive electrical charge; mass ≈1 AMU

Neutron - electrically neutral; mass ≈ 1 AMU (proton)

Electron - a unit of negative electrical charge; mass ≈ 1/1840 AMU

FUJI NDT Systems — Figure 1.1.4 — Quality Consulting Co. & Associates

The basic structure of the atom is conceived as consisting of a small, relatively heavy nucleus made up of protons and neutrons surrounded by electrons revolving in orbital shells about the nucleus.

Atomic Energy Levels

The atom is normally electrically balanced with the number of protons in the nucleus being equal to the number of electrons. Therefore, an atom with 18 protons in its nucleus would have 18 orbital electrons as shown in Figure 1.1.5.

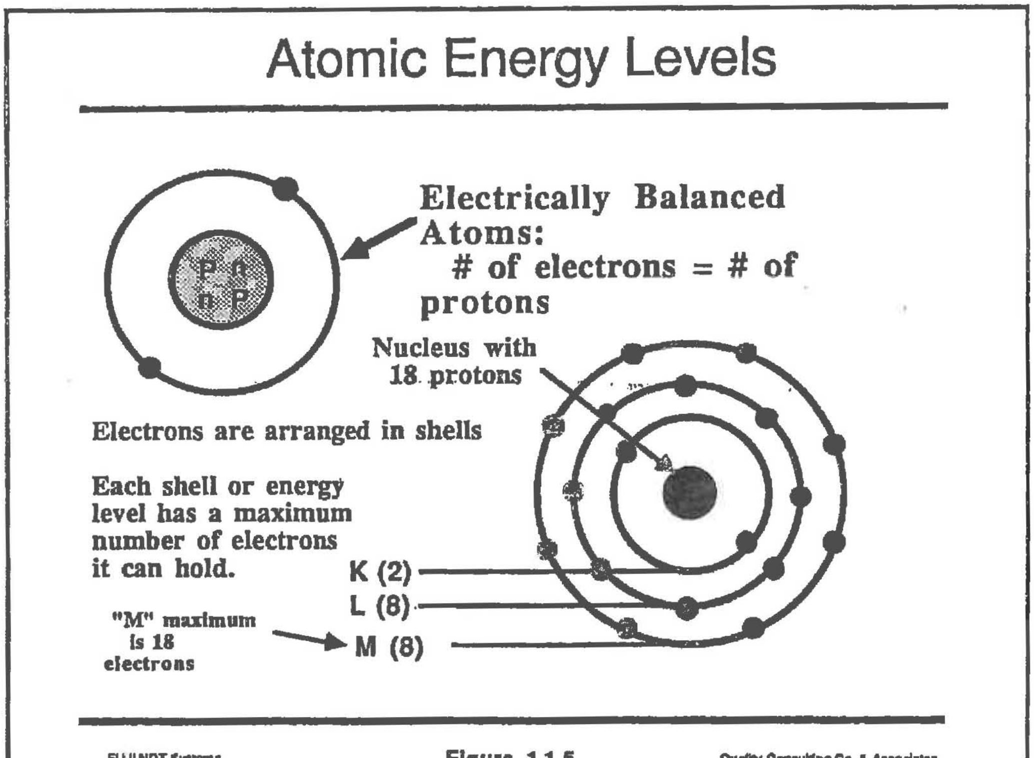


Figure 1.1.5

The shells of an atom have different energy levels with the outer shells having the higher energy content and the inner shells having the higher binding force. Each shell also cannot contain any more than a maximum number of electrons. For example, the K shell can contain 2, the L shell 8, and the M shell 18.

The charge on the nucleus of an atom is determined by the number of protons in the nucleus. This number of protons also determines the type of element. There are more than 100 elements that have been discovered. These elements have been given atomic numbers which represent the nuclear charge or number of protons. The atomic number is identical to the number of orbital electrons.

Atomic Numbers and Weight

The symbols for the elements are commonly written with subscripts and superscripts. The subscript denotes the atomic number and the superscript refers to the sum of the neutrons and protons which is approximately the atomic weight.

Atomic Number & Weight

hydrogen $^{1}_{1}H$ cobalt $^{59}_{27}Co$

helium $^{4}_{2}He$ iridium $^{192}_{77}Ir$

Subscript = atomic number or number of protons (nuclear charge)

Superscript = total of protons and neutrons (approximate atomic weight)

Atomic Number (No. of Protons) - determines the element and chemical properties

Atomic Weight (Protons + Neutrons) - determines physical properties

Isotopes of Elements - Atoms of the same elements with different number of neutrons

FUJI NDT Systems Figure 1.1.6 Quality Consulting Co. & Associates

Isotopes of an element are atoms of the element with the same number of protons and different numbers of neutrons. The atom retains the same chemical properties but differs in the atomic weight.

Periodic Table of Elements

NONMETAL

KEY: 77 (Atomic Number) / Iridium (Name of Element) / Ir (Chemical Symbol) / 192.2 (Atomic Weight)

TRANSITION ELEMENTS

METAL-LOIDS — NON-METALS — METALS

1A	2A	3B	4B	5B	6B	7B	8	8	8	1B	2B	3A	4A	5A	6A	7A (Halogens)	8A (Inert Gases)	
1 Hydrogen H 1.008																	2 Helium He 4.003	2
3 Lithium Li 6.94	4 Beryllium Be 9.01											5 Boron B 10.8	6 Carbon C 12.0	7 Nitrogen N 14.0	8 Oxygen O 16.0	9 Fluorine F 18.9	10 Neon Ne 20.1	2 8
11 Sodium Na 22.9	12 Magnesium Mg 24.3											13 Aluminum Al 26.9	14 Silicon Si 28.0	15 Phosphorus P 30.9	16 Sulfur S 32.0	17 Chlorine Cl 35.4	18 Argon A 39.9	2 8 8
19 Potassium K 39.1	20 Calcium Ca 40.1	21 Scandium Sc 44.9	22 Titanium Ti 47.9	23 Vanadium V 50.9	24 Chromium Cr 51.9	25 Manganese Mn 54.9	26 Iron Fe 55.8	27 Cobalt Co 58.9	28 Nickel Ni 58.7	29 Copper Cu 63.5	30 Zinc Zn 65.3	31 Gallium Ga 69.7	32 Germanium Ge 72.5	33 Arsenic As 74.9	34 Selenium Se 78.9	35 Bromine Br 79.9	36 Krypton Kr 83.8	2 8 18 8
37 Rubidium Rb 85.4	38 Strontium Sr 87.6	39 Yttrium Y 88.9	40 Zirconium Zr 91.2	41 Columbium Cb 92.9	42 Molybdenum Mo 95.9	43 Technetium Tc (99)	44 Ruthenium Ru 101.1	45 Rhodium Rh 102.9	46 Palladium Pd 106.4	47 Silver Ag 107.8	48 Cadmium Cd 112.4	49 Indium In 114.8	50 Tin Sn 118.6	51 Antimony Sb 121.7	52 Tellurium Te 127.6	53 Iodine I 126.9	54 Xenon Xe 131.3	2 8 18 18 8
55 Cesium Cs 132.9	56 Barium Ba 137.3	57-71 (Lanthanum Series)	72 Hafnium Hf 178.4	73 Tantalum Ta 180.9	74 Tungsten W 183.8	75 Rhenium Re 186.2	76 Osmium Os 190.2	77 Iridium Ir 192.2	78 Platinum Pt 195.1	79 Gold Au 196.9	80 Mercury Hg 200.6	81 Thallium Tl 204.3	82 Lead Pb 207.1	83 Bismuth Bi 208.9	84 Polonium Po 210	85 Astatine At (211)	86 Radon Rn 222	2 8 18 32 18 8
87 Francium Fr (223)	88 Radium Ra 226	89-103 (Actinium Series)																

57 Lanthanum La 138.9	58 Cerium Ce 140.1	59 Praseodymium Pr 140.9	60 Neodymium Nd 144.2	61 Promethium Pm (145)	62 Samarium Sm 150.3	63 Europium Eu 151.9	64 Gadolinium Gd 157.2	65 Terbium Tb 158.9	66 Dysprosium Dy 162.5	67 Holmium Ho 164.9	68 Erbium Er 167.2	69 Thulium Tm 168.9	70 Ytterbium Yb 173.0	71 Lutetium Lu 174.9	2 8 18 32 9 2
89 Actinium Ac 227	90 Thorium Th 232	91 Protactinium Pa 231	92 Uranium U 238	93 Neptunium Np (237)	94 Plutonium Pu (242)	95 Americium Am (243)	96 Curium Cm (245)	97 Berkelium Bk (249)	98 Californium Cf (251)	99 Einsteinium Es (254)	100 Fermium Fm (252)	101 Mendelevium Md (256)	102 Nobelium No (253)	103 Lawrencium Lw (257)	2 8 18 32 ? 9 2

Bracketed Mass Numbers are Representative of the Most Stable Isotope of the Element.

