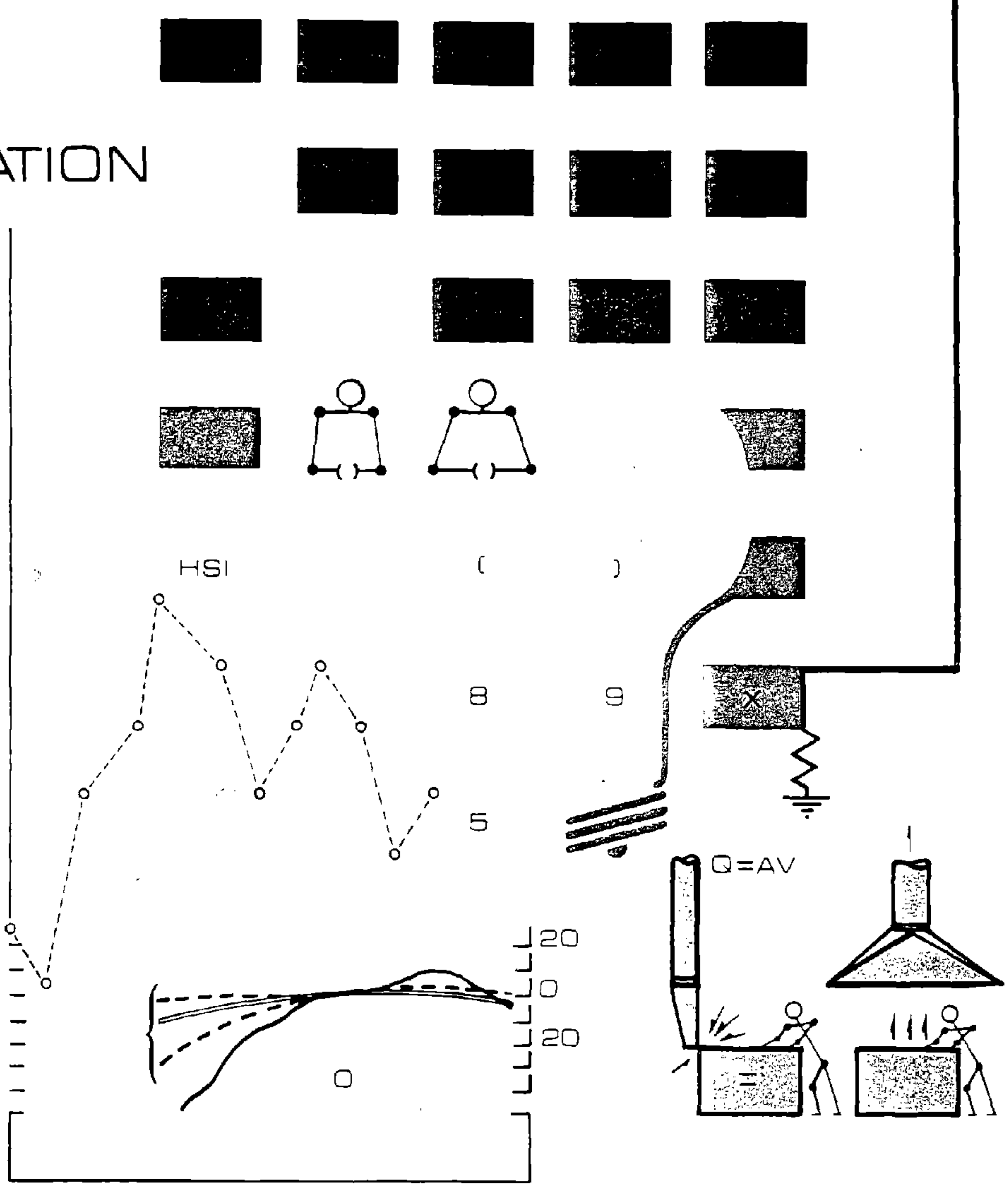
552

INDUSTRIAL HYGIENE ENGINEERING & CONTROL

RADIATION



Instructor Manual

U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health

Division of Training and Manpower Development

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16. Abstract (Limit: 200 words) The information provided in this instructor's manual was intended for use in a college setting for students at an advanced level of industrial hygiene training. This module covered nonionizing and ionizing radiation. Information was reviewed concerning the basic properties, sources, biological effects, and threshold limit values of nonionizing radiation, including ultraviolet, infrared, radio frequencies, microwaves, and lasers. Also included was a discussion of the various applications of nonionizing radiation, and related hazards. A review was presented of methods for evaluating and controlling ultraviolet and microwave radiation and lasers. The manual contained a review of the chemistry and physics of ionizing radiation, including both particulate and electromagnetic wave radiation, and a discussion of the various applications of ionizing radiation and related hazards. Instruments typically used to survey and monitor ionizing radiation sources were discussed, including ion chambers, proportional counters, C-meters, dosimeters, and film badges. The basic concepts for monitoring and controlling ionizing radiation hazards were reviewed, including the uses of shielding, protective clothing, facilities design and personnel monitoring.

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INTRODUCTION TO INDUSTRIAL HYGIENE ENGINEERING AND CONTROL (552)

This is a modularized course designed for use as a one, two, or three week short course or as a one or two semester academic course at either the undergraduate or graduate level. It examines the fundamentals for design of controls to eliminate or satisfactorily deal with occupational health hazards. Lectures, augmented by problem solving sessions, are intended to assist the trainee in selecting, designing, and applying control methods in the work environment. Primary attention is given to industrial ventilation, noise and vibration control, heat stress, and industrial illumination as well as new engineering topics.

The training course manual has been specially prepared for the trainees attending the course and should not be included in reading lists of periodicals as generally available.

Module 6 — Instructor's Manual

NONIONIZING AND IONIZING RADIATION

Division of Training and Manpower Development
National Institute for Occupational Safety and Health

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Center for Disease Control

Cincinnati, Ohio

November 1978

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FOREWORD

The material presented in this document is designed for use in a college or university classroom and is directed to students at an advanced level of study in industrial hygiene. The course may also be utilized in total or in part as the basis for short course offerings.

This material was developed under sponsorship of the National Institute for Occupational Safety and Health, Division of Training and Manpower Development, Cincinnati, Ohio, (Contract CDC—210—75—0076). Serving as Project Officer for the development of this material was Robert B. Weidner, J.D., Branch Chief, Division of Training and Manpower Development.

The lesson plans and accompanying text entitled *Industrial Hygiene Engineering and Control* were prepared by the staff of Management Resource Associates, Monroeville, Pennsylvania. Serving as authors were Bruce B. Byers. Ronald J. Hritz, and James C. McClintock. Also assisting, as consultants to the development of the materials, were Ralph J. Vernon, Ph.D., and Richard B. Konzen, Ph.D., of Texas A&M University.

Art work for the text was prepared by Carole D. Byers. Manuscript preparation was the responsibility of Elaine S. Holmes.

TABLE OF CONTENTS

INTRODUCTION

Purpose of the Course

The course materials are designed for presentation to students at the baccalaureate or graduate level of study in Industrial Hygiene. The materials presuppose that the student has completed introductory courses in recognition, measurement, and evaluation of occupational health hazards. The materials are designed in such a manner that they are applicable as a two-semester course or a three-week intensive study short course. In addition, the materials may be divided to provide courses of a shorter duration. Since the course is divided into self-contained modules, each module can be used as the basis for the development of a course. (e.g., Module 2, Industrial Ventilation can be utilized as a one-semester offering or a one-week short course.)

The emphasis in each module is the control of occupational hazards. However, this emphasis does not preclude the inclusion of recognition, measurement and evaluation topics within the module. Summary material covering these important areas is included where appropriate within each module. This inclusion is based upon the authors' belief that problem identification and definition are important steps that must be taken before adequate control can be implemented.

Content

The materials are divided into eight (8) self-contained modules. Each module is divided into units and lessons. For the most part, the lessons are based upon a one-hour class session for presentation. The modules that are included, as well as the *minimum* time available to cover the modules are:

Module	*Title*	*Minimum Time*
1	Introduction to Industrial Hygiene Engineering and Control	7 Hours
2	Industrial Ventilation	31 Hours
3	Thermal Stress	4 Hours
4	Sound	7 Hours
5	Industrial Illumination	3 Hours
6	Nonionizing and Ionizing Radiation	8 Hours
7	Ergonomics	5 Hours
8	Other Topics	7 Hours
	Total Time	72 Hours

The time allotted is a minimum time that does not include allowance for testing and review of problems and exercises. Based upon the expereinces gained in a pilot test of the materials, the time allotted above provides for only a brief coverage of the topics included. For thorough coverage of each subject, the allotted time should be increased to at least 120 hours. In any case, the time required is dependent upon the level of detail and completeness of coverage of each topic that is desired.

Course Prerequisites

The students should have taken courses in recognition, measurement and evaluation of occupational health hazards. At a minimum, the students should have completed the following NIOSH sponsored courses or their equivalent:

—Recognition, Evaluation and Control of Occupational Hazards
—Industrial Hygiene Measurements

In addition, the students should have completed education in undergraduate mathematics through the calculus and undergraduate science including general and organic chemistry, physics, and biology. Additional engineering courses such as fluid mechanics and thermodynamics will be helpful to the student.

Components of the Course

The Course Manual is designed to provide the technically competent instructor with the basic educational materials from which to conduct the training sessions. It is not the purpose of the Course Manual to provide a complete skill and knowledge package from which the instructor can obtain the technical competency necessary to conduct training, since such competence is assumed to be an attribute of any instructor chosen to teach in the program. Should the instructor wish to brush up on certain skills and knowledge, the references cited as well as the accompanying text, *Industrial Hygiene Engineering and Control*, will provide a basis for this undertaking.

The course is organized with three (3) basic elements. These elements are:

1. Module—A complete, self-contained package of educational materials that is directed toward the attainment of skills and knowledge in a subject area. These modules can be presented as a stand-alone course or can be combined in various ways to construct courses for use with selected groups of students.

2. Unit—A self-contained package of educational materials that is directed toward attainment of a subset of skills and knowledge in a subject area. The unit does not necessarily lend itself to use as a stand-alone package since certain segments of the skills and knowledge presented depend upon completing previous units within the module.

3. Lesson—Generally, an artificial segmentation of a unit for administrative purposes. Lesson segments are normally one hour in length and, as far as is practical, cover a logical subset of knowledge or skills. Lessons allow for the scheduling of the training in various educational environments.

Instructor's Manual—The Module Plan

The module plan contains the following components:

1. Unit and Lesson Topic Outlines—This outline presents the topics covered within the module and the schedule for presentation of these topics. This information provides a concise and organized summary of the subject material in the module.

2. Terminal Objectives—General competency statements related to the skills and knowledge that should be possessed by the student upon completion of

the module. The skill objectives relate to the manipulative, computational, or decision-making skills that the student should attain upon completion of the module. The knowledge objectives relate to the subject knowledge that the student requires in order to perform the required skills. These objectives serve as a basis upon which an evaluation can be made of the student's mastery of the subject material included in the module.

3. Self-Tests—Postmodule self-tests along with the correct answers to these tests are included with each module.

4. References—A list of reference material can be consulted by the instructor or students.

Instructor's Manual—The Unit Plan

The unit is made up of a number of specific components and contains the lesson content outline. The components of the unit plan are:

1. Performance Objectives—Skill and knowledge objectives related to the subject matter included within the unit. These objectives are written in behavioral terms (i.e., an observable activity or result that can be evaluated quantitatively, as specified, and which is conducted or obtained under specific conditions). The objectives that are presented within the unit plan are of a more specific nature than those terminal objectives or competency statements that are specified by the module plan. The performance objectives presented within the unit might be thought of as enabling objectives; i,e., they represent the skills and knowledge that the student must attain in order to complete the requirements of the terminal objectives for the module.

2. Unit Activities—Activities that the student must perform to complete the unit. Reading assignments, reference materials, and outside activities are presented.

3. Required Facilities, Equipment, and Materials—Materials—The required facilities, equipment and materials that should be available for presentation of the unit. The equipment and materials listed are divided into those which are educational and those which are content oriented (e.g., 16 mm projector vs. pitot tube).

4. Content Outline—Presents an organized outline of the topics to be covered during the presentation of the unit. The content outline is divided into the lesson outlines necessary for completion of the units.

   In addition, the content outline contains instructions to the instructor and reference to slides and overlays that should be used in conjunction with the lecture. These instructions present the sequence of instructor activities, such as when to present a given slide, when a demonstration is required, or when an instructor's experience might be of value.

   Since the course is designed to be taught by technically competent instructors, the material in the lesson content outline is of a topical nature with only that explanation present that should be emphasized to the student. It is expected that the instructor's skill and knowledge will allow for the depth of presentation and emphasis required. The instructor is encouraged to present material relevant to experience, wherever possible, in order to provide the students with a referent to the subject.

5. Demonstration Outlines—Appropriate outlines for classroom and laboratory demonstrations and sample problems to be presented to the class. The demonstrations are designed to present an outline of the procedural steps that are important in performing the particular measurement, design, or calculation. Steps that are critical or that may lead to common errors are emphasized in the demonstration outlines.

6. Practice Exercises—A series of practice exercises that can be given to the student. These practice exercises can be used as either classroom or laboratory exercises or as homework assignments. Solutions to problems involving calculations are also provided.

Audio Visual Aids

A set of slides, which are referenced in the lesson outlines, have been prepared and are available for use in presenting the course.