FUJI NDT Systems

Figure 1.1.7

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The Periodic Table of Elements

In 1869 Lothar Meyer and Dmitri Mendeleyev made a list of all the chemical elements known at the time in order of increasing masses. By subdividing the list into groups or periods, they could see that a repetition, or re-ocurrence, of similar chemical and physical properties occurred at more or less regular intervals. There were many empty places in the table into which Mendeleyev correctly assumed unknown elements would fit. Based on the table, he was able to predict the characteristics of the missing elements from the properties of the nearby known elements. From the periodic table, the periodic law of the elements was derived. It states that the properties of the chemical elements depend on the structure of the atom and that these properties vary periodically with the atomic number of the element.

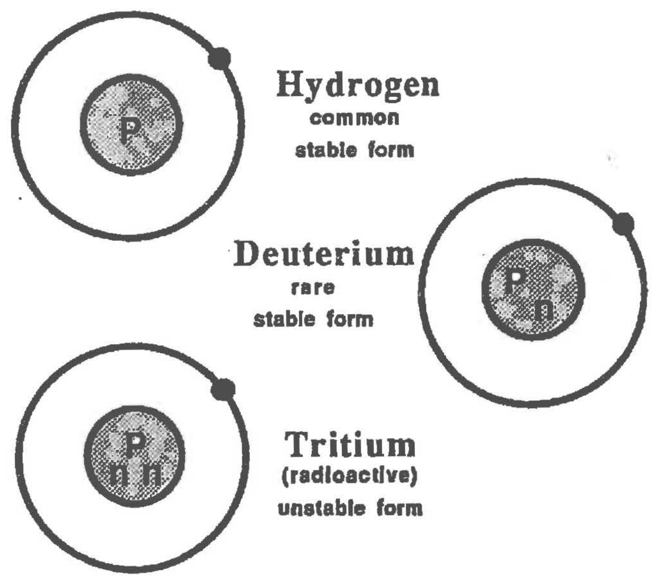
The 18 vertical columns in the table are called groups, and the elements in each group have similar properties. These similarities are repeated periodically in the horizontal rows, comprising the seven periods. All the elements in each row have the same arrangement of electrons in the various shells of the atoms.

Isotopes

Elements with a common atomic number (the same number of protons) and a different atomic weight (a different number of neutrons) are called isotopes of that element. There are stable and unstable isotopes. The stable isotope is not radioactive, whereas the unstable isotope is radioactive. Radioactive isotopes are also called radioisotopes.

Isotopes

Isotopes of Hydrogen



Atoms of the same element with a different number of neutrons have different physical characteristics and are called isotopes.

FUJI NDT Systems | Figure 1.1.8 | Quality Consulting Co. & Associates

The number of isotopes for each element varies. For example, hydrogen's most common form has 1 proton and no neutrons. There are also two isotopes of hydrogen. One is called deuterium which has one proton and one neutron. Deuterium is a stable isotope. The other is Tritium which has one proton and two neutrons and is an unstable isotope. Being unstable (radioactive) means an isotope will change in some way to attain a stable condition and in the process of this change, the nucleus will emit energy in the form of radiation.

Origin and Types of Radiation

X-Ray Generation

Radiation from an x-ray machine is produced when high speed (high energy) electrons bombard a dense target material (generally tungsten) and interact with the atoms of the target material. The usable continuous spectrum of x-rays produced is a result of the electrons giving up the energy, gained through velocity, to the target atoms in a process referred to as bremsstrahlung (German for braking ray).

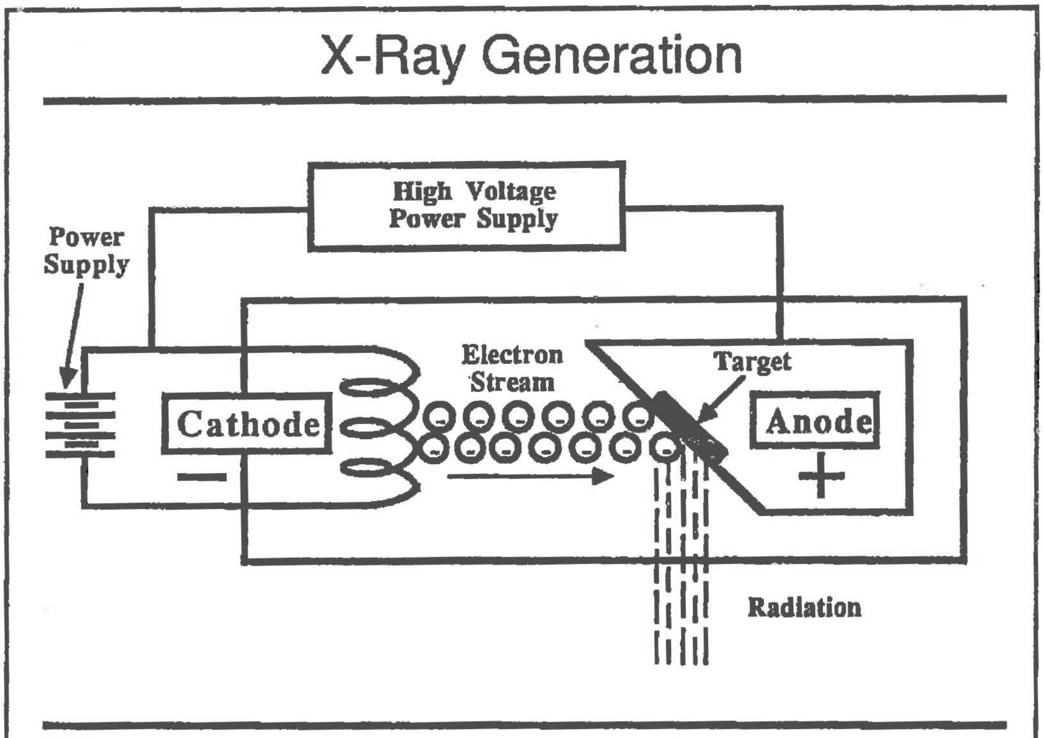


Figure 1.1.9

It is important to note that x-ray machines are not radioactive. X-ray machines only emit radiation when they are energized. The instant the power to the x-ray machine is turned off the radiation emission stops.

Radiation from Nuclear Decay

There are a number of naturally occurring radioisotopes, one of which is the element radium. An unstable isotope undergoes a breaking up or disintegration of the nucleus as it seeks a stable state and in the process, the nucleus gives off radiation. In this process the nucleus changes but does not disappear. The emission of radiation in this process is known as radioactive decay.

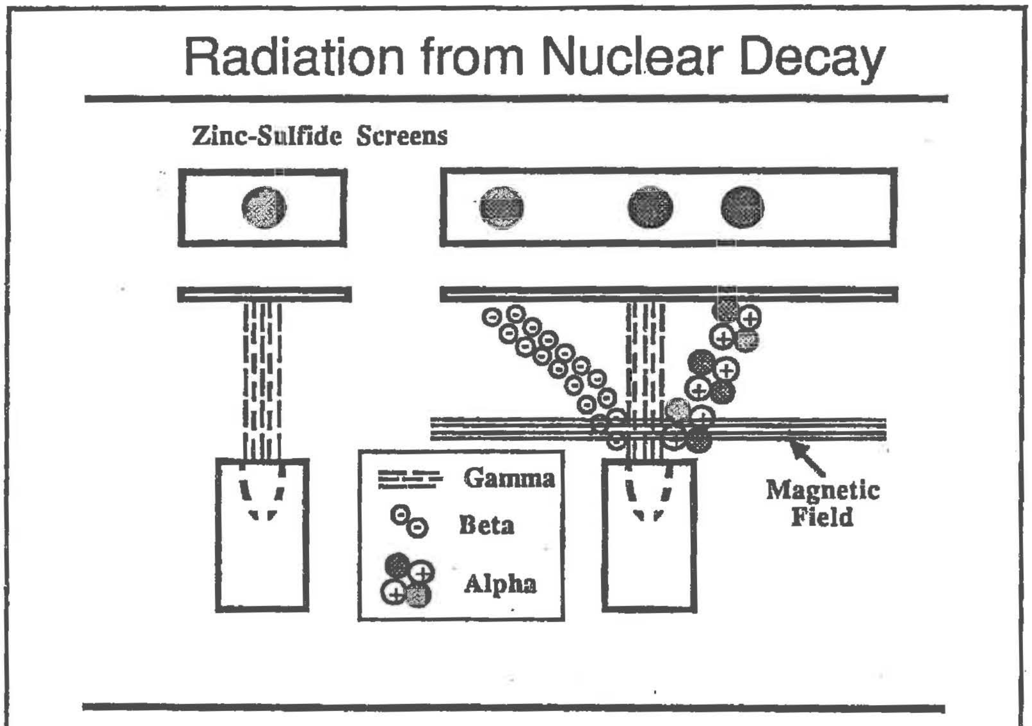


Figure 1.1.10

During his radiation experiments, Ernest Rutherford placed a bit of radioactive material in a lead container. A small opening in the container allowed only a narrow beam of radiation to escape. He found that when he placed a zinc sulfide plate in the radiation beam a small circle began to glow. When he placed a strong magnetic field near the beam it caused 3 spots to appear on the zinc sulfide screen. This experiment showed that there were 3 different types of radiation present; alpha particles, beta particles and gamma rays:

1. The alpha particle was identified as being two protons and two neutrons (the same as a helium nucleus). The positive charge of the alpha particle caused the particle to be deflected by the magnetic field.

2. The beta particle was identified as being a lightweight negatively charged particle (the same as an electron). The negative charge of the beta particle caused the beta particle to be deflected in the opposite direction of the positively charged alpha particle. The beta particle's deflection was greater than the alpha particle's deflection even though the alpha particle charge is twice that of the beta particle. This is due to the great difference in their mass.

3. The third type of radiation that was identified was unaffected by the magnetic field. This radiation was identified as the gamma ray which is not a charged particle, but was found to demonstrate the same characteristics as the earlier discovered x-rays.

Research has shown that the x-rays and gamma rays have a dual character, acting sometimes like a particle and other times like a wave. It was postulated that the energy of these rays were in discrete packets of electromagnetic energy known as photons. Photons have momentum but no mass or electrical charge.

Creating a Radioactive Isotope (Radioisotope)

As well as the many isotopes of the various elements that occur in nature, there are many common man-made artificial radioactive isotopes or radioisotopes. Radioisotopes are produced by bombarding an element such as Cobalt 59 with an excess of neutrons in a nuclear reactor. The atoms in the element in turn absorbs some of the neutrons, thereby increasing the atomic weight of the element, creating a radioisotope of the element and, in the case of Cobalt 59, the radioisotope is Cobalt 60. This process is known as activation.

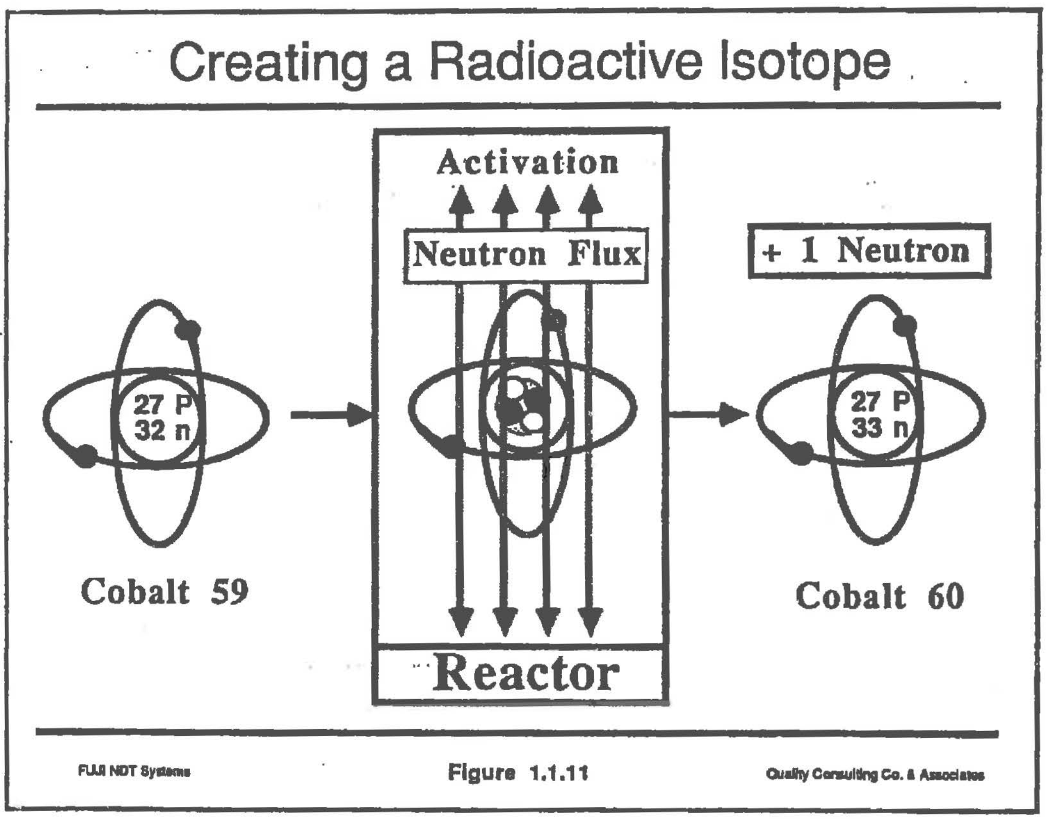


Figure 1.1.11

The Decay of Radioisotopes

As radioactive materials decay, they follow well-defined schemes. A simple example of one of these schemes is shown in figure 1.1.13. The unstable radioisotope, Cobalt 60, in turn decays to the stable element Nickel 60. The energy of gamma ray or x-ray photons is expressed in electron volts (eV). During the disintegration process, 10% of the Cobalt 60 atoms emit a beta particle and then emit a gamma photon of 1.33 MeV energy. 90% emit a beta particle and then emit, in turn, a gamma photon of 1.17 MeV and one of 1.33 MeV.

The Decay of Cobalt 60

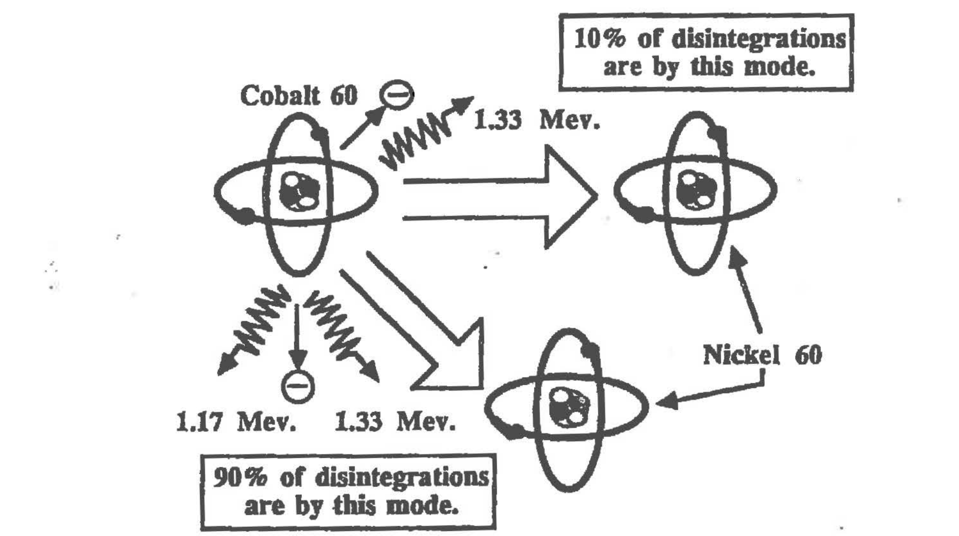


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Figure 1.1.12

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Human Exposure to Radiation

Human exposure to radiation comes from many sources. Figure 1.1.13 names natural background, man-made sources and occupational exposure as the three sources of radiation exposure to humans. About fifty percent of the average individual's radiation exposure comes from natural background radiation and the other 50% comes from man-made sources of radiation.

The average radiation worker's occupation involves additional exposure above that received from natural background and what we categorize as man-made sources which is mostly medical diagnostics. The exposure is called occupational exposure and is unique in that it is accounted for by monitoring devices. The average gamma radiographer receives an average annual exposure of approximately 5 times that of the average individual who is a non-radiation worker.

Human Exposure to Radiation

Source	Percent of Annual Exposure
Exposure from Natural Background	
Cosmic Rays (sun and outer space)	14
Building materials	2
Human body	12
The earth	13
Approx. % of average annual exposure	50
Exposure from Manmade Sources	
Medical (mostly diagnostic x-rays)	45
Fallout from atomic bombs	2.5
Nuclear power	0.15
Consumer products (mostly color TV's)	0.5
Approx. % of average annual exposure	50
Occupational Radiation Exposures	
Workers at Gamma Radiography Companies	3X*
Gamma radiographers	5X**

* The average radiation exposure for workers at gamma radiography companies is approximately 3 times that from natural and manmade sources in the U.S. (this is approximately the same as the exposure for airline pilots who fly an average of 3,000 miles per day)

** The average radiation exposure for gamma radiographers is approximately 5 times that from natural and manmade sources in the U.S.