MODULE 6

NONIONIZING AND IONIZING RADIATION

INSTRUCTOR'S MANUAL

Unit and Lesson Topic Outline

Nonionizing and Ionizing Radiation	Module 6

The topics listed below are included within this module. The recommended time to be allotted for each topic is also given. Depending upon the particular class, this time may vary slightly; however, the total time for the entire module should not exceed the time given.

Unit	Lesson		Time/hrs.	
1		Nonionizing Radiation		
	1	Principles of Nonionizing Radiation	2	Review of the basic properties, sources, biological effects, and TLV's of nonionizing radiation, including ultraviolet, infrared, radio frequencies, microwaves, and lasers. Also includes a discussion of the various applications of nonionizing radiation, including related hazards.
	2	Control of Nonionizing Radiation	1	Review of methods of evaluation and control of ultraviolet and microwave radiation and lasers.
2		Ionizing Radiation		
	1	Principles of Ionizing Radiation	2	Review of the chemistry and physics of ionizing radiation, including both particulate and electromagnetic wave radiation. Also includes a discussion of the various applications of ionizing radiation and related hazards.
	2	Monitoring Instruments	1	Review of the instruments typically used to survey and monitor ionizing radiation sources, including ion chambers, proportional counters, G-M meters, dosimeters, and film badges.
	3	Control of Ionizing Radiation	2	Review of the basic concepts for monitoring and controlling ionizing radiation hazards. Included is a review of the uses of shielding, protective clothing, facilities design, and personnel monitoring.
				Total Module Time--8 Hours

Terminal Objectives	
Nonionizing and Ionizing Radiation	Module 6

The objectives presented represent the compentencies that the student should possess upon completion of this module. All objectives are directed toward the student's obtaining certain category levels of skill and knowledge.

Terminal Objectives

1. Upon request, the student will be able to write a paragraph that describes the properties of electromagnetic radiation.
2. Upon request, the student will be able to describe the difference between ionizing and nonionizing radiation.
3. Upon request, the student will be able to write a paragraph describing each type of radiation listed. The description will include the source, general application or use, biological effect, and protective measures normally taken to protect against each type of radiation.
   a. ultraviolet radiation
   b. infrared radiation
   c. microwave radiation
   d. alpha particles
   e. beta particles
   f. X-radiation
   g. gamma radiation
   h. neutrons
4. Given a situation describing the use of a nonionizing radiation source that is potentially dangerous, the student will be able to
   a. identify the radiation hazard
   b. recall at least two associated hazards related to the specified source
   c. describe the procedures necessary to further analyze the potential hazard
   d. using any references selected by the student, outline a procedure for minimizing or removing the hazard

Terminal Objectives	
Nonionizing and Ionizing Radiation	Module 6

5. Given a situation describing the use of an ionizing radiation source and any references selected by the student, the student will be able to

   a. calculate the potential radiation hazard.
   b. outline the procedure for controlling and mointoring the hazard. The outline must include a discussion of:

      (1) shielding requirements
      (2) changes in operating procedures
      (3) protective equipment used for personnel
      (4) changes in facilities design
      (5) monitoring procedures (including instrumentation) to be implemented
      (6) control of waste disposal (if applicable)

   The description will include:

   a. type and amount of radiation source
   b. description of the operating procedures and use of the radiation source
   c. present protective equipment and procedures being implemented
   d. location of personnel with respect to radiation source and mean exposure time of each of the personnel
   e. sample readings taken at the location of each of the personnel
   f. dimensions of the room
   g. any control devices presently being used that are not radiation oriented (e.g., ventilation systems)

UNIT 1

NONIONIZING RADIATION

Performance Objectives

Lesson	Nonionizing Radiation	Module 6 Unit 1
1	1. Given a list of statements, the student will be able to recognize the one that best defines a. photon b. wavelength c. frequency d. relationship between wavelength and frequency	
1	2. Given a list of regions on the electromagnetic spectrum, the student will be able to recognize the relative location of the region with respect to the other regions listed based upon frequency; e.g., ultraviolet has a higher frequency than infrared.	
1	3. Given a list of statements, the student will be able to select the one that best defines a. nonionizing radiation b. ionizing radiation c. relationship of ionizing and nonionizing radiation	
1	4. Given a list of statements, the student will be able to recognize the statement that best describes a. region of electromagnetic spectrum b. potential sources for the radiation c. biological effects, including critical organ for each of the following regions: 1. ultraviolet 2. infrared 3. radio frequency (microwaves)	
1	5. Given any references of the student's choice, the student will be able to determine the threshold limit value for a specified wavelength in the a. ultraviolet region b. infrared region c. radio frequency region	
1	6. Given a list of statements, the student will be able to recognize the one that best describes the principle of operation of the a. klystron b. magnetron	
1	7. Given a list of statements, the student will be able to recognize the one that best describes the principle of operation of a laser.	
1	8. Given no aids, the student will be able to recall and describe why lasers present a potential hazard.	

Performance Objectives		
Lesson	Nonionizing Radiation	Module 6 Unit 1

Lesson		
1	9.	Given a list of statements, the student will be able to recognize the one which best defines the difference between a CW and a pulsed laser.
1	10.	Given the a. output power b. pulse length c. focal size the student will be able to calculate the power density generated by a laser.
1	11.	Given no aids, the student will be able to recall at least one source and three related hazards for ultraviolet, infrared, and radio frequency regions.
1	12.	Given no aids, the student will be able to recall at least two uses and three related hazards for a laser.
2	13.	Given a list of statements, the student will be able to recognize the one(s) which best describe the principle of operation of ultraviolet detection devices; e.g., photon and thermal.
2	14.	Given a list of statements, the student will be able to recognize the one which best describes the need for ultraviolet survey instruments approximating the ultraviolet actinic curve.
2	15.	Given a series of incremental measurements from an ultraviolet source, a table of relative spectral effectiveness by wavelength, and the TLV table for effective irradiance, the student will be able to calculate the effective irradiance and if the TLV has been exceeded for a specified exposure time.
2	16.	Given a list of statements, the student will be able to recognize the one(s) which best describe factors affecting the accurate measurement of ultraviolet radiation.
2	17.	Given no aids, the student will be able to recall the effect of time and distance upon exposure level of electromagnetic radiation.
2	18.	Given a description of a work situation, including the exposure rate of ultraviolet radiation, the student will be able to calculate the maximum permissible time of exposure based upon the TLV.
2	19.	Given a situation describing the exposure level for specified wavelengths of ultraviolet radiation and a table of eyewear specifications, the student will be able to select the eyewear which attenuates the exposure below TLV for the given situation.
2	20.	Given the power output, beam divergence, beam diameter, and a formula to calculate beam intensity, the student will be able to calculate the beam intensity of a selected laser.

Performance Objectives		
Lesson	Nonionizing Radiation	Module 6 Unit 1
2	21. Given a list of statements, the student will be able to recognize the one(s) which best describe(s) the principle of operation of laser survey instruments; e.g., photon, thermal.	
2	22. Given no aids, the student will be able to recall the criteria for classifying lasers in the five categories.	
2	23. Given a list of statements, the student will be able to recognize the one(s) which correctly define(s) operational requirements for a specified class of lasers; e.g., Class I--no requirements.	
2	24. Given a situation describing the exposure level for specified wavelengths of a laser and a table of eyewear specifications, the student will be able to select the eyewear which attenuates the exposure below TLV for the given situation.	
2	25. Given a list of statements, the student will be able to recognize the one which best describes the difference between the "near" and "far" field of radio frequency radiation.	
2	26. Given the antennae area and wavelength (radio frequency), the student will be able to calculate the radius of the near field.	
2	27. Given a list of statements, the student will be able to recognize the one(s) which best describe(s) the principle of operation of microwave detection devices; e.g., photon and electrical.	
2	28. Given no aids, the student will be able to recall at least five (5) potential hazards of radio frequency radiation to be evaluated.	

Unit Activities--Instructor	
Nonionizing Radiation	Module 6 Unit 1

In order to present the unit material to the students, the instructor will be responsible for the following activities:

Lesson 1--Principles of Nonionizing Radiation

Classroom Presentation

Conduct a discussion concerning the basic theory of nonionizing radiation. Specifically, ultraviolet, infrared, radio frequencies, microwaves, and lasers should be discussed. Also included is a discussion of the applications and related hazards.

Time Allotted

2 Hours

Demonstrations

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Unit Activities--Instructor	
Nonionizing Radiation	Module 6 Unit 1

Lesson 2--Control of Nonionizing Radiation

Classroom Presentation

Present a lecture on controlling nonionizing radiation. Specifically, ultraviolet radiation, microwave radiation, and lasers are discussed. Emphasis should be placed upon general concepts of control.

Time Allotted

1 Hour

Demonstrations

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Unit Activities--Student	
Nonionizing Radiation	Module 6 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Principles of Nonionizing Radiation

Classroom Activity

Attend a lecture concerning the basic theory of nonionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 1
the Industrial Environment--its Evaluation and Control		Chapter 28 pp. 357-376
PROBLEMS		
Self-Test	Section 5	Section 5

Unit Activities--Student	
Nonionizing Radiation	Module 6 Unit 1

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 2--Control of Nonionizing Radiation

Classroom Activity

Attend a lecture on the control of nonionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 2
PROBLEMS		

Facilities, Equipment, and Materials	
Nonionizing Radiation	Module 6 Unit 1

Facilities

Lecture/discussion--normal classroom

Equipment

Educational

- Chalkboard
- Chalk
- Eraser
- 35 mm slide projector with remote control
- Screen

Health and Safety

Monitoring Devices

- Ultraviolet radiation
- Lasers
- Microwave radiation

Visuals

Slide Series--Industrial Hygiene Engineering and Control
Module 6, Unit 1

References Used in Class

Industrial Hygiene Engineering and Control
the Industrial Environment--its Evaluation and Control

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
I. Introduction	Slide 6.1.1.--Radiation
A. Prior Module--Discussed Visible Radiation--Light	Briefly review topics discussed in last module which dealt with electromagnetic radiation.
1. Light has characteristics of waves and particles. 2. Light is energy released from de-excitation of electron. 3. Energy released in discrete units--quantum of energy--photon. 4. Each wave in visible spectrum has a characteristic: a. wavelength b. frequency c. photon energy	
5. Characteristics can be correlated using the following: a. $C = f\lambda$, where C = speed of light (3×10^{10} cm/sec) f = frequency of oscillations/sec λ = wavelength (cm) b. $E = hf$, where E = photon energy (Joules) h = Plank's constant (6.6×10^{-34} Joule/sec) f = frequency of oscillations/sec	Slide 6.1.1.2.--Relationship of Frequency, Wavelength, and Photon Energy
6. The importance of visible radiation--eye sensitive to this spectrum regions.	
B. Electromagnetic Spectrum	Slide 6.1.1.3.--Electromagnetic Spectrum
1. All radiations fundamentally alike in that they are produced by moving electrical charges. 2. Movement can be molecules, electrons, neutrons, etc.	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
3. All radiation has same basic properties of visible radiation.	
II. Radiation--Overview	
A. Radiation--Emission of particles or energy in wave form.	
B. Vary in wavelength (λ) and frequency (f).	
C. Units of Measure	Present an overview of the units that will be discussed in conjunction with nonionizing radiation.
1. Wavelength a. length from peak to peak b. units--see slide	Slide 6.1.1.4.--Units of Measure--Wavelength
2. Frequency a. oscillations per second b. units--see slide	Slide 6.1.1.5.--Units of Measure--Frequency
3. Unit prefixes--used in conjunction with basic units.	Slide 6.1.1.6.--Table of Unit Prefixes It may be of value to review unit prefixes in the metric system to aid future discussions.

TABLE OF UNIT PREFIXES

Multiples and Submultiples	Prefix	Symbol
1,000,000,000,000 = 10^{12}	tetra-	T
1,000,000,000 = 10^{9}	giga-	G
1,000,000 = 10^{6}	mega-	M
1,000 = 10^{3}	kilo-	k
100 = 10^{2}	hecto-	h
10 = 10	deka-	D
0.1 = 10^{-1}	deci-	d
.01 = 10^{-2}	centi-	c
.001 = 10^{-3}	milli-	m
.000001 = 10^{-6}	micro-	μ
.000000001 = 10^{-9}	nano-	n
.000000000001 = 10^{-12}	pico-	p

Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
4. Energy a. joule--work done when a constant force of 1 meter moves a body 1 meter b. erg--work done when a constant force of 1 dyne moves a body 1 centimeter 1 joule = 10^7 ergs c. electron volt--energy acquired by a body whose charge equals that of an electron when body falls through a potential difference of one volt 1 eV = 1.602×10^{-19} joules	Slide 6.1.1.7.--Units of Measure--Energy
5. Energy density. a. above units over a unit area b. e.g.,--joules/cm^2	
6. Power a. unit work divided by time b. e.g., --watt = joules/second	
D. Spectrum is divided into regions 1. Radio frequency 2. Microwave 3. Infrared 4. Visible 5. Ultraviolet 6. X-rays 7. Gamma rays	Slide 6.1.1.8.--Electromagnetic Spectrum Review the spectrum with the students. Identify the boundaries and possible source for each region.
E. Radiation also exists which is not electromagnetic in nature but particulate. 1. Formed from radioactive decay or nuclear reaction. 2. Have high energy necessary for ionization (discussed later).	Slide 6.1.1.9.--Particulate Radiation Identify types of particulate radiation briefly for students. It will be discussed later.