Source: NCRP Report No. 45, 1975 and NCRP Report No. 45, 1977

FUJI NDT Systems — Figure 1.1.13 — Quality Consulting Co. & Associates

Review The Quiz

Lesson 1 Quiz

Circle and/or fill in the correct answer for the following:

1. Elements with common atomic numbers but with different atomic weights are called:

   A. Ions
   B. Isotopes
   C. Radioactive
   D. Elements

2. Artificial isotopes are produced by bombarding an element in a nuclear reactor with:

   A. radiation.
   B. protons.
   C. electrons.
   D. neutrons.

3. Describe the basic structure of the atom.

   ____

   ____

   ____

   ____

   ____

4. All isotopes are radioactive to some degree.

   A. True
   B. False

5. Name the different types of radiation that Ernest Rutherford identified.

   ____

   ____

   ____

6. The average gamma radiographer receives approximately 5 times the radiation exposure of the average non-radiation worker.

   A. True
   B. False

Lesson 2

Lesson 2
Radiation Properties and Sources

Study

The Outline

II. Characteristics of Radiation, Ionization and Industrial Sources
- A. Characteristics of Radiation
  1. Electromagnetic Radiation
  2. Electromagnetic Spectrum
  3. Radiation Characteristics
  4. Particle, Gamma & X-Radiation
- B. Ionization and Ions
  1. Photoelectric Effect
  2. Compton Scatter
  3. Pair Production
  4. Absorption
- C. Industrial Radiation Sources
  1. Gamma Ray
  2. X-Ray

Learn

The Key Terms

activity — The activity of a radioisotope is the number of disintegrations that occur for a given radioisotope during a given length of time. Activity is measured in curies.

Compton scatter — A process in which a photon transfers a portion of its energy to dislodging and accelerating an orbital electron and a lower energy photon is scattered at an angle to the original photon path.

curie (ci)	The basic unit used to describe the intensity of radioactivity (disintegration rate) of a radioisotope. One curie represents a disintegration rate of 3.7×10^{10} disintegration events per second.
electromagnetic radiation	Radiation consisting of electric and magnetic waves that travel at the speed of light.
frequency	The number of cycles or wave motion passing a given point in a given time interval.
half-life	The time required for one half of the atoms in a radioactive substance to disintegrate.
ion	An atom, group of atoms, molecules or particles that have acquired or are regarded as having a net electric charge.
ionization	Any action that disrupts the electrical balance of an atom and results in the production of ions.
pair production	A process by which electromagnetic radiation of 1.02 MeV or greater transforms its energy into an electron-positron pair during its interaction with an atom.
photoelectric effect	A process by which electromagnetic radiation is absorbed completely when it interacts with matter.
velocity	Distance traveled in a specified amount of time.
wavelength	The linear distance a wave must travel to complete one cycle.

Read The Text

Working Safely in Gamma Radiography

Chapter 2	Pages 10 through 12a
Chapter 3	Pages 20b through 24

Complete The Quiz

Complete the quiz at the end of this lesson.

Watch The Video Tape

Lesson 2 - Radiation Properties and Sources

Follow The Lecture

Characteristics of Radiation, Ionization and Industrial Sources

Characteristics of Radiation

Electromagnetic Radiation

Electromagnetic radiation is energy transmitted in waves that show electric and magnetic effects. This type of radiation has definite wavelength, frequency and velocity. The product of the frequency

and wavelength for all electromagnetic radiation is equal to the speed of light, a constant. The energy of electromagnetic radiation is indirectly proportional to its wavelength. Low frequency, long wave length radiation has low energy while high frequency, short wave length radiation has high energy.

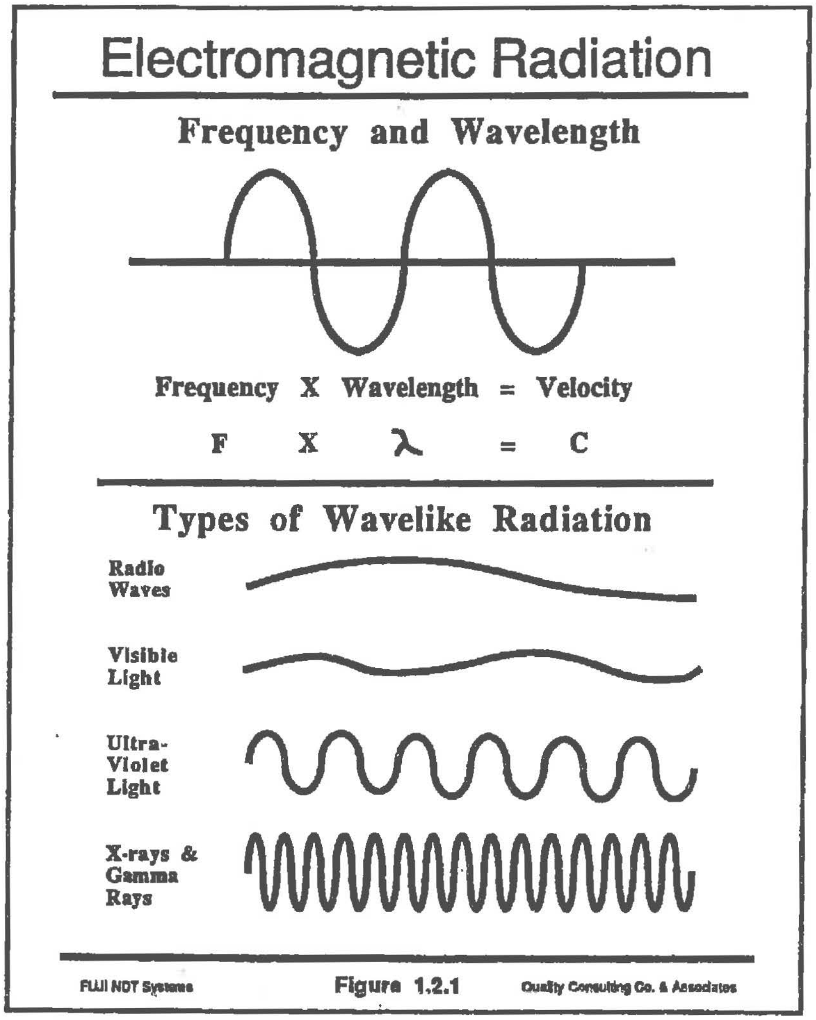
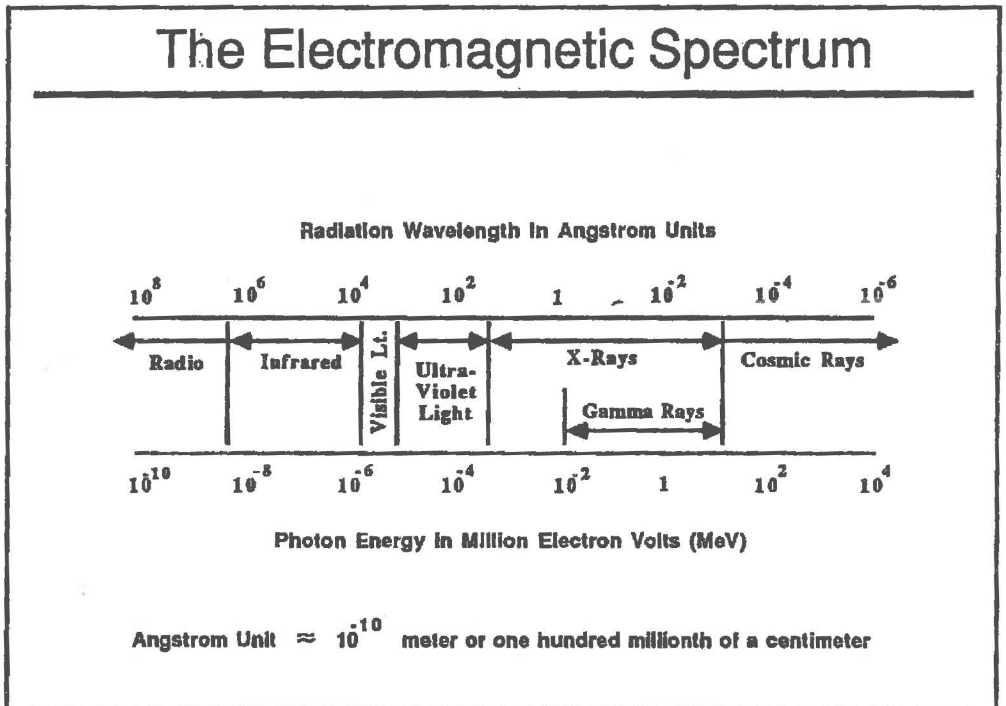


Figure 1.2.1

By looking at some of the different types of electromagnetic radiation, as shown in Figure 1.2.1, it can be seen that x-rays and gamma rays have higher frequency and shorter wave length than, for example, ultraviolet light. Therefore, x-rays and gamma rays have higher energy than ultraviolet light. The higher energy x-rays and gamma rays penetrate matter deeper than the ultraviolet radiation, the depth of penetration being dependent upon the energy or quality of the radiation.

Electromagnetic Spectrum

All electromagnetic radiation exhibits the dual character mentioned in Lesson 1 for x-rays and gamma rays. That is, sometimes they act like particles and other times like waves. The energies of the waves are said to be discrete packets of energy known as photons. The electromagnetic spectrum is a grouping of electromagnetic waves according to their photon energy or wavelength. Within the spectrum there is a gradual shift from one type of radiation to another. The group having the highest energy photons with the shortest wavelength is the cosmic ray.



FUJI NDT Systems Figure 1.2.2 Quality Consulting Co. & Associates

Figure 1.2.2 shows that x-rays and gamma rays have that same energy or wavelength and are shown to occupy the same area of the electromagnetic spectrum. It is important to note that x-rays and gamma rays are in essence the same, their only difference being their origin.

Radiation Characteristics

Electromagnetic Radiation

Electromagnetic radiation consists of electromagnetic waves of energy with no mass and no electrical charge. Electromagnetic radiation travels in straight lines at 186,000 miles per second (the speed of light).

X-Rays and Gamma Rays

Being electromagnetic radiation, x-rays and gamma rays exhibit all the characteristics noted above and, in addition, they penetrate and ionize matter, including human cells. X-rays and gamma rays do not make matter radioactive in the conventional energy ranges commonly used in industrial radiography. They cannot be reflected, although they are scattered, nor are they affected by magnetic fields. One of the most critical factors when considering human safety is that they cannot be detected by the human senses.

Radiation Characteristics

Electromagnetic Radiation

- No Mass
- No Electrical Charge
- Travels in Straight Lines
- Travels @ Speed of Light

X-Rays and Gamma Rays

- All of the Above
- Penetrates Matter
- Ionizes Matter
- Cannot be Reflected (May be Scattered)
- Not Affected by Magnetic Fields
- Is not Detected by the Human Senses

Alpha, Beta and Neutron

- Has Mass
- Travels @ Sub-Light Speeds
- Penetrates Matter Somewhat
- Ionizes Matter
- Is not Detected by the Human Senses

FUJI NDT Systems Figure 1.2.3 Quality Consulting Co. & Associates

There are some exceptions to these characteristics. Low energy x-rays generated below 10 KeV exhibit deflection. These energies, at high intensities, are useful in treating skin cancer. This low energy characteristic does not affect industrial applications. Also, linear accelerators with energies greater than 10 MeV will activate certain materials such as aluminum, beryllium, copper and silver. These activated materials give off beta particles, photons and neutrons of high intensity for a short duration. Activation can begin at energies as low as 6 MeV for certain materials. One should seek the guidance of the accelerator manufacturer for its safe operation.

Alpha, Beta and Neutron

Conventional industrial radiography uses either x-rays or gamma rays to produce radiographs. Neutron radiography refers to a radiographic process that uses a stream of neutrons rather than electromagnetic radiation. Neutrons are particulate radiation just as alpha and beta particles are.

While this course is primarily concerned with x-ray and gamma ray radiation safety, it is important that the radiographer have an understanding of some of the characteristics of particulate radiation. Unlike x-rays and gamma rays particulate radiations have mass and travel at sub-light speeds. Each penetrates matter to a different degree and each ionizes matter such as human cells. While alpha and beta particles ionize matter directly, the neutron ionizes indirectly. A neutron has little effect on electrons since it has no electric charge and the electrons are of such a minute size. If a neutron hits the nucleus of an atom and is absorbed or causes fission, the nucleus may emit particles that ionize. While neutrons can activate matter causing it to become radioactive, alpha and beta do not make matter radioactive. It is important to note that alpha, beta and neutron radiation, just as with x-ray and gamma rays, cannot be detected by the human senses.

Particle, Gamma and X-Radiation

Figure 1.2.4 identifies some of the properties of electromagnetic and particulate radiation, including mass in atomic mass units, electrical charge and approximate energy range in MeV

Particle, Gamma & X-Radiation

Type	Mass	Charge	Energy (MeV)
Neutron	1 A.M.U.	0	0 to >20
Alpha Particle	4 A.M.U.	+2	4 to 10
Beta Particle	1/1840 A.M.U.	±1	0.025 to 3.15
Gamma Ray	0	0	0.04 to 3.2
X-Ray	0	0	up to 30 MeV

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Figure 1.2.4

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Ionization

An electrical balance of an atom is maintained when an equal number of protons and electrons exist. When an event takes place that causes an orbital electron to be ejected there is a disturbance in the electrical balance of the atom. This disturbance is called ionization. An ion is an atom, group of atoms, or free particles with either a positive or negative charge.

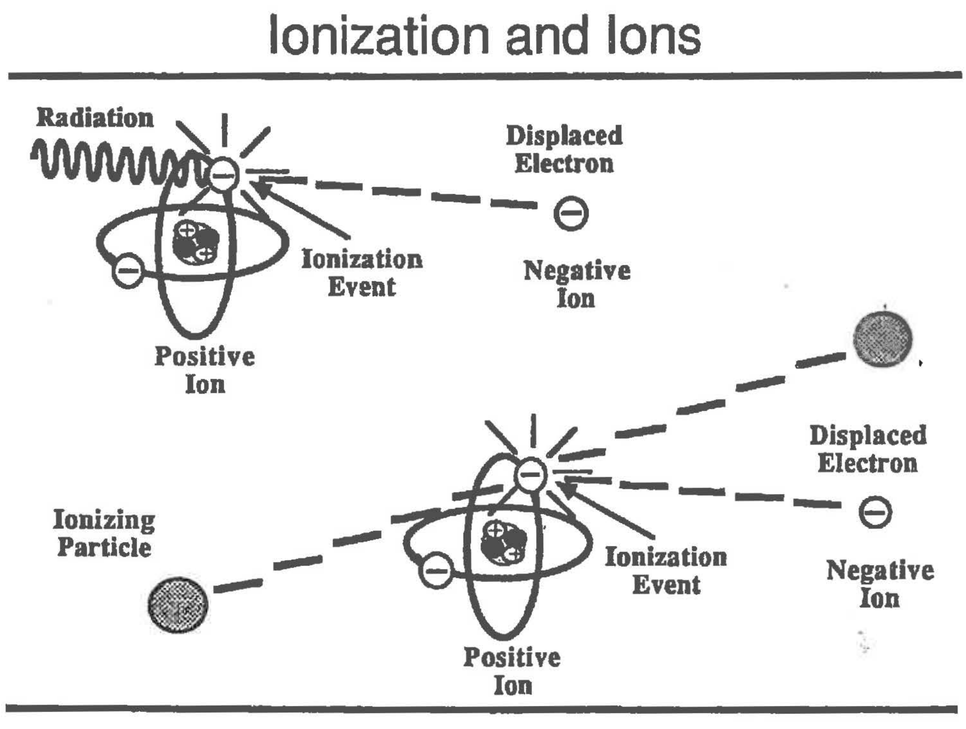


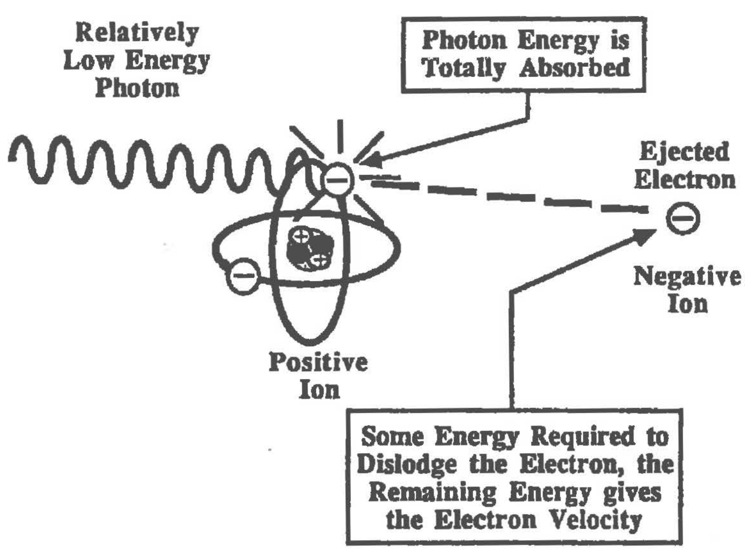
Figure 1.2.5

Matter in the path of x-rays, gamma rays and particulate radiation is ionized when the energy of the ray or particle dislodges a charged particle, usually an electron, from an atom. The dislodged electron is a negative ion and the atom, since it lost a negative electron, having been neutral, becomes a positive ion. The ionization processes whereby x-rays or gamma rays passing through matter lose energy to atoms are known as the photoelectric effect, Compton scatter and pair production.