TOPIC	REMARKS
3. Types a. alpha--helium nucleus b. beta--electrons c. neutrons	
F. Radiation can be divided into two segments. 1. Ionizing vs. nonionizing. 2. Based upon photon energy available. 3. Definition. a. ionizing--removal of electron from atom, forming positive and negative ion b. nonionizing--energy sufficient to excite atoms but not sufficient to remove electron	Slide 6.1.1.10.--Ionizing vs. Nonionizing Radiation
4. Known that 10 electron volts (eV) required to cause ionization of oxygen or hydrogen molecule; 10 eV can be set as lower limit for ionizing energy.	Ask students if they are familiar with "electron volt" as a unit of energy (force). If they are not, explain terminology.
5. Using the equations. $E = hf$ $C = f\lambda$ The minimum wavelength can be determined which causes ionization. $E = hf \qquad C = f\lambda$ $\therefore E = \frac{Ch}{\lambda}$ or $\lambda = \frac{h \cdot C}{E}$ $\lambda = \dfrac{(6.6 \times 10^{-34} \text{joule-sec})\left(\dfrac{3.0 \times 10^{10} \text{cm}}{\text{sec}}\right)}{\dfrac{10 \text{ eV} \cdot 1.602 \times 10^{-19} \text{joules}}{\text{eV}}}$ $\lambda = 1.24 \times 10^{-5}$ cm	Slide 6.1.1.11.--Calculation of Minimum Ionization Wavelength

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
6. Therefore, all radiation with λ greater than 1.24×10^{-5} cm will be considered nonionizing, including a. ultraviolet b. visible c. infrared d. radio frequency e. microwave	Slide 6.1.1.12.--Electromagnetic Spectrum Ionizing vs. Nonionizing Radiation Review the areas of the spectrum that are categorized ionizing and nonionizing with the students. Inform students that each segment of ionizing and nonionizing radiation will be presented in detail.
III. Nonionizing Radiation--General	
A. Definition--Radiation with sufficient energy to cause excitation of electrons, atoms, or molecules but insufficient energy to cause ionization.	Slide 6.1.1.13.--Nonionizing Radiation--Definition
B. Characteristics 1. All electromagnetic radiation. a. caused by moving charges b. electrical field with accompanying magnetic field	Slide 6.1.1.14.--Nonionizing Radiation Characteristics This section is a review of characteristics presented for all radiation.
2. Waves vary. a. wavelength (λ) b. frequency (f) c. intensity-strength--varies inversely with distance (d) by a factor of $1/d^2$--(inverse square law)	
3. Radiation can be considered in some instances discrete particles. a. quantum of energy--discrete energy and momentum b. if λ increases, energy decreases	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
4. No sharp dividing lines between regions--arbitrarily established.	
C. Sources	Slide 6.1.1.15.--Nonionizing Radiation--Sources
1. Come from variety of sources. a. designed--microwave unit b. by-product--welders arc	
2. Examples.	
a. radio frequency--oscillating electrical current b. infrared--heated bodies--rotation of atoms c. visible--electron transition of energy levels	Ask students to give examples of each type of radiation listed.
3. Source of nonionizing radiation usually gives off more than one frequency. a. sun vs. welder's arc--broad band source b. radio antennae--must be filtered but essentially narrow band source	
D. Biological Effects	Slide 6.1.1.16.--Nonionizing Radiation--Biological Effects
1. Eye. a. very sensitive to radiation injury; e.g., (1) conjunctivitis (2) keratitis b. not equally sensitive to all wavelengths--e.g., visible vs. ultraviolet c. can be indicator of radiation exposure because of sensitivity	
2. Thermal effect--body's absorption of nonionizing radiation causes heating of tissue.	

Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
3. Photochemical--causes chemical changes in body; e.g., development of pigment in skin from exposure to sun. 4. Carcinogenic--may catalyze tumors or cancer.	
IV. Nonionizing Radiation--Specific Regions	
A. To Be Discussed	
1. Ultraviolet. 2. Visible. 3. Infrared. 4. Radio frequencies. 5. Microwaves. 6. Lasers.	Inform students that this section will deal with a. characteristics b. sources/application c. biological effects d. permissible exposure limit values for each region.
B. Ultraviolet Region	
1. Highest energy region of the nonionizing radiation.	
2. Normally divided into three regions.	Slide 6.1.1.17.--Ultraviolet Radiation Spectrum
a. vacuum (1) $< 1.6 \times 10^{-5}$ cm (160 nm) (2) radiation can exist only in a vacuum (3) radiation completely absorbed by air	
b. far (1) $1.6 - 3.2 \times 10^{-5}$ cm (160-320 nm) (2) for λ --160-200 nm poorly transmitted through air --200-320 nm absorbed by ozone layer	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
c. near (1) $3.2\text{-}4.0 \times 10^{-5}$ cm (320-400 nm) (2) transmits through air particularly through glass	
d. most critical range is between 240-320 nm; highest biological effect in this range.	
3. Sources of ultraviolet radiation.	Slide 6.1.1.18.--Sources of Ultraviolet Radiation
a. sun (1) primarily radiation from middle and near region (2) typical solar radiation on a midsummer day, temperate latitude --total ultraviolet-daily cumulative dose ($\lambda < 400$ nm) = 2×10^{-3} J/cm^2 --only 1×10^{-5} J/cm^2 is erythemally effective (explained later)	
b. incandescent, fluorescent light sources c. welding operations d. plasma torches e. lasers	Ask students to give examples of uses of ultraviolet radiation and related hazards.
4. Applications a. food sterilization--germicidal lamp	Have students explain setup for process they are discussing. If necessary, draw diagram on chalkboard.

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
b. "black light"--blue-printing, laundry mark identification, dial illumination. c. fluorescent light sources d. by-product (source, not application) (1) sun--outdoor work (2) electric arc welding	
5. Biological effects. a. skin reddening (erythemal effect) (1) absorption of ultra-violet radiation causes skin to redden (2) different λ has different effect	Slide 6.1.1.19.--Standard Erythemal Curve
-general erythemal range, λ = 240-320nm -maximum effect - 296.7 nm -minimal effect - 265-285 nm -secondary effect- 250 nm (3) signs/symptoms -dependent on dosage received -simple reddening, blisters -desquammation--peeling of skin (4) latent period--time required for onset of symptoms -dependent on dosage -may range from 2 to several hours -peak effect usually occurs 12-24 hrs after exposure	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
-symptoms will subside if UV source is removed	
(5) skin develops protective mechanism for subsequent exposures (suntan) increased pigmentation in upper layer of skin	
(6) dosage required to cause erythema	
-average Caucasian, 0.02-0.03 J/cm^2 -untanned skin requires less -Negroid skin--two to three times as much	
b. effect on the eye	Slide 6.1.1.20.--Biological Effects--Ultraviolet Radiation
(1) conjunctivitis and keratitis	
-exposure above threshold limit value (TLV) causes inflammation of conjunctiva and cornea -cornea most vulnerable	
--anascular--cannot dissipate heat --abundance of nerve endings increases intensity of pain	
-maximum damage when λ = 288 nm -signs/symptoms	
--conjunctivitis; inflammation of conjunctiva --photophobia; abnormal intolerance of light --pain	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
--blepharitis--inflammation of the eyelid --keratitis--inflammation of cornea --blepharospasms--tight closing of lids, reflex protective mechanism -latent period; time required for onset of symptoms --dependent on dosage --may take 30 min to 24 hrs to appear	
-e.g., welder's "flash burn" -symptoms regress after several days with no permanent damage -no tolerance is established because of repeated exposure	Explain term to students.
(2) fluorescence -if $\lambda \approx 360$ nm, excite the lens or vitreous humor of the eye -vitreous humor fluoresces causing diffuse hazziness and decreased visual acuity -condition is strictly temporary and has no detrimental effect -"internal haze" should disappear when exposure ceases	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
c. carcinogenic effect (1) ultraviolet radiation with λ < 320 nm related to cancer as catalyst (2) increased number of cases of skin cancer in outdoor workers who are simultaneously exposed to chemicals such as coal tar derivatives, benzopyrene, methyl cholanthrene and other anthracene compounds (3) however, no causes of industrially induced skin cancer reported to date; rationale--dosages required to cause cancer are in excess of dosage required to cause skin and eye burns; pain would be intolerable.	
d. bactericidal effect (1) nucleoproteins absorb peak at 160 nm; i.e., precipitation of proteins (2) causes irreparable damage to certain bacteria (3) low pressure mercury discharge lamps (254 nm) used as bactericides; can cause erythema and conjunctivitis	
e. summary--review curve	Slide 6.1.1.21.--Ultraviolet Action Spectrum

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
6. Other indirect effects. a. if $\lambda < 250$ nm; can cause dissociation of molecular oxygen to form ozone (O_3); ozone TLV = 0.1 ppm b. if $\lambda < 160$ nm (vacuum); can cause dissociation of molecular nitrogen which in turn reacts to form nitrogen oxides c. if $\lambda < 290$ nm; can cause the decomposition of chlorinated hydrocarbon (e.g., CCL_4, trichloro-ethylene) to form toxic gases; e.g., HCL, phosgene	Slide 6.1.1.22.--Indirect Effects of Ultraviolet Radiation
7. Exposure criteria. a. initial experimentation shows (1) threshold for injury to be 0.15×10^{-1} joules/cm^2 for $\lambda = 280$ nm (2) total ultraviolet radiation of 0.2 joules/cm^2 is necessary to produce damage b. according to ACGIH (1) for spectral region, 320-400 nm total irradiance (a) 1 mW/cm^2 for $>10^3$ second (16 min) (b) 1 joule/cm^2 for $< 10^3$ second	Slide 6.1.1.23.--Exposure Criteria Ultraviolet Radiation (λ = 320-400 nm)

TOPIC	REMARKS
(2) for spectral region; 200-315 nm over 8-hr period is present in table. See slide.	Slide 6.1.1.24.--Ultraviolet Radiation TLV Values

Relative Spectral Effectiveness by Wavelength

Wavelength (nm)	TLV (mJ/cm^2)	Relative Spectral Effectiveness--S_λ
200	100	0.03
210	40	0.075
220	25	0.12
230	16	0.19
240	10	0.30
250	7.0	0.43
254	6.0	0.5
260	4.6	0.65
270	3.0	1.0
280	3.4	0.88
290	4.7	0.64
300	10	0.30
305	50	0.06
310	200	0.015
315	1000	0.003

(3) if broad band, must calculate effective irradiance to compare to standard TLV.

Slide 6.1.1.25.--Effective Irradiance Calculation

$E_{eff} = \Sigma E_\lambda S_\lambda \Delta\lambda$, where

E_{eff} = effective irradiance (W/cm^2)

E_λ = spectral irradiance in $W/cm^2/nm$

S_λ = relative spectral effectiveness

$\Delta\lambda$ = band width in nanometers

Discuss briefly equation and tables, but it will be repeated later.

Inform students more time will be spent on TLV for all radiation during the discussion of recognition and control of nonionizing radiation.

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
	Slide 6.1.1.26.--Effective Irradiance--TLV

Permissible Ultraviolet Exposures

Duration of Exposure Per Day	Effective Irradiance E_{eff} ($\mu W/cm^2$)
8 hrs	0.1
4 hrs	0.2
2 hrs	0.4
1 hr	0.8
30 min	1.7
15 min	3.3
10 min	5
5 min	10
1 min	50
30 sec	100
10 sec	300
1 sec	3,000
0.5 sec	6,000
0.1 sec	30,000

B. Visible Light--Discussed previously in module on Illumination.

C. Infrared Radiation (IR Radiation)

Slide 6.1.1.27.--Infrared Radiation--Location

1. Found at lower end of visible spectrum.
2. Range--750 nm - 10^{-1} cm.
3. Divided into two regions.
   a. near region < λ 750 nm, 5.0 μm
   b. far region λ - 5.0-3000 μm
4. Sources of radiation.

Slide 6.1.1.28.--Infrared Radiation--Sources

   a. hot furnaces
   b. molten metals or glass
   c. arc processes

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1
TOPIC	**REMARKS**
5. Applications--generally heating a. drying and baking of paints, varnishes, enamels b. heating of metal parts for forming, thermal aging, brazing c. dehydrating textiles, paper, leather, food-stuffs, sand molds d. spot and localized heating of desired object e. by-product (source, not application) (1) molten metal or glass (2) most arcing processes	Slide 6.1.1.29.--Infrared Radiation--Applications
6. Biological effect. a. IR radiation perceptible as warmth to the skin b. for λ >1.5 μm, energy absorbed by the skin because water content--absorption of energy causes an increase in temperature c. signs/symptoms (1) skin burn (2) vasodilation of capillary beds (3) erythema (4) blistering (5) pain (6) increased pigmentation d. no latent period e. extended exposure to intense IR radiation minimized because of pain provoked by exposure	Slide 6.1.1.30.--Infrared Radiation--Biological Effect

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
f. effect on the eye (1) IR radiation (near region) can cause damage to cornea, iris, lens, and retina (2) e.g., --retinal burns --formation of cataracts (opacity of the lens); requires many years of daily exposure	
7. Threshold limit values.	Slide 6.1.1.31.--Infrared Radiation--TLV
a. concerned most exposure to eye b. damage dependent upon wavelength absorbed	
c. damage caused at levels of 4-8 J/cm^2 d. acceptable TLV: 0.4-0.8 J/cm^2 e. may be reduced by a second factor of ten (10) to reduce chronic effects	Write on chalkboard.
D. Radio Frequencies	Slide 6.1.1.32.--Radio Frequencies
1. Obey general laws of electromagnetic radiation. 2. Range a. frequency: 1×10^{11} to 1×10^{12} Hz b. λ: 3×10^{-3} to 1×10^{8} M 3. Radio frequency induces a. electrical current in conductors b. displacement current in semi-conductors (transforms radiation energy to heat)	Inform students that this discussion is radio frequencies in general and that microwaves, a subset of radio frequencies, will be discussed separately.