Photoelectric Effect

The photoelectric effect is a phenomenon whereby there is total absorption of photon energy during interaction with an atom. Part of the photon energy is given up to break the binding force that holds an electron in its orbital shell and the remaining energy is used up to give the dislodged electron velocity. The atom becomes a positive ion and the ejected electron becomes a negative ion. This is the predominate effect in the absorption of low energy photons.

Photoelectric Effect



FUJI NDT Systems — Figure 1.2.6 — Quality Consulting Co. & Associates

Compton Scatter

When higher energy photons (relative to those that cause the photoelectric effect) interact with the atoms in matter, the phenomenom known as Compton scatter occurs. Compton scatter is the absorption of some of the energy of a photon. The absorbed energy breaks the binding force that holds the electron in its shell and gives the dislodged electron velocity.

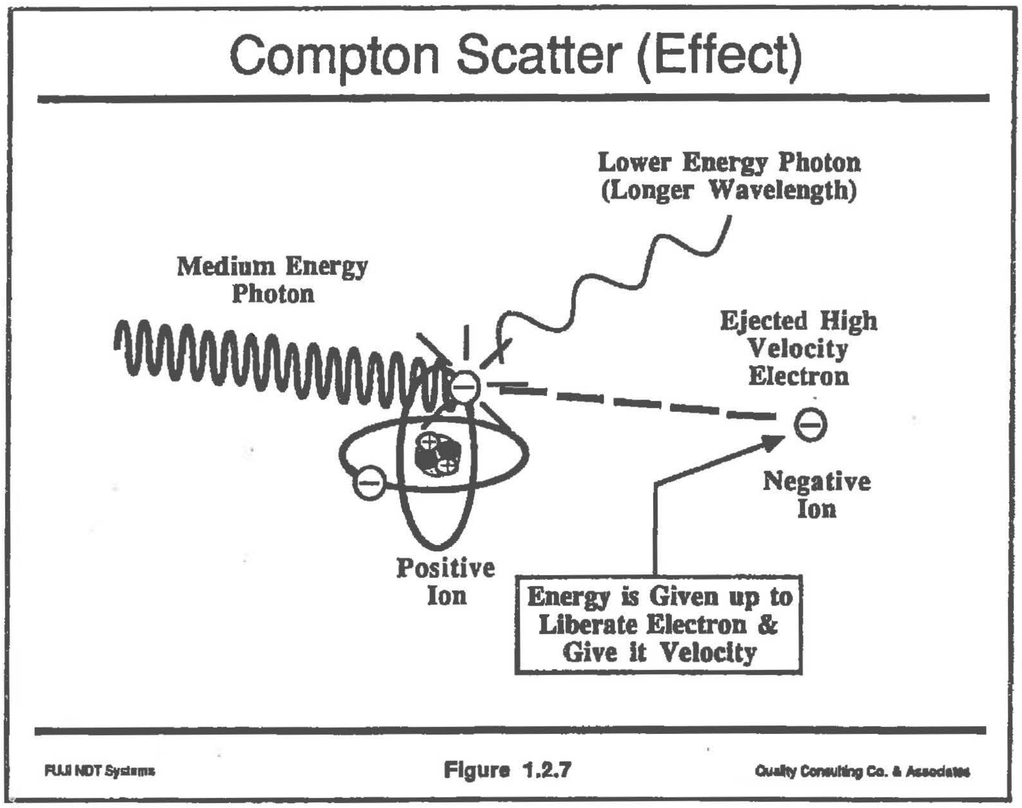


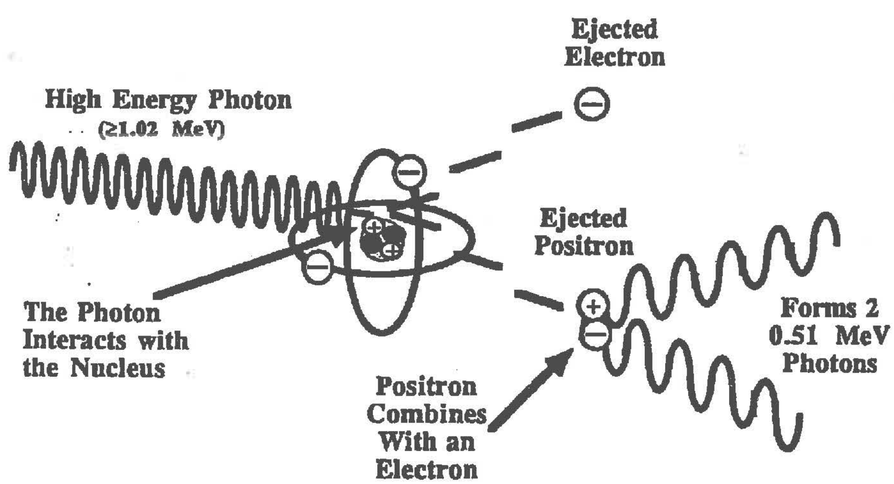
Figure 1.2.7

Ionization has occurred due to interaction of radiation with an atom. The atom becomes a positive ion and the dislodged electron a negative ion. The energy which has not been given up to the electron continues as a lower energy photon. This lower energy longer wavelength photon leaves the atom at an angle to the original path of the incident photon. This lower energy photon ionizes other atoms through Compton scatter or the photon energy is completely absorbed by the photoelectric effect.

Pair Production

The even higher energy photons of 1.02 MeV or more cause a phenomenon in the atoms of matter known as pair production. This process occurs when the higher energy photon approaches the nucleus and changes from energy to an electron-positron pair. The positron is a extremely short-lived particle with a positive charge and the same mass as the electron. The positron combines with an electron and changes into 2 gamma rays with 0.51 MeV photon energy each. These photons then cause ionization through Compton scatter or the photoelectric effect.

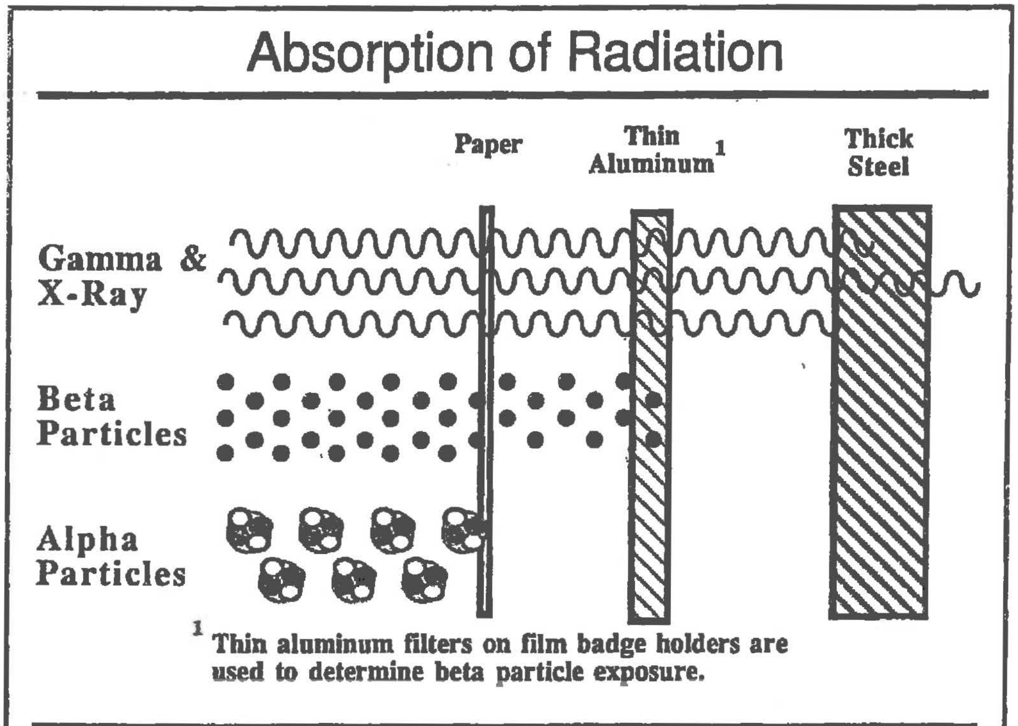
Pair Production



FUJI NDT Systems | Figure 1.2.8 | Quality Consulting Co. & Associates

Absorption of Radiation

Gamma rays and x-rays are absorbed to varying degrees by different materials. They are theoretically never completely absorbed, whereas the particulate radiations are completely stopped by a given amount of matter. Alpha particles are stopped by as little as a sheet of paper, beta particles can be stopped by a thin sheet of aluminum.