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
4. Radio frequencies can be divided into two zones.	
a. caused because of wave interaction with source (antennae)	
b. near field (Fresnel zone)	Slide 6.1.1.33.--Fresnel Zone
(1) field where interaction occurs	
(2) radius of field calculated by $R = \frac{A}{2\lambda}$ where R = radius of Fresnel zone (M); A = area of antennae (M^2); λ = wavelength (M)	
(3) energy transmitted by both electric and magnetic vector in near field	Moving electrical charges and magnetic fields generated were previously discussed in Module 4.
(4) energy difficult to measure in near field because of interaction--very complex process	
(5) if measured (a) volts/m for electric field (b) amps/m for magnetic field	
c. far field (Fraunhofer zone)	
(1) energy transmitted by electric vector only	
(2) field strength measured in volts/meter	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(3) possible to relate power density and energy density by $$P = \frac{E^2}{120\pi}$$ where P = power density (W/m^2) E = field strength (V/m)	
5. Sources a. telecommunications b. high frequency heating c. scientific instruments--instrumentation chemistry	Slide 6.1.1.34.--Radio Frequencies Sources/ Application Ask students to name sources of radio frequency and prepare list on chalkboard.
6. Application a. heating (1) metal--hardening metal surfaces, annealing (2) wood working--bonding plywood, laminating (3) food industry--sterilizing containers and killing bacteria (4) molding plastics; curing and vulcanizing rubber b. radio communications (1) broadcasting (2) radar	Ask students to give practical examples of uses/sources of radio frequency radiation. Have students explain procedure for application and working environment. If necessary, draw a diagram on the chalkboard.
7. Biological effects. a. effect of radio frequency varies greatly in individuals; factor may be 100:1	Slide 6.1.1.35.--Radio Frequencies Biological Effects

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
b. generally affects the autonomic nervous system c. thermal effect (1) for an increase in body temperature, the body must have a diameter at least 1/10 of the wavelength--$\lambda > 20$ m to have no thermal effect on the body (2) body acts as semiconductor -electromagnetic radiation transformed to heat -absorption and transformation dependent upon water content -depth of penetration dependent upon fatty tissue (3) radio frequency may be reflected at interfaces of dielectrically nonhomogenous layer, giving rise to "standing wave"--causes concentration of energy.	
(4) rate of energy absorption and heat accumulation dependent upon -field strength and power density -length of exposure; intermittent vs. continued -environmental temperature and humidity	Explain to students how each factor is important.

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
-type of clothing -type of body layers -reflection of waves (5) effect on specific organs; e.g., (a) eye --lens can be affected because of difficulty in heat dissipation --cell mitosis disrupted --cataracts may form (b) testes--if temperature raised --germ cells easily damaged --less androgen produced; decrease in sex hormone --pituitary hypofunction (c) central nervous system --thick bone, fatty content facilitate penetration and hinder heat dissipation --spherical shape may cause reflection and concentration of energy --brainstem and hypothalamus sensitive to radiation	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
d. nonthermal effects (1) effect of electric/ magnetic field -particles greater than 15 μm in diameter tend to polarize -no free histological structures > 15 μm exist in body; therefore; polarization does not occur but potential for polarization exists (2) demodulating effect -affect organs displaying modulating electrical activity; e.g., heart, central nervous system -change in amplitude and peak frequencies in EEG and EKG (3) molecular effect -causes excitation of molecules -potential for molecular polarization -can exert catalytic action upon some chemical and enzymatic reactions	
8. Hazards. a. thermal effect of electromagnetic radiation b. electrical hazards and potential X-radiation of high voltage equipment	
9. Safety limit standards.	Slide 6.1.1.36.--Radio Frequency TLV Levels
(a) limits based upon (1) thermal effects	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(2) nonthermal effects (3) individual sensitivity	
b. USSR health standards	
(1) 3-30 MHz	
(a) inductance heating --20 V/m (electrical field) --5 A/m (magnetic field)	
(b) dielectric heating, broadcasting --20 V/m	
(2) 30-300 MHz (a) 5 V/m	
(3) 300-300,000 MHz	
(a) 10 μW/cm^2--continuous exposure, average working day (b) 100 μW/cm^2--2 hrs per 24/hr period (c) 1 mW/cm^2--15 to 20 min per 24-hr period	
c. USA standard	Slide 6.1.1.37.--Radio Frequency Exposure Criteria
(1) continuous action across all frequencies (2) power density of 10 mW/cm^2 for 0.1 hr or longer (3) energy density of 1 mW/cm^2 for any 0.1 hour period	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
E. Microwaves	
1. Radio frequencies above 1000 MHz are classified as microwaves.	Slide 6.1.1.38.--Microwaves--Region/Basic Properties
2. Basic properties. a. acts as any electromagnetic radiation b. long-range transmission properties in air, including through rain and darkness c. follow a quasi-line-of-sight path with diffraction spreading d. may be readily generated with high power densities e. unique absorption properties in dielectric insulators leading to uniform heat disposition in many materials f. strongly reflected and contained by metallic surfaces	
3. Types of microwaves. a. continuous wave (CW)--microwaves always being generated b. pulsed wave (1) on for a short period (one microsecond) then off for a long period (10^3 microseconds) (2) advantages--power obtained for short period greater than CW mode	Slide 6.1.1.39.--Types of Microwaves

TOPIC	REMARKS
4. Microwave frequencies used.	
a. established by FCC	
b. four frequencies selected for industrial, scientific and medical use (ISM)	Slide 6.1.1.40.--Sample Microwave Frequency Assignments
(1) 2450 ± 50 MHz is most commonly used in industry--microwave heating	Frequency / Wavelength 915 ± 25 MHz — 32.8 cm 2450 ± 50 MHz — 12.25 cm 5800 ± 75 MHz — 5.17 cm 22125 ± 125 MHz — 1.36 cm Give the students an example use of each specific frequency of microwave.
c. frequencies selected for communications	Slide 6.1.1.41.--Sample Frequency Assignments Designation / Wavelength S band — 10 cm X band — 3 cm K band — 1.2 cm
5. Sources of microwaves.	
a. practical sources; e.g.,	
(1) klystron--generates low power levels (1 watt)	
(2) magnetron--generates high power levels (1 Kwatt--on a CW basis)	
b. produced by deceleration of electrons in an electric field; as electrons slow down, energy released in the form of microwaves	
c. e.g., klystron	Slide 6.1.1.42.--Klystron--Schematic
(1) components	Briefly explain components of klystron and its operation.
(a) evacuated glass tube	
(b) electron emitting cathode	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(c) accelerating (positive) grid (d) two metal ring-like microwave cavities --buncher (cavity and grids) --catcher (cavity and grids) (e) anode--catches (f) coaxial feed line (2) operation (a) high speed stream of electrons produced by cathode (b) electrons accelerated by accelerating grid (c) in buncher cavity, electrons modulated by microwave field into bunches (d) when bunched electrons pass catcher grid, electrons slow down and microwave radiation is produced (e) microwaves removed by coaxial cable (f) electrons captured at anode (3) specific radiation released dependent on (a) dimension of tube (b) dimension of cavity (c) velocity of electron	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(4) reflex klystron most prominent; single cavity operation; principle the same	
d. e.g., magnetron	Slide 6.1.1.43.--Magnetron Schematic
(1) high power source (2) operates on same principle (3) variation vs. klystron	
(a) electric beam more intense because of circular orbit (b) multiple number of cavities; six or more (c) same cavities bunch electrons and slow down electrons (d) allows for more efficient cooling	
6. Biological effects.	Slide 6.1.1.44.--Microwaves--Biological Effects
a. similar to biological effects caused by radio frequencies only more so b. thermal effect	
(1) more important vs. nonthermal (2) takes place throughout volume and does not originate from the surface (excessive penetration) (3) depth of penetration dependent on	
(a) frequency (b) type of tissue relative to water content	

Lesson Outline

Principles of Nonionizing Radiation

Module 6
Unit 1
Lesson 1

TOPIC	REMARKS
--fat and bone have low water content and absorption characteristics --skin and muscle have high water content and absorption characteristics	
(4) generally affects body as described in section on radio frequency radiation	Review effects for students, including: a. general heating b. factors influencing rate of absorption of heat accumulation c. effect on specific oxygen
7. Nonthermal effects--same as for radio frequency; review for students.	
8. Exposure criteria	Slide 6.1.1.45.--Microwaves--Exposure Criteria

Power Density	Exposure Time Allowed
a. < 10 mW/cm^2	8 hr (continuous exposure)
b. >10 mW/cm^2 < 25 mW/cm^2	10 min/60 min period during the day
c. >25 mW/cm^2	No exposure

TOPIC	REMARKS
F. Lasers	
1. Acronym--Light Amplification by Stimulated Emission of Radiation.	Slide 6.1.1.46.--Laser
2. Can involve ultraviolet, infrared, visible, or microwave (maser) radiation.	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
3. Laser is device that produces a concentrated light beam with the following properties: a. coherent--highly uniform in phase over an extended area; allows for a narrow directional beam over long distance b. monochromatic--emitted radiation has a very narrow wavelength band c. brightness--highly uniform in direction d. total power density can be very high	Inform students that principles of operation and specific instruments will be discussed later, along with a more detailed discussion of the basic properties.
4. Laser sources. a. variety of sources (1) dependent on power and wavelength of interval (2) categories	
(a) ruby crystal (b) gaseous (c) injection type	This is discussed in more detail later in the lesson.
b. basic elements--three	Slide 6.1.1.47.--Laser Schematic
(1) optical cavity--consisting of at least two mirrors; one mirror must be partially transmissive (2) active laser medium--material that can be excited from unenergized ground state to a relatively long-lived excited state (3) means of "pumping"--procedure for supplying excitation of energy	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
c. basic principle of operation; e.g., ruby crystal--steps involved	Slide 6.1.1.48.--Multi-Level Atomic Emitting System
(1) flashtube flashes--optical pumping to excited level (2) chromium ions excited to metastable state (3) metastable state long lived but triggered when critical level of photons present (4) once critical level reached, presence of photons stimulates emission of other photons and chromium ions return to ground state again (5) simultaneous emission of photons forms coherent light (6) sequence requires approximately 10^{-3} seconds	Explain to students the intermediate nonemitting energy levels involved in process. Draw examples of other multi-level excitation/de-excitation processes; e.g., four-level process.
(7) coherent wave produced because of the critical level of photons required for stimulated emission	Ask students if they understand the concept of stimulated emission. If necessary, redefine the procedure.
d. specific categories of lasers	Slide 6.1.1.49.--Types of Lasers Have students refer to text.
(1) solid crystal with impurities. (a) e.g., ruby, neodymium doped glass (b) wavelength produced -ruby: 0.6943 micron wavelength -other: 1.06 micron wavelength	Inform students that specific type of laser is important only because of wavelength produced and potential power.

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(c) power obtainable to 100 watts	
(2) gaseous	It is not necessary for the student to learn each category but only to be aware that different types exist.
(a) e.g., molecular nitrogen (b) wavelength produced dependent upon optical cavity production	
(3) continuous gas laser	
(a) e.g., helium-neon laser (b) wavelength produced; e.g., 0.6238 microns (c) power range; 1 to 100 mwatts	
(4) semi-conductor diode laser	
(a) e.g., gallium arsenide (b) wavelength produced; e.g., 0.91 microns (c) power range; 20 watts	
e. types of operation	
(1) laser may be pulsed or continuous (2) continuous--laser continuously operating (3) pulsed--de-excitation of lasing materials over very short period of time (e.g., 10^{-6} seconds) causes tremendous increase in power density.	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
f. specific principles	
(1) coherence--all waves in phase	Slide 6.1.1.50.--Wave Properties
(a) time coherence--in phase in a number of planes (b) space coherence--in phase across a given phase	
(2) beam divergence--very little variance in beam spread with distance from laser	Slide 6.1.1.51.--Beam Divergence
(a) two regions of beam spread	
-parallel region given by $L = \frac{D^2}{2.44\lambda}$ where L = parallel region, D = beam diameter, λ = wavelength	It is not necessary for the students to learn formulas. Information provided to clarify concept of beam divergence.
-divergent region: beam diverges and intensity decreases such that $\phi = \frac{1.22\lambda}{D}$ where ϕ = beam divergence angle	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(3) power density (a) can produce high power densities because -pulsed system: energy emitted over short period of time -beam divergence minimized -coherent light can be focused on small image size (b) power measured in terms of joules/sec or watts; if time of pulse decreased, watts increased (c) power density is defined as power per unit area; if area reduced; power density increases (d) laser produces peak power of 1 joule, but -pulse is 10^{-6} seconds -focused on 1 mm^2 area then becomes a power density of $\frac{1 \text{ joule} \times \frac{1}{10^{-6} \text{ sec}}}{0.01 \text{ cm}^2} = 10^8 \text{ W/cm}^2$	An example can be used that illustrates the importance of pulse width and focal size. Put example on chalkboard.

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(e) random reflecting surfaces -beam or section thereof may be reflected with little loss of intensity -important factor to consider during safety analysis	
5. Applications a. project reference lines for construction; e.g., laying pipelines, tunnels b. welding and micro-machining fine parts c. laser surgery (1) kill malignant tissue (2) remove warts and birthmarks d. transmit communication signals e. drilling through rock (tunnels)	Slide 6.1.1.52.--Laser Applications Ask students to give practical examples of use/source of laser operation. Have students explain procedure for application and working environment. If necessary, draw a diagram on the chalkboard.
6. Biological effects. a. the eye and skin seem most vulnerable b. eye (1) dependent upon type of laser beam, namely -wavelength -output power -beam divergence -pulse repetition frequency (2) critical because of lens focusing beam on fovea--several magnitudes greater	Slide 6.1.1.53.--Laser--Biological Effect

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(3) general thermal -heating of retina or cornea depending upon wavelength --visible light affects retina and retinal pigment; because of high intensity, protective reflex will prevent long duration of exposure; e.g., 10^{-6} W/cm^2 --cornea and skin affected with infrared and ultraviolet radiation; eye not sensitive to these λ; therefore, no protective reflex will be stimulated -retinal burns may occur if beam power is greater than 1 mW/cm^2 c. general body (1) severe damage to skin and underlying organs can be caused by high intensity beam (2) occasional exposure < 1mW/cm^2 is not expected to cause damage (3) repeated exposures between 10^{-3} and 10^{-6} W/cm^2 are undesirable 7. Hazards a. laser (1) high energy beam--direct and reflected (2) high voltage equipment (X-radiation)	

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
(3) ionization of air around beam may produce ozone (4) pressure in flash lamp may cause explosion	
b. associated equipment	
(1) cryogenic gases used as coolants (2) flammable solvents and materials associated with operation	
8. Exposure criteria.	Slide 6.1.1.54.--Laser--Exposure Criteria
a. exposure criteria dependent upon	
(1) continuous vs. pulsed, multiple pulsed (2) duration of exposure (3) direct or reflected beam (4) wavelength (5) skin vs. eye exposure	
b. because of the many factors, specific TLV values are available for various combinations	
	Review generally the tables provided in the Instructor's Lesson Plans and textbook. Generally discuss trends apparent in TLV levels. Be sure to discuss exposure as it relates to: a. continuous wave b. pulsed wave c. multiple pulsed train wave

Lesson Outline	
Principles of Nonionizing Radiation	Module 6 Unit 1 Lesson 1

TOPIC	REMARKS
V. Summary A. Discussed 1. Characteristics. 2. Sources/application. 3. Biological effects. 4. TLV For 1. Ultraviolet 2. Visible 3. Infrared 4. Radio frequencies 5. Microwave 6. Lasers	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
	Inform students that the discussion of control of nonionizing radiation will be limited to a. ultraviolet radiation b. lasers c. microwaves
I. Ultraviolet Radiation	Sections A, B, and C are a review from the first lesson. Delete if appropriate.
A. Range--Roughly 100-400 nm	Slide 6.1.2.1.--Ultraviolet Radiation Spectrum This slide is in the first lesson.
B. Specific Regions--Based Upon Effect on Man 1. Keratitic a. inflammation of the cornea greatest b. 200-320 nm 2. Erythemal--causing skin reddening. a. causing pronounced skin reddening and blistering b. 250-320 nm 3. Actinic--having a general adverse effect a. having general adverse effect on man b. 200-315 nm	
C. Sources 1. Sun--most UV below 300 nm; filtered by atmosphere. 2. Low intensity. a. low pressure mercury vapor b. sunlamps c. black-light lamp 3. High intensity. a. high pressure mercury vapor b. high pressure xenon arcs	Slide 6.1.2.2.--Sources of Ultraviolet Radiation Review from Lesson 1.

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
c. xenon-mercury arcs d. carbon arcs e. plasma torches f. welding arcs	
D. Taking Measurements	
1. When measuring UV, measurement must reflect UV relative to effectiveness by wavelength; can be accomplished two ways:	
a. filtering system which mimics actinic curve; measures UV which has greatest effect on man	Slide 6.1.2.3.--Actinic Curve and Comparable Filtering
b. if UV broad band source, must measure at specific wavelength and calculate effective irradiance (E_{eff})	Slide 6.1.2.4.--Effective Irradiance Formula Formula $E_{eff} = \Sigma E_\lambda S_\lambda \Delta\lambda$ where E_{eff} = effective irradiance E_λ = spectral irradiance ($W/cm^2/nm$) S_λ = relative actinic spectral effectiveness (from table) $\Delta\lambda$ = band width (nm)
(1) measure specific band widths (2) calculate exposure for each (3) adjust according to relative actinic spectral effectiveness (S_λ) (4) sum of all widths	
2. Sample measurement.	
a. measurement instrument may (1) read power density directly (2) read amps and require conversion using calibration factor (calibration factor provided by manufacturer)	

Lesson Outline

Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
b. given (1) distance from source (2) time of exposure exposure can be calculated and compared to TLV	
Example Using a photometer, a reading of 0.5 μA is taken at 90 cm (the mean body/eye distance of the worker). If the worker is exposed to this radiation for approximately 15 minutes per 8-hour shift, is the TLV exceeded? What is the maximum exposure time per 8 hours? (Assume calibration factor = 90.6 $\mu A/cm^2/\mu A$ and filters corrected to 270 nm).	Slide 6.1.2.5.--Example--Ultraviolet Exposure
Solution $0.5\ \mu A \times \frac{90.6\ \mu W}{cm^2\ \mu A} = \frac{45.3\ \mu W}{cm^2}$ $\frac{45.3\ \mu J}{sec\text{-}cm^2} \times \frac{900\ sec}{8\ hr} = \frac{40.77\ mJ/cm^2}{8\ hr}$ $TLV = \frac{3.0\ mJ}{cm^2}$ for 8-hour period Therefore: TLV exceeded Permissible exposure time in seconds for exposure to actinic ultraviolet radiation incident upon the unprotected skin or eye may be computed by dividing 0.003 J/cm^2 by E_{eff} in W/cm^2. The exposure time may also be determined using the table which provides exposure times corresponding to effective irradiances in $\mu W/cm^2$. What is maximum exposure time per 8-hrs? $\frac{3.0\ mJ}{cm^2} \times \frac{cm^2 sec}{45.3 \mu J} = 66$ seconds	Slide 6.1.2.6.--Solution--Ultraviolet Exposure

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
E. Detection of Ultraviolet Radiation--Instruments	Slide 6.1.2.7.--Instrumentation
1. Two major classes of detectors--based upon ultraviolet interaction. a. photometer b. thermal	Review basic principles of each type of monitoring instrument. Briefly describe the advantages and disadvantages of each. It is appropriate to have sample monitoring equipment including probes and filters. Describe the typical use of monitoring equipment.
2. Photoelectric devices. a. use phototube and photomultiplier. b. depend upon the ejection of an electron when UV interacts with metal c. photomultiplier used with low UV levels	
3. Photovoltaic devices a. production of voltage difference in device caused by UV absorption b. e.g., (1) selenium photocells (2) silicon solar cells	
4. Thermal devices a. production of voltage by increased temperature caused by UV absorption b. change in voltage proportional to UV radiation c. e.g., thermopile	
5. Filters	
a. allow for discrimination of wavelengths b. discrimination necessary because of variation in effect of UV radiation wavelengths	Remind students of erythemal curves versus wavelengths.

TOPIC	REMARKS

c. effective irradiance can then be calculated.

6. Monochrometer

a. serves purpose of filter
b. separates UV radiation into single wavelength
c. allows analysis by wavelength

F. Assume a monochrometer is used and the following readings obtained. Is the TLV exceeded if the average exposure is 30 minutes per 8-hour day?

λ (nm)	Reading ($\mu W/cm^2$)
200	0.08
220	0.09
240	0.18
260	0.18
280	0.27
300	0.36

$\Delta\lambda = 20nm$

Slide 6.1.2.8.--Example--Effective Irradiance Calculation

Refer to TLV tables, Module 6, Lesson 1, pages 6.25 and 6.26.

Solution

$$E_{(200)} = \frac{0.08\mu W}{cm^2} \cdot \frac{0.03}{nm} \cdot 20nm = 0.048\mu W/cm^2$$

$$E_{(220)} = \frac{0.09\mu W}{cm^2} \cdot \frac{0.12}{nm} \cdot 20nm = 0.216$$

$$E_{(240)} = \frac{0.18\mu W}{cm^2} \cdot \frac{0.30}{nm} \cdot 20nm = 1.08$$

$$E_{(260)} = \frac{0.18\mu W}{cm^2} \cdot \frac{0.65}{nm} \cdot 20nm = 2.34$$

$$E_{(280)} = \frac{0.27\mu W}{cm^2} \cdot \frac{0.88}{nm} \cdot 20nm = 4.752$$

$$E_{(300)} = \frac{0.36\mu W}{cm^2} \cdot \frac{0.30}{nm} \cdot 20nm = 2.16$$

$10.596\ \mu W/cm^2$

Using table,

$TLV = 1.7\ \mu W/cm^2$

Therefore, value is 6.2 times permissible value.

Slide 6.1.2.9.--Solution--Effective Irradiance Calculation

Relative Spectral Effectiveness by Wavelength

Wavelength (nm)	TLV (mJ/cm^2)*	Relative Spectral Effectiveness--Sλ
200	100	0.03
220	25	0.12
240	10	0.30
260	4.6	0.65
280	3.4	0.88
300	10	0.30

* 1 (mJ/cm^2) = 10^{-3} J/cm^2

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
G. Factors Influencing Measurements- To avoid errors of major magnitude, the following must be considered:	Slide 6.1.2.10.--Factors Influencing Measurements
1. Monitoring instrument must match spectral output of UV source.	
2. Solarization or aging of lenses may require periodic calibration.	
3. Water vapor in atmosphere.	
a. reduces readings by absorbing UV	
b. affects electronic circuitry	
4. Meters directional.	
5. Reflection of UV from nearby source or high intensity visible light can affect reading.	
6. Inverse square law must be considered--distance critical to measurement.	Inverse square law should be briefly described to the students.
H. Personnel Protection	
1. Primary concern is exposure to skin and eyes.	Slide 6.1.2.11.--Protective Tools
2. Three protective tools which can be used:	
a. time	
b. distance	
c. shielding	
3. Time.	
a. by decreasing time of exposure, total exposure decreased.	Point out that first example illustrated that TLV would not be exceeded for 8-hour period of personnel exposed for only 66 seconds rather than 15 minutes per 8-hour segment.

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
b. when analyzing potential hazard, important to know time of exposure to calculate potential exposure c. analysis of job may indicate procedure changes that may reduce exposure time	
4. Distance.	
a. intensity is decreased by the square of the change in distance (inverse square law)	Inform the students that the "inverse square law" does not apply to lasers.
b. e.g., if reading is $\frac{15\mu W}{cm^2}$ at 1 ft, it will be $\frac{15}{(2)^2} = \frac{3.75\mu W}{cm^2}$ at 2 feet	Put example on chalkboard.
c. distance may not be a useful tool because of type of work involved; e.g., welding d. two important points (1) all measurements should be taken at distance that approximates worker distance; if hands are normally closer, measurements should be taken at those distances (2) effort should be made to maximize distance to minimize exposure; e.g., use of tongs to handle materials; automation	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
5. Shielding. a. necessary to shield the skin and eyes specifically b. can be done using three types of shielding (1) enclosures (2) protective clothing (3) eye protection c. enclosures (1) minimize exposure to -person working directly with UV source -personnel in vicinity (2) selection of enclosure material dependent upon -wavelength -properties of wavelength involved --reflectance --absorption characteristics -e.g., clear glass opaque to UV and transparent to visible light -e.g., red opaque filter--opaque to visible light; transparent to UV source (3) any enclosure area should be adequately marked and labeled as a radiation area	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
d. protective clothing	
(1) can be worn to minimize UV exposure	
(2) heavy clothing will absorb most UV	
(3) dark clothing should be worn to avoid reflectance	
(4) e.g., gloves, overalls, face shield	Slide 6.1.2.12.--Protective Clothing Point out flash goggles worn by operator.
(5) type of clothing dependent upon radiation source and type	
e. protective eye shields	
(1) can shield eyes against radiant energy	
(2) selection of filters based upon type (wavelength) and intensity of radiation	
(3) various filters transmit differently for different wavelengths	Slide 6.1.2.13.--Ultraviolet Filters Have students refer to textbook rather than looking at slide. Point out different transmissions for various wavelengths.
(4) e.g., typical filter lens requirements for welders	Slide 6.1.2.14.--Eye Protection for Welders
(5) therefore, given the type of operation, wavelength transmitted, and measured exposure, proper eye protection may be determined.	Emphasize that broad band souces must be analyzed as such. Proper filtering for a given λ may be inadequate for other wavelengths present.

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
	Inform students that control of IR radiation is similar to UV radiation.
6. Miscellaneous hazard control.	Slide 6.1.2.15.--Nonradiation Hazards
a. associated nonradiation hazards must also be considered (1) high voltage (2) ozone production (3) chemical reactions	
b. high voltage (1) instrument producing UV may require high voltages for operation; possible electrocution (2) high voltage may precipitate the extraneous production of X-radiation.	X-radiation discussed in Unit 2.
c. ozone production (1) UV reacts with oxygen (O_2) in atmosphere to produce ozone (O_3); may be several feet away	Briefly describe toxic properties of O_3. TLV = 0.1 ppm:O_3.
(2) adequate ventilation necessary.	Slide 6.1.2.16.--Ventilation System/Welders
d. chemical reactions (1) UV reduces chlorinated hydrocarbons (trichloroethylene) to toxic substance (2) UV causes formation of nitrogen oxides (3) forms toxic fumes if procedure involves base metals including elements such as zinc, beryllium, lead, cadmium	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
(4) because of potential chemical reactions -location of UV source must be evaluated; e.g, near degreasing operation using chlorinated solvents -adequate ventilation must be provided	
I. General Survey Techniques	
1. When surveying area, a diagram of area should be prepared indicating a. UV source b. personnel location c. protective devices in use; e.g., (1) signs (2) screens d. potential hazards; e.g., lack of ventilation	
2. Sample form can be used as a basis for the survey.	Slide 6.1.2.17.--Sample Survey Form Have students examine sample form in textbook.
3. Form review. a. USING ORGANIZATION--company or division b. ADDRESS-- c. TYPE OF EQUIPMENT--UV source, e.g., welder, germicidal lamp, xenon lamp d. INTENDED USE--purpose of source; e.g., research construction material testing e. MANUFACTURER--model, serial number; identifies special source	Briefly review key information on form. It is not necessary to cover each component in great detail.

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
f. OTHER--general information g. WELDER ONLY--refers to operating parameter of welder (1) GAS-- (2) VOLTAGE/CURRENT--if electric welder is used (3) FILLER--welding rod (4) MATERIAL--material being welded; including coatings (5) DUTY CYCLE--operation time in 8-hour shift of any UV source h. MONITORING INSTRUMENT--device used to monitor UV i. PROBE--detector used j. FILTER--type of filter k. ATTACHMENTS--attenuators, screen, beam splitter used l. WAVELENGTH RANGE--sensitivity range of monitoring system m. DISTANCE TO SOURCE--distance from measure point to source n. D/R (1) D--direct reading (2) R-reflected reading o. KEY--keyed location on diagram p. INSTRUMENT READING--$\mu W/cm^2$ q. EXPOSURE TIME--average exposure per 8-hour day to level of exposure measured r. EXPOSURE/DAY-- s. ENVIRONMENT--drawing of area, including (1) UV source (2) point of measurement (3) personnel location (time of exposure/day) (4) non-UV hazards (5) protection devices	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
t. PERSONNEL--the type of personnel (e.g., student, machinist, etc.), location, and exposure time/day should be recorded. u. PERSONNEL PROTECTION-- (1) existing protection devices (2) recommended protection devices added; e.g., paint walls to reduce reflection v. SURVEY BY/DATE--signature of surveyor.	NOTE: The form is not intended to be standard but a guide to needed information. Give examples of UV hazard and procedures for control. Review and assign Practice Exercise pertaining to UV radiation.

ULTRAVIOLET RADIATION SURVEY

GENERAL INFORMATION

USING ORGANIZATION		ADDRESS	
TYPE OF EQUIPMENT		INTENDED USAGE	
MANUFACTURE	MODEL	SERIAL NUMBER	OTHER

HAZARD DETERMINATION

WELDER ONLY	GAS	CURRENT	VOLTAGE	FILLER	MATERIAL	DUTY CYCLE

MONITORING INSTRUMENT	PROBE	FILTER
ATTACHMENT	WAVELENGTH OR WAVELENGTH RANGE	

DISTANCE TO SOURCE (METERS)	D/R	KEY	INSTRUMENT READING ($\mu W/cm^2$)	EXPOSURE TIME 8/HR	EXPOSURE/DAY (3×10^{-3} J/cm^2) IRRADIANCE

ENVIRONMENT

PERSONNEL

BACKGROUND
SAFETY TRAINING
UNAWARE ONLOOKER
OTHER

PERSONAL PROTECTION

IN USE

SIGNS	SKIN CREAM	PARTITIONS
EYE PROTECTION	CLOTHING	OTHER
RESTRICTED AREA	CURTAINS	
GLOVES	ENCLOSURES	

RECOM-MENDED

SURVEYED BY　　　　DATE

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
II. Lasers	Slide 6.1.2.18.--Lasers
A. Hazard	
1. Reason for hazard--concentration of energy on a point target.	
2. Predominately affects	Slide 6.1.2.19.--Observing Laser Light
a. eye--parallel rays may be focused to a point image	
b. skin	
3. TLV established for eye and skin.	
B. Measurement of Laser Beam	
1. Number of periodic measurements not necessary for protection program because	
a. accuracy of manufacturers' specifications	
b. high cost of detectors	
c. complexity of radiometric measurement techniques	
2. Possible to beam intensity (I) at a selected range.	Slide 6.1.2.20.--Beam Intensity
a. must know	
(1) power output (E) in watts	
(2) range of interest (r) in centimeters	
(3) beam divergency (ϕ) in radians	
(4) beam diameter (a) in mm	
b. formula $I = \dfrac{Ee^{-ur}}{[(\pi/4)(a + r\phi)]^2}$	Note: (e^{-ur}) is atmospheric attenuation and can be ignored if range less than 10 kilometers. r = range in cm u = attenuation/cm

TOPIC	REMARKS
Example	Put example on chalkboard.
A typical laser has an initial beam diameter of one inch (2.54 cm), power output of 5 mW, and a beam divergence of 0.1 milliradians (10^{-4} radians). What is the beam intensity at 60 cm?	
Solution	
$I = \frac{E}{\left[(\pi/4)(a + r\phi)\right]^2}$	
$I = \frac{5mW}{\left[(\pi/4)(2.54 + 60cm(10^{-4}\ radians))\right]^2}$	
I = 1.25 mW at 60 cm	
	Ask the students if this exceeds the TLV for direct eye exposure (ocular viewing).
	Assume the laser beam is
	1. 312 nm - TLV = 250 mJ/cm^2
	2. Exposure is 1 minute (60 sec)
	Response:
	$\frac{2.33mJ}{sec\text{-}cm^2} \times 60 = \frac{139.8mJ}{cm^2}$
	$\frac{139.8mJ}{cm^2} < \frac{250\ mJ}{cm^2}$ (↑ TLV)
	Therefore, does not exceed TLV.

TOPIC	REMARKS
c. using same equation, can calculate	
(1) maximum viewing time at given distance	
$t = (I_t E)\left[(0.7854(a + r\phi))\right]^2$	Slide 6.1.2.21.--Calculation of Maximum Viewing Time Given Distance
where t = time (sec) I_t = TLV (Joule/cm^2) - wavelength specific E = power output (Joule/sec - W) a = beam diameter (cm) r = specified distance (cm) ϕ = beam divergence (radians)	If necessary, derive formula for students.
(2) minimum viewing distance given a specified viewing time $r = \dfrac{\left[\dfrac{\left(\dfrac{E \cdot t}{I_t}\right)^{\frac{1}{2}}}{0.7854}\right] - a}{\phi}$	Slide 6.1.2.22.--Calculation of Minimum Viewing Distance Given a Specified Viewing Time
3. Must know a. wavelength and TLV b. approximate direct viewing time for 8-hour period c. minimum (average) viewing distance during direct viewing	

TOPIC	REMARKS
Example A typical laser operating at 312 nm has an initial beam diameter of 1.5 cm, a power output of 2.25 mW, and a beam divergence of 0.1 milliradians. Calculate: A. Maximum direct viewing time for 8-h period if the average viewing distance is 50 cm. B. Minimum viewing distance if the average viewing time is 3 minutes per 8-hour period. Assume TLV = 250 mJ/cm^2.	Slide 6.1.2.23.--Sample Calculations
Solution A. $t = (I_t E)\left[(0.7854(a + r\phi))\right]^2$ $I_t = 250\ mJ/cm^2$ $E = 2.25\ Mw$ $a = 1.5\ cm$ $r = 50\ cm$ $\phi = 10^{-4}$ radians $t = \left(\frac{250\ mJ}{cm^2} \cdot \frac{sec}{2.25\ mJ}\right)\left[(0.7854\ (1.5\ cm + (10^{-4}))\right]^2$ t = 155.2 seconds t = 2.59 minutes	Slide 6.1.2.24.--Solution--Part A

TOPIC	REMARKS
B. $$r = \frac{\left[\frac{\left(\frac{E \cdot t}{I_t}\right)^{\frac{1}{2}}}{0.7854}\right] - a}{\phi}$$	Slide 6.1.2.25.--Solution--Part B
$E = 2.25$ mW $I_t = 250$ mj/cm^2 $t = 3 \times 60 = 180$ sec $a = 1.5$ cm $\phi = 10^{-4}$ radians	
$$r = \frac{\left[\frac{\left(\frac{2.25/180}{250}\right)^{\frac{1}{2}}}{0.7854}\right] - 1.5}{10^{-4}}$$	
$r = 1200$ cm	This example illustrates the importance of properly controlling laser operation. If the direct viewing is increased by 25 seconds (180-155), the safe viewing distance varies from 50 cm to 1206 cm (a 24-fold increase).
4. Photon devices. a. measure rate at which light quanta are absorbed b. e.g., (1) photoelectric (2) photoconductive (3) photovoltaic	It may be appropriate to have an instrument available and briefly describe 1. components 2. basic use 3. steps for use
5. Thermal devices. a. measure effect of heat and temperature change when absorbing light energy b. e.g., (1) calorimeter (2) bolometer (3) thermocouple	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
6. Operational devices. a. application of devices b. aperature stop should closely approximate pupil opening--7 mm c. calibration of detector required based on type of laser and wavelength involved d. read-out is instrument specific; may be necessary to convert readings to W/cm^2	Briefly describe various uses for each of the above.
C. Control of Hazard 1. Control based primarily upon a. educating operating personnel b. providing warnings to unsuspecting persons c. engineering design which minimizes hazard 2. For purposes of control, government classifies lasers based upon potential hazard as follows:	
a. Class I--exempt laser devices; may be viewed directly; incapable of producing damaging radiation b. Class II--lower power laser; may be viewed directly for short periods of time only c. Class III--medium power laser; cannot be viewed directly d. Class IV--cannot be viewed directly or have skin exposed to diffusely reflected beam	Slide 6.1.2.27.--Laser Classes

<table>
<tr><th colspan="2">Lesson Outline</th></tr>
<tr><td>Control of Nonionizing Radiation</td><td>Module 6
Unit 1
Lesson 2</td></tr>
<tr><th>TOPIC</th><th>REMARKS</th></tr>
<tr><td>e. Class V--Class II, III, or IV laser contained in protective housing as to be incapable of emitting hazardous radiation</td><td></td></tr>
<tr><td>3. They have also established operating requirements in general and for each class as follows:</td><td>It is not necessary to cover all class requirements but merely point out protection steps that may be taken.</td></tr>
<tr><td>a. general operating requirements
(1) protective housing and interlocks that prevent human access during operation
(2) Class III-IV--key activated master control
(3) Class II,III, IV--visible or audible indication of laser emission
(4) Class II, III, IV--controls located outside beam area
(5) viewing optics must reduce emission to below TLV levels</td><td></td></tr>
<tr><td>b. e.g., Class IV lasers
(1) restricted entry to facility--interlock
(2) fail-safe system
(3) alarm system
(4) panic button
(5) good illumination--150 footcandles minimum
(6) light colored diffuse room surfaces
(7) operate by remote control
(8) designed to reduce fire hazard, buildup of fumes, etc.</td><td>The following illustrate protective procedures and installation requirements for the various classes of lasers.

Slide 6.1.1.28.--Class IV Requirements</td></tr>
</table>

Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
c. e.g., Class III (1) well-controlled area (2) no specular surfaces (3) terminate beam with diffuse material and minimum reflection (4) eye protection for direct beam viewing	Slide 6.1.2.29.--Class III Requirements
d. e.g., Class II (1) posting of signs in area (2) control of beam direction	Slide 6.1.2.30.--Class II Requirements
e. Class I--no requirement	
4. Further, the following guidelines are presented for consideration. a. laser attended during all times of operation b. personnel educated in operation of laser potential hazards c. non-instructed personnel not permitted in laser area d. laser equipment and area properly posted e. direct viewing should not be done using binoculars or telescope f. laser should not be aimed at occupied areas without appropriate shielding g. methods of confining laser plumes and laser-induced vaporization should be used h. nonreflecting surfaces should surround laser area i. beams passing through glass should pass through perpendicularly j. beam direction should be controlled and minimized k. combustible solvents and materials should be stored away from laser	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
l. potential non-laser hazards should be considered. (See other side of outline)	Put on chalkboard. <u>Potential Non-Laser Hazards</u> a. Voltage sources and leads. b. X-radiation from high-voltage sources. c. Ozone generation from high-voltage sources and ultraviolet radiation. d. Underground electrical equipment, including laser heads and work stations. e. Toxic materials. f. Combustible materials. g. Chemically active materials. h. Cryogenic fluids. i. Inert purging gases. j. Flash-lamp explosion. k. Radiation other than laser beam may also be hazardous. l. Violent interactions can occur during the interaction of laser radiation and materials. Explosions, fires, chemical reactions, brilliant plumes, and toxic emission may occur. m. Mechanical items may break. High-speed mechanical scanners, Q-switches, choppers, and so forth, can fatigue and break. n. Interlocks may fail. o. Accidental discharging of laser can occur. p. Ultraviolet and infrared beams cannot be seen. q. Fallible human beings operate lasers.
m. protective eyewear should be provided in any instance where potential exposure is above $1 \mu W/cm^2$	Will be discussed later more specifically.

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
n. periodic (annual) medical examinations, including eye examination, should be performed on all personnel working near laser	Will be discussed later more specifically.
5. Eye protection.	
a. provided when exposure may exceed 1μW/cm^2	
b. eyewear design	
(1) prevent observation of reflected beam; side panels necessary	Slide 6.1.2.31.--Protective Eyewear--Goggles
(2) curved lenses--diffuse beam	Slide 6.1.2.32.--Protective Eye-Wear--Curved Lenses
c. eyewear parameters	
(1) wavelength--must absorb all wavelengths emitted	
(2) optical density--must reduce intensity to acceptable level (optical density = $\log_{10} \frac{1}{\text{transmittance}}$	
(3) laser beam irradiance; based upon maximum output potential of laser	
(4) visible transmittance--filter out laser; transmit maximum visible light	
(5) filter damage threshold--filters damaged by high-energy lasers	
d. method of construction	
(1) spectral absorption by filter	
(2) selective reflection from dielectric coating	Slide 6.1.2.33.--Eyewear Construction--Dielectric Plate

Laser Eye Protection Goggles
Based on Manufacturers' Information†

$$\text{OPTICAL DENSITY} = \log_{10} \frac{1}{\text{Transmittance}}$$

Manufacturer or Supplier	Catalogue Number	Argon 4880 Å	HeNe 6328 Å	Ruby 6943 Å	GaAs 8400 Å	Nd 10600 Å	CO_2 10.6 μ	UV < 4000 Å > 3000 Å	Coated Filter	Approx. Cost $	No. of glass filters & thickness of each	Visible Light trans-mission	Useful Range Å
American Optical Co.	SCS—437,* SCS—440	0.15	0.20	0.36	1	5	High	No	No	55	1, 3.5 mm	90 %	10600 10600
	580, 586*	0.2	2	3.5	4	2.7	—	>0.2	No	35, 25*	1, 3.5 mm	27.5%	—
	581, 587*	0.6	4.1	6.1	5.5	3	—	>1.6	No	35, 25*	1, 3.5 mm	9.6%	6328
	584	0	1	5	13	11	High	>0.6	No	55	2, 2 mm	46 %	10600
	585	0.3	2	8	21	17	High	>0.6	No	55	2, 2 mm	35 %	6943-10600
	590*	13	0	0	0	—	—	>14	No	25*	1, 3 mm	23.7%	4550-5150
	599	11	0	0	0	—	—	>14	No	35	1, 2.5 mm	24.7%	4550-5150
	680	0	0	.0	0	0	50	No	No	35	1, 2.7 mm	92 %	10600
	698	13	1	4	11	8.5	High	>14	No	55	2, 2&3mm	5 %	10600 and 5300
Bausch & Lomb	5W3754	15	0.2	0	0	0	≥35	20	Yes	39	1, 7.9 mm	4.3%	3300-5300
	5W3755	4	0	0	0	0.1	≥35	10	Yes	39	1, 7.9 mm	57 %	4000-4600
	5W3756	0.8	12	15	5.6	4.8	≥35	3	Yes	39	1, 6.4 mm	6.2%	6000-8000
	5W3757	0.9	4.5	7.7	12	5.7	≥35	2	Yes	39	1, 7.1 mm	4.7%	7000-10000
	5W3758	1.9	1.8	2.2	4.8	7.5	≥35	2	Yes	39	1, 7.6 mm	3 %	10000-11500
Control Data Corp.	TRG-112-1	—	5	12	30	30	—	No	No	50	1, 6 mm	22 %	6943
	TRG-112-2	10	0	0	0	0	—	No	No	50	1, 6 mm	31 %	4880
	TRG-112-3	5	2	6	15	15	—	No	No	50	2, 3 mm	5 %	6943-4880
	TRG-112-4	—	—	—	—	—	High	No	No	50	1, 5 mm	92 %	106000
Fish-Schurman Corp.	FS650AL/18	0.34	3.8	10	>10	>10	—	No	No	30	1, 6 mm	30 %	6943, 8400, 106000
Glendale Optical Co.	NDGA**	1	0.5	2	16	16	High	>20	No	25	Plastic	60 %	8400, 10600
	R**	0.4	2.2	6.3	0.4	0.0	High	5	No	25	Plastic	19 %	6943
	NH**	0.4	5	2.5	0.6	0.5	High	>10	No	25	Plastic	19 %	6328
	A**	15	0	0	0	0	High	>12	No	25	Plastic	59 %	4880, 5143
	NN**	0	0	0	0	0	High	>12	No	25	Plastic	70 %	3320, 3370
Spectrolab	—	8	5	9	13	12	0	8	Yes	115	2, 3.2 mm	<5 %	Broadband

*Spectacle Type. †See reference 24.

**Available in goggles or spectacle type

CAUTION

1. Goggles are not to be used for viewing of laser beam. The eye protective device must be designed for the specific laser in use.
2. Few reliable data are available on the energy densities required to cause physical failure of the eye protective devices.
3. The establishment of engineering controls and appropriate operating procedures should take precedence over the use of eye protective devices.
4. The hazard associated with each laser depends upon many factors, such as output power, beam divergence, wavelength, pupil diameter, specular or diffuse reflection from surfaces,

Reprinted from the Industrial Environment--its Evaluation and Control

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
e. using paramaters discussed, select appropriate eyewear.	Slide 6.1.2.34.--Laser Eye Protection Chart Have students examine chart in textbook. Briefly review data on chart.
6. Medical surveillance. a. medical examination should be given to all personnel working near laser. b. examination should include (1) opthalmologic examination (2) dermatologic examination c. persons with following conditions should not be permitted to work near lasers (1) eye disease (2) skin problems (3) chronic pulmonary or cardiovascular disease (4) chronic emotional and mental illness (5) hypothyroidism (6) diabetes (7) pregnancy	Slide 6.1.2.35.--Medical Surveillance
7. Summary. a. general hazard b. measurement of lasers c. control of hazards d. eye protection e. medical surveillance	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
III. Microwaves	Slide 6.1.2.36.--Microwaves
A. Hazards	Review
1. Absorption of microwave radiation may cause	
a. general temperature increase at exposure site b. potential cataract formation c. central nervous system changes; e.g., changes in brain wave patterns	
2. TLV established to minimize exposure.	
a. identify for power and energy density b. previously presented (Lesson 1)	
B. Measurement of Microwaves	
1. Microwave has two vector components.	
a. near field--electric field (E) and magnetic field (H) b. far field--no interaction between H, E, and the source of the wave c. distance from antennae to intersection of near and far field is given as	
$r = \frac{A}{2\lambda}$	Slide 6.1.2.37.--Radius/Far Field Formula
where r = radius of near field A = area of antennae λ = wavelength	
2. Possible to calculate safe distance in far field--must know:	
a. wavelength (λ) (cm)	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
b. effective area of antennae (A) (cm^2) c. average power output (A) (mW) d. power density (W) (mW/cm^2) e. formula r (safe distance) = $\left(\frac{A \cdot P}{\lambda^2 \cdot W}\right)^{0.5}$	
3. Survey instruments. a. most survey instrumentation designed to measure in far field b. usually calibrated in mW/cm^2 c. measurements in near field (calculated using previous equation) more complicated d. generally, far field measurements adequate	
4. Measuring instruments.	
a. microwave survey instruments consist of	Consumer Product Safety does this measurement on products.
(1) probe (2) meter and amplifier (3) power source	Slide 6.1.2.38.--Components of a Microwave Survey Instrument
b. general instrument requirements (1) portable (2) rugged (3) easily readable (4) probe--directionally independent	
c. detectors--two categories (1) thermal (2) electrical	Slide 6.1.2.39.--Microwave Detectors

TOPIC	REMARKS
d. thermal detector (1) absorption of microwave radiation causes change in resistance (bolometer) (2) e.g., (a) thermistor--as temperature rises resistance decreases (b) baretter--as temperature rises, resistance rises (3) thermocouple--produces voltage when heated (4) air pressure system--measurement of pressure changes in confined gas when exposed to microwave radiation and heated (5) problem with thermal detection--sensitive to ambient temperature changes e. electrical detectors (1) diode or rectifier used to convert RF current into direct current (2) system is extremely sensitive f. except air pressure system, all detectors require antenna (probe) to convert wave RF to wire-conducted RF (1) probe--λ specific; however may be able to get with band detector	

TOPIC	REMARKS
(2) when used, must be parallel to field to avoid field disturbance	
g. instruments usually calibrated for specific use upon purchase	
5. Measurement taking.	
a. measure should be taken periodically in any area of potential wave leakage; e.g., wave guides, doors, wave source	
b. measurements should be taken in all areas of potential exposure, based upon floor plan of work area	
6. Calculation of exposure.	
a. done as for UV radiation	
b. factors	
(1) exposure	
(2) time	
(3) distance (inverse square law)	
C. Hazard Control	Slide 6.1.2.40.--Hazard Control
1. Hazards best controlled by:	
a. engineering design	
(1) location of antennae	
(2) appropriate shielding	
b. safe operating procedures	
2. When surveying for potential hazards, the following should be given consideration as potential hazard sources:	
a. improper installation	
(1) poor location	

Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
(2) lack of proper grounding of low-frequency supply (3) inadequate or inoperable interlocks, controls, relays, and fuses (4) inadequate shielding of RF areas and circuits b. unsafe operating practices (1) unauthorized personnel operating equipment (2) unauthorized adjustment of controls (3) lack of attention while operating equipment (4) reaching into hoppers or conveyors to adjust or extract pieces (5) failure to shut down equipment and report operating defects such as faulty operating sequence, relays that stick, circuit breakers that do not open or close properly, interlocks that fail or are blocked out (6) feeding of brazing or soldering alloys during heating cycle c. faulty maintenance practices (1) poor maintenance schedule (2) unauthorized repairmen	

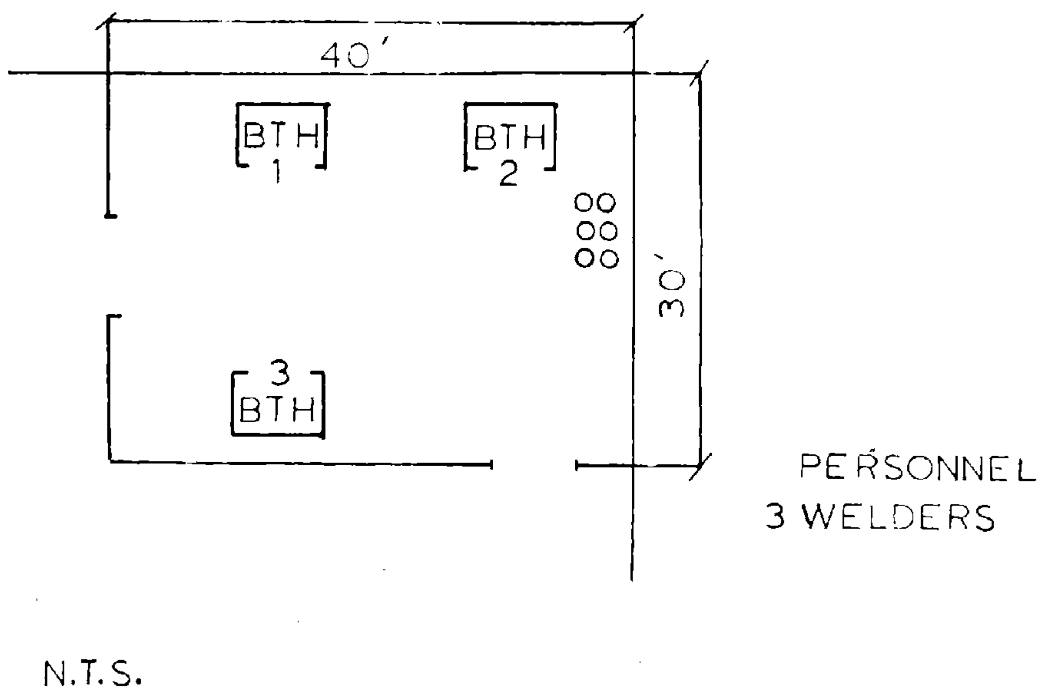
Lesson Outline	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
(3) failure to shut off power and use lockout procedures before servicing	
(4) not discharging capacitors (stored-up charge has lethal possibilities)	
(5) failure to short high-voltage leads to ground before working on equipment	
(6) improper tools and failure to pick up tools after job	
(7) lack of final check, after repairs or adjustments have been made, before energizing equipment	
3. Use of protective clothing is minimized except in special instances.	
4. Areas of microwave and RF usage should be properly posted.	Slide 6.2.1.41.--RF Signs
5. Shielding materials and enclosures may be considered; e.g.,	
a. similar principles in shielding as previously described	
b. e.g., sample attenuation factor	Slide 6.1.2.42.--Shielding Attenuation Factor/ Microwave
D. Summary--Microwaves	
1. Hazards.	
2. Measurement of microwaves	
3. Hazard Control	
IV. Summary	
A. UV Radiation	
B. Lasers	
C. Microwaves	Ask for questions.

Practice Exercise	
Control of Nonionizing Radiation	Module 6 Unit 1 Lesson 2

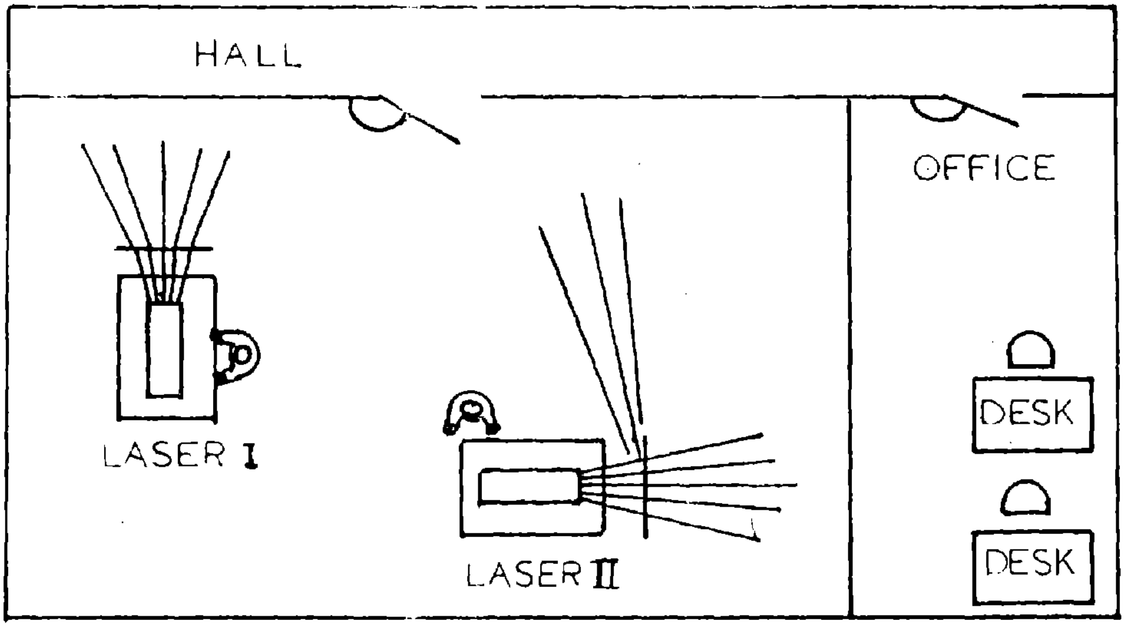
1. Referring to the welding shop defined in the Case Study presented in Module 1, Unit 1, Lesson 2, identify

   a. Potential radiation and nonradiation hazards
   b. a plan for measurement and evaluation of potential hazards
   c. procedure and equipment use which can be implemented to increase personnel protection.



Process Description

1. Parts are delivered to the welding shop by hand truck.
2. Welding is done to specification on cleaned parts.
3. Some of the galvanized parts are sent to welding.
4. Booths #1 and #2 are used for acetylene cutting and welding using an oxygen assist.
5. Booth #3 used for gas shielded metal arc welding. Carbon dioxide is used as the gas shield.
6. Parts are moved from welding by cart pulled manually or by forklift.



2. The above facility houses two laser systems. Laser I has been classified as a Class II laser, and the second laser is a Class III laser.

   a. What potential hazards exist?

   b. What changes should be made or what protective equipment should be used which would decrease the potential hazard of each of these units, both design and operation?

UNIT 2

IONIZING RADIATION

Performance Objectives

Lesson | **Ionizing Radiation** | **Module 6, Unit 2**

1 — 1. Given a list of statements, the student will be able to <u>recognize</u> the statement which best defines each of the following:

- a. atom
- b. proton
- c. neutron
- d. electron
- e. ion
- f. isotope

1 — 2. For each of the following

- a. alpha
- b. beta (positron and negatron)
- c. gamma
- d. X-radiation
- e. neutron

the student will be able to <u>recall</u> the following information:

- (1) type of radiation (particle or photon)
- (2) charge (+, -, or neutral)
- (3) atomic weight (nearest amu)
- (4) relative energy level
- (5) relative range
- (6) potential health hazard
- (7) relative penetrating capability
- (8) source (machine, radioisotope)

1 — 3. Given a list of statements, the student will be able to <u>recognize</u> the statement which best defines:

- a. half life ($T^{\frac{1}{2}}$)
- b. radioactive decay
- c. radioactive decay chain
- d. daughter products

1 — 4. Given the atomic number and weight of a radionuclide (e.g., ($_{92}U^{232}$) and a list of at least three radioactive emissions (e.g., alpha, positron, gamma), the student will be able to chart the radioactive decay chain and identify the product by number and weight.

1 — 5. Given a list of statements, the student will be able to <u>recognize</u> the one(s) that best describe(s) the production of X-radiation.

1 — 6. Given the following list of terms:

- a. electron-volt
- b. curie
- c. roentgen
- d. rad
- e. rem
- f. fluence
- g. flux density

the student will be able to <u>recall</u> the correct definition for each.

1 — 7. Given the number of disintegrations per second for a radioisotope, the student will be able to calculate the activity of the radioisotope in curies.

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2

1 8. Given an exposure rate in roentgens or rads, the type of radiation (alpha, beta), and the QF value for each type of radiation, the student will be able to calculate the dose equivalent.

1 9. Given a list of statements, the student will be able to <u>recognize</u> the one which best defines ionization.

1 10. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the lethal dose energy relative to normal cell energy production.

1 11. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the difference between the direct and indirect action of radiation.

1 12. Given a list of statements, the student will be able to <u>recognize</u> the one which best defines

a. external radiation hazard
b. internal radiation hazard

and the student will be able to <u>recall</u> one type of radiation which exemplifies each.

1 13. Given a description of an employee who has received an acute dose of radiation, the student will be able to <u>recall</u>

a. signs/symptoms of acute whole body radiation
b. projected long-term effects of exposure to ionizing radiation.

1 14. Given a list of doses (rads), the student will be able to <u>recognize</u> the LD_{50} of ionizing radiation.

1 15. Given an exposure rate (rads or roentgens) for a specified period of time, the QF values, the type of radiation involved, and an MPD table, the student will be able to calculate the dose equivalent and determine if the MPD has been exceeded.

1 16. The student will be able to <u>recall</u> the definition of

a. MPD
b. MPC

1 17. Given a radioactive source with known exposure rate given in dose equivalents, the student will be able to calculate the maximum exposure time for the employee, so that the MPD is not exceeded.

1 18. The student will be able to <u>recall</u> at least four uses of ionizing radiation. They may include

a. radiation gauges
b. static eliminators
c. X-ray analysis
d. self-luminous compounds
e. tracers

Lesson	Ionizing Radiation	Module 6 Unit 2

2 19. Using no references, the student will be able to recall at least three hazards associated with radiation use. The three hazards may be taken from the following list:

a. direct radiation
b. high voltage of associated equipment
c. unwanted radiation (e.g., using primarily a beta source which also emits gamma)
d. chemical or toxic properties of radionuclide in solution.

2 20. Given a list of statements, the student will be able to recognize the statement which best describes the principle of operation of the ionization chamber.

2 21. Given a list of statements, the student will be able to recognize the one which best describes the difference between air equivalent and tissue equivalent chambers.

2 22. Given a list of statements, the student will be able to recognize the statement which best describes the operation difference between the ion chamber and the proportional chamber.

2 23. Given a description of the Geiger-Mueller counter, the student will be able to recall the principle and steps of its operation.

2 24. Using no references, the student will be able to recall

a. two advantages

(1) sensitivity
(2) portable
(3) generally rugged

b. two disadvantages

(1) count not proportional to absorbed dose
(2) blocking of readings
(3) directional sensitivity

of the G-M counter. The advantages/disadvantages must come from the list provided.

2 25. Given a list of statements, the student will be able to recognize the one which best describes the principles of operation of the

a. scintillation detector
b. photographic device
c. thermoluminescent device
d. photoluminescent device
e. semiconductor device

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2

Lesson	Objective
2	26. Given a list of statements, the student will be able to <u>recognize</u> the statement(s) that describe(s) a. advantages b. disadvantages of the use of film badges as a radiation monitoring device.
2	27. Using no references, the student will be able to <u>recall</u> at least one difference between a pocket dosimeter and a pocket ion chamber.
2	28. Given a description of a situation which has a potential radiation hazard, a list of the types of radiation involved, and any reference materials, the student will be able to select the appropriate monitoring device (e.g., G-M counter versus proportional counter).
3	29. Given a list of statements, the student will be able to <u>recognize</u> the one(s) which best describe the responsibilities of the safety professional with respect to radiation protection.
3	30. Given a list of statements, the student will be able to select the one(s) which best describe(s) the purpose of a radiation safety program.
3	31. Given a list of statements, the student will be able to <u>recognize</u> the one which best describes the function of "distance" from the source as a protective measure against radiation exposure.
3	32. Using no references, the student will be able to <u>recall</u> and list at least four responsibilities of the safety professional with respect to the monitoring and control of radiation.
3	33. Given an exposure rate (rads or R) at a specified distance, the student will be able to calculate the change in exposure rate caused by a specified change in distance.
3	34. Given a list of statements, the student will be able to select the one which best describes <u>half value layer</u> (HVL).
3	35. Given the exposure rate, at a specified distance, of a radionuclide, the HVL of the radionuclide, and a table of HVL attenuation coefficients, the student will be able to calculate a. the attenuation caused by a certain thickness of shielding b. the shielding required for a certain attenuation or reduction in exposure rate.
3	36. Given an exposure rate at a specified time, a half-life attenuation table, and the half-life value for the radionuclide, the student will be able to calculate the change in exposure rate due to a known elapsed time.

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2

3 37. Given the activity in curies of a known gamma-emitting radionuclide, the energy in MeV, the fraction of disintegrations emitting the energy, and the distance from the source, the student will be able to calculate the absorbed dose in mR/hr.

3 38. Given the absorbed dose (as calculated above), the student will be able to calculate the effect of modifying

a. time of exposure
b. distance from source
c. shielding

for gamma emitters.

3 39. Given

a. workload--mamp-min/week
b. use factor
c. occupancy factor
d. tube voltage
e. distance from source to personnel

HVL table for X-radiation, and an Average Radiologic Output Table for X-ray machine, the student will be able to calculate the shielding necessary to meet the MPD value of 0.1 R/hr.

3 40. Given a list of statements, the student will be able to recognize the one which defines

a. range
b. unit density

as used in reference to beta particles.

3 41. Given the unit density of a specified beta emitter and the density of a shielding material selected, the student will be able to calculate

a. the attenuation of a given thickness of shielding
b. the shielding required to stop all beta particles

3 42. Given a list of statements, the student will be able to recognize the one which best describes why light elements are used to shield beta emitters.

3 43. Given a list of statements, the student will be able to recognize the one which best describes the danger involved with alpha emitters.

3 44. Given the hydrogen density of a material, a table or graph of hydrogen attenuation coefficients, and the formula for calculating HVL, the student will be able to calculate the HVL value for a neutron for a specified energy level.

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2

3 45. Given a description of a situation describing the use of a known radiation source and the protective measures taken, the student will be able to determine if the protective measures are adequate and the steps necessary to correct any deficiencies.

3 46. Given a description of a radiation area, the student will be able to recall and list the procedure for making routine measurements, including the components of an operations analysis.

3 47. Given a list of statements, the student will be able to recognize the one which best describes the procedure for

a. smear (wipe) test for surface contamination
b. air analysis
c. water sample analysis

3 48. Given a description of a procedure involving radiation and an employee's activities when working with the radiation source, the student will be able to determine the proper location for the placement of personnel monitors.

3 49. Given a description of a facility using radioisotopes with a potential for contamination, the student will be able to identify potential problems in the design of the facility. These problems may include:

a. inadequate shielding
b. rough, porous working surfaces
c. dust collecting areas; including suspended lights and pipes, roof trusses
d. nonenclosed shelving
e. poor construction, causing potential leakage
f. inavailability of special handling equipment
g. inadequate or inappropriate heat and exhaust system design
h. insufficient containment procedures; e.g., glove box

3 50. Given a description of a radiation area, including the level of radiation involved and any references selected by the student, the student will be able to select the appropriate radiation warning signs for that area.

3 51. Given the amount and type of radioactivity involved, the air/water flow of the given system, and Handbook #69, the student will be able to calculate the maximum radioactive waste which can be disposed of by

a. release into the air
b. release into tidal waters or sewage system
c. incineration

Performance Objectives		
Lesson	Ionizing Radiation	Module 6 Unit 2
3	52. Given the amount and type of radioactivity involved and the NRC limits for burial procedures, the student will be able to calculate what percent of the radioisotope may be disposed of by burial.	
3	53. Given no references, the student will be able to <u>recall</u> the primary differences between shielding garments and protective clothing.	
3	54. Given a list of statements, the student will be able to <u>recognize</u> the one(s) which best describe the purpose and components of a. pre-employment medical examinations b. periodic medical examinations c. follow-up examinations	
3	55. Given a list of statements, the student will be able to recognize the one which best describes the procedure for decontamination of personnel and facilities.	

Unit Activities--Instructor	
Ionizing Radiation	Module 6 Unit 2

In order to present the unit material to the students, the instructor is responsible for the following:

Lesson 1--Principles of Ionizing Radiation

Classroom Presentation

Present a lecture related to the physics and chemistry of ionizing radiation. The lecture should emphasize the properties and characteristics of alpha, beta, gamma, X-, and neutron radiation. Also, the lecture is designed to present such topics as common units of radiation measure, biological effects of radiation, established exposure limits, and common applications. By the completion of this lesson, the student should have a basic understanding of the principles of ionizing radiation.

Time Allotted

2 Hours

Demonstrations

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Lesson 2--Monitoring Instrumentation

Classroom Presentation

This lesson