FUJI NDT Systems

Figure 1.2.9

Quality Consulting Co. & Associates

Industrial Radiation Sources

Gamma Ray Measurements

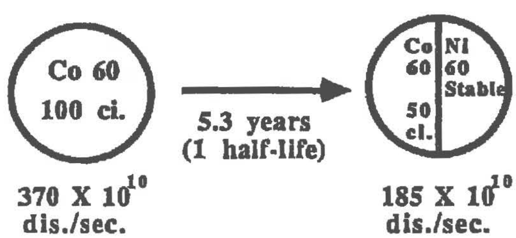
The activity of a radioisotope is the number of disintegrations that occur in a given radioisotope, during a given amount of time. Activity is measured in curies which is defined as 3.7×10^{10} disintegrations per second. As radioisotopes decay, their activity is subsequently reduced.

Gamma Ray Measurements

Activity The number of curies for a radioisotope.

Curie 3.7×10^{10} disintegrations per second.

Half-Life The time required to reduce the activity of a radioisotope to one-half.



Time (Years)	Half-Lifes	Activity (Curies)
0	0	100
5.3	1	50
10.6	2	25
15.9	3	12.5
21.2	4	6.25

FUJI NDT Systems   Figure 1.2.10   Quality Consulting Co. & Associates

The period of time it takes to reduce a given activity of radioisotope to one-half is known as its half-life. The example shown in Figure 1.2.10 is for Co-60 (Cobalt-60) which has a half-life of 5.3 years. Starting with a 100 curie source of Co-60 (370×10^{10} disintegrations per second), at the end of 5.3 years (1 half-life), the activity of the source would be 50 curies (185×10^{10} disintegrations per second). Also at this point, half the radioisotope Co-60 would have decayed to the stable isotope Ni-60 (Nickel-60). In another 5.3 years, the activity of the 50 curie Co-60 source would be 25 curies. This halving of the activity continues for each additional 5.3 year period, but the activity of a radioisotope never reaches zero.

Radioisotope Decay Charts

Manufacturers of radioisotopes provide graphs with each source they ship. These graphs are drawn on semilog paper and are known as source activity "decay charts". The decay chart is used to accurately determine the activity of the source on any given date. The semilog graph paper is used so that the activity of the source is displayed on a straight declining diagonal line making it easy to use.

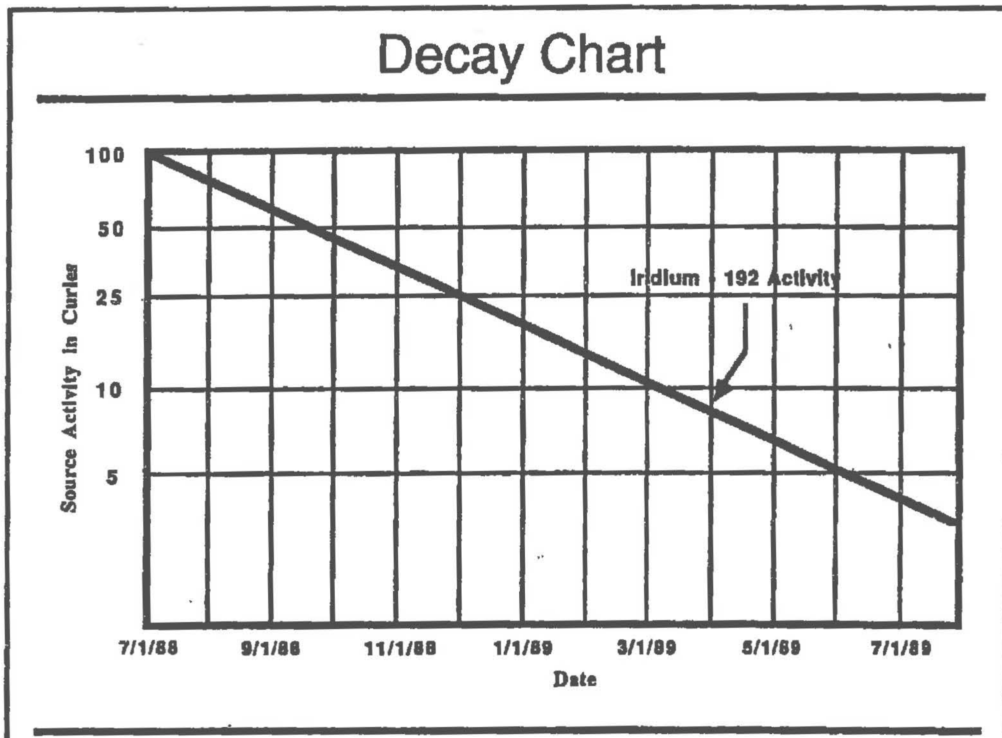


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Figure 1.2.11

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To determine the activity of the source for a given date, locate the date on the horizontal axis. Move from that point vertically up to the diagonal source activity line. From this point move horizontally over to the vertical axis and read the curie strength. This reading is the activity of the source on the selected date.

Radioisotope Characteristics

Figure 1.2.12 lists the most common radioisotopes in use for industrial radiographic operations today with Cobalt-60 and Iridium-192 being the most commonly used. Cesium-137, a powder form requiring double encapsulation for safety purposes, is primarily used as a calibration source. Thulium- 170 is only used for special applications because of its low energy.

Radioisotope Characteristics

Characteristic	Radioisotope			
	Cobalt 60	Iridium 192	Cesium 137	Thulium 170
Daughter Element	Ni 60	Pt 192	Ba 137	Yb 170
Half-life	5.3 yrs.	74.3 days	30.1 yrs.	134 days
Specific Activity (Ci/g)	50	350	25	1,000
Beta (MeV)	0.31	0.6	0.5	1.0
Useful Gamma (MeV)	1.17, 1.33	0.31,0.47 0.60	0.66	0.084 to 0.052

FUJI NDT Systems Figure 1.2.12 Quality Consulting Co. & Associates

The characteristics detailed in the figure for these industrial radioisotope sources include:

- the final stable daughter element to which the radioisotope decays;
- the half-life;
- the specific activity being the concentration of radioactive material expressed as curies per gram (two of the same radioisotopes with the same number of curies with different specific activities will have different weights and dimension);
- the beta energy in MeV emitted during decay, and;
- the principal or useful gamma energy in MeV emitted during decay. It is important to note that each radioisotope has fixed discrete emissions of electromagnetic waves of given energy.

X-Ray Spectrum

X-ray machines come in a variety of configurations and energy outputs up to 30 MeV. All x-ray machines put out a continuous spectrum of x-rays. This spectrum covers a wide band of wavelengths and energy content. X-ray machines, therefore, differ from radioisotopes in that x-ray machines put out a spectrum of energies and radioisotopes put out discrete energy levels.

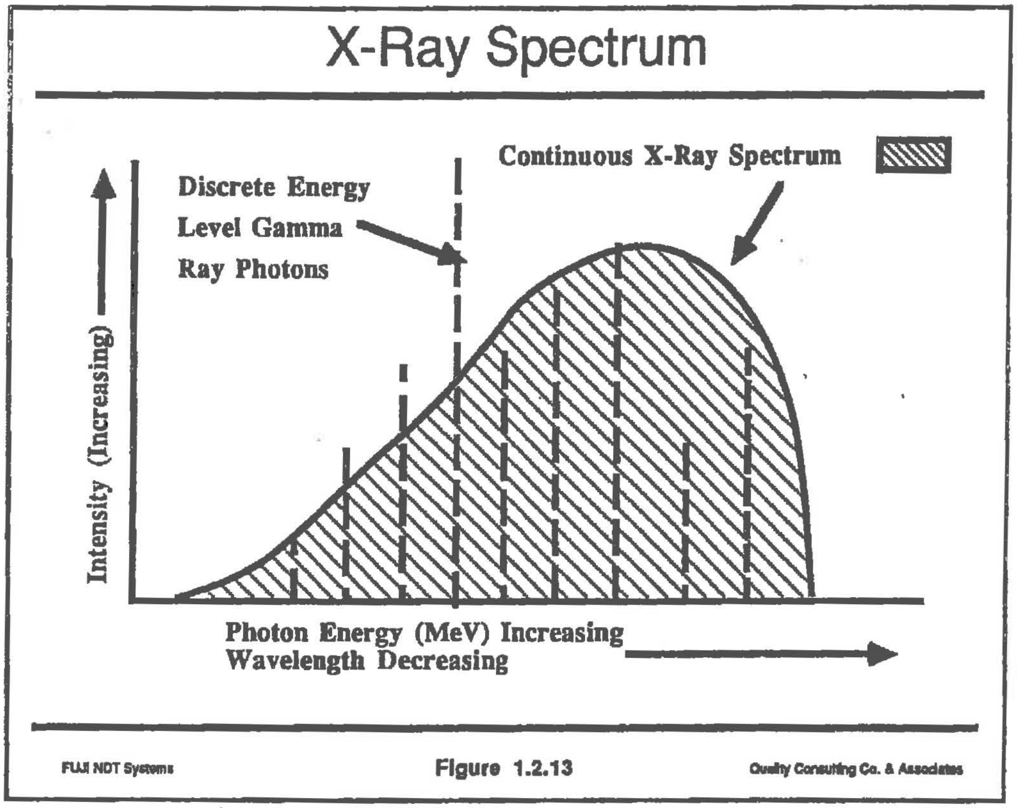

Figure 1.2.13

Review

The Quiz

Lesson 2 Quiz

Circle and/or fill in the correct answer for the following:

1. Which of the electromagnetic ionization events create an electron and a positron?

   A. Photoelectric effect
   B. Compton scatter
   C. Pair production
   D. None of the above

2. Which of these sources of Iridium 192 has the highest specific activity?

   A. 200 curies weighing 1 gram
   B. 200 curies weighing 2 grams
   C. 200 curies weighing 3 grams
   D. All of the above have the same specific activity

3. Long wavelength radiation has high energy and relatively high power for penetrating matter.

   A. True
   B. False

4. List four characteristics of x-rays and gamma rays:

   A. ______________________________

   B. ______________________________

   C. ______________________________

   D. ______________________________

5. An ion is a(n) ____________ with either a positive or negative charge.

   A. Atom
   B. Group of atoms
   C. Free particle
   D. All of the above

6. Which of the following may be completely absorbed by a piece of paper?

   A. Alpha particles
   B. Beta particles
   C. Gamma rays
   D. High energy x-rays

Lesson 3

Lesson 3
Units of Measurement and Dose

Study

The Outline

III. Radiation Measurement Units and Radiation Dose
  A. Units of Measurement
    1. Roentgen (R)
    2. Radiation Absorbed Dose (rad)
    3. Quality Factor (Q)
    4. Radiation Equivalent Man (rem)
  B. Theory of Allowable Dose - ALARA Philosophy
  C. Exposure Limits
  D. Planned Special Exposures

Learn

The Key Terms

ALARA — Acronym for "as low as is reasonably achievable" which means making every reasonable effort to maintain radiation exposures as far below the dose limits as is practical, considering the benefits derived from its use and the consequences incurred from any exposure.

CDE — Acronym for "committed dose equivalent" which means the dose equivalent to organs or tissues of reference that will be received from an the intake of radioactive material during the 50 year period following the intake. *This does not apply to the dose from x-ray and gamma ray exposure.*

CEDE — Acronym for "committed effective dose equivalent" which is applicable to exposure of body organs or tissue. It is the sum of DDE, CDE and weighting factors. *This does not apply to the dose from x-ray and gamma ray exposure.*

DDE	Acronym for "deep-dose equivalent" which applies to external whole-body exposure such as exposure to industrial x-rays and gamma rays.
declared pregnant woman	A woman who has voluntarily informed her employer, in writing, that she is pregnant and the estimated date of conception.
dose equivalent	The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and sievert.
external dose	That portion of the dose equivalent received from radiation sources outside the body, such as from industrial x-rays and gamma rays.
extremities	The hands, elbows, feet, knees, or legs below the knee.
internal dose	That portion of the dose equivalent received from radioactive material taken into the body, such as from airborne radiation.
LDE	Acronym for "eye (lens) dose equivalent" which applies to the external exposure to the lens of the eye. Eye dose applies to shallow dose exposures that are not common to industrial radiography energy ranges. An exposure to some form of airborne radioactive material to the eyes is applicable.
milli (m)	Indicates one-thousandth (10^{-3}) of a unit. For example, a milliroentgen is one-thousandth (0.001) of a roentgen.
occupational dose	The dose received by an individual in a restricted area or in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material. Does not include exposure from background radiation and medical practices.

PSE	The acronym for "planned special exposure" which is an infrequent exposure to radiation, separate from and in addition to the annual dose limits.
quality factor (Q)	The quality factor or relative effectiveness of a given kind of ionizing radiation in producing a biological response from an absorbed dose. The Q for x-rays, gamma rays and beta particles is 1.
rad	The acronym for "radiation absorbed dose" which is a measure of the dose of any ionizing radiation to animal tissues in terms of the energy absorbed per unit mass of the tissue. One rad is the dose corresponding to the absorption of 100 ergs per gram of tissue.
rem	The acronym for "roentgen equivalent man" which is the special unit of any of the quantities expressed as dose equivalent. It is a measure of the dose of any ionizing radiation to body tissues in terms of its estimated biological effect relative to the exposure. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor.
restricted area	Any area for which access is controlled for purposes of protection of individuals against undue risks of exposure to radiation and radioactive materials.
roentgen (R)	The amount of x- or gamma radiation that will produce one electrostatic unit of charge in one cubic centimeter of dry air at 32° F and standard atmospheric pressure.
SDE	The acronym for "shallow dose equivalent" which is applicable for types of radiation that have very low tissue penetrating capabilities and the maximum dose achieved from exposure is at the skin surface. *This does not apply to the dose from x-ray and gamma ray exposure.*
SDE_ME	The acronym for "shallow dose equivalent", maximum extremity, in rems. *This does not apply to the dose from x-ray and gamma ray exposure.*

SDE_WB	The acronym for "shallow dose equivalent", whole body, in rems. *This does not apply to the dose from x-ray and gamma ray exposure.*
TEDE	The acronym for "total effective dose equivalent" which is the sum of deep-dose equivalent (external exposures) and the committed effective dose equivalent (internal exposures).
TODE	The acronym for "total organ dose equivalent" which is the sum of deep dose equivalent (external exposure) and the committed dose equivalent (internal exposure) to the organ receiving the highest dose. The DDE from industrial exposure would be added to any internal exposure. Does not apply to exclusive industrial radiographic exposures.
whole body	The head and trunk (including male gonads), arms above the elbow, and legs above the knees.

Read — The Text

Working Safely in Gamma Radiography

Chapter 2 Page 12 through 13c
Chapter 8 Page 90c through 91b

Note: *Working Safely in Gamma Radiography* was written in September 1982 and reflects the regulations enforced at that time. Some of the referenced reading material will not be aligned with current regulations.

Complete — The Quiz

Complete the quiz at the end of this lesson after reading the lecture notes.

Follow The Lecture

Units of Measurement and Dose

Basic Radiation Measurement Units

Figure 1.3.1 lists some basic units of radiation measurement.

Units of Measurement

1994 Revision

R	Symbol for roentgen, a unit of measure for x-ray and gamma ray
rad	Radiation Absorbed Dose
Q	Quality factor or relative effectiveness
rem	Roentgen Equivalent Man

FUJI NDT Systems — Figure 1.3.1 — Quality Consulting Co., Inc.

Roentgen - R

The roentgen is the unit of measurement of gamma ray or x-ray radiation in air. The roentgen is the amount of x- or gamma radiation that will produce one electrostatic unit (ESU) of charge in one cubic centimeter of air at standard temperature (32°F) and standard atmospheric pressure.

Radiation Absorbed Dose - Rad

Since the roentgen is based on ionization in air, it cannot be used to measure radiation dose in animal tissue because different radiant energies interact differently with animal tissue. The unit of absorbed dose in animal tissue is the rad. The rad applies to various types of radiation including alpha, beta, gamma, x-ray and neutron. The rad and the roentgen are nearly equivalent and therefore are considered equal for practical purposes.

Quality Factor - Q

For different types of radiation there is a different biological effect for the same radiation absorbed dose (rad). The Quality Factor (Q), formally known as the Relative Biological Effectiveness (RBE), has been established by the National Committee on Radiation Protection for each radiation type. Figure 1.3.4 shows some of these values.

Roentgen Equivalent Man - Rem

Rem is the unit used to measure the biological effect of a radiation dose on humans. Rem is the product of the rad multiplied by Q.

SI Units

The standard international (SI) unit equivalents for the above are:

Gray (Gy) is the SI unit of absorbed dose.

1 gray	=	1 joule/kilogram, or
	=	100 rads
1 rad	=	100 ergs/gram, or
	=	0.01 joules/kilogram, or
	=	0.01 or 10^{-2} gray
1 roentgen	=	2.58 X 10^{-4} coulombs/kilograms air

Sievert (Sv) is the SI unit of any of the quantities expressed as dose equivalent. The dose equivalent in sievert is equal to absorbed dose in grays multiplied by the quality factor.

1 sievert	=	100 rems
1 rem	=	0.01 or 10^{-2} sievert

Basic Radiation Units

The units of R and rem are many times too large for practical use. Therefore the prefix milli (m), which stands for one thousandth, is applied as a prefix to the units.

Basic Radiation Units

milli (m)	=	prefix for 1/1,000 (0.001)
1 roentgen (R)	=	1,000 milliroentgen (mR)
1 rem	=	1,000 millirem (mrem)

FUJI NDT Systems — Figure 1.3.2 — Quality Consulting Co., Inc.

One milliroentgen (mR) is equal to one thousandth of a roentgen. One roentgen is equal to 1,000 milliroentgens (mR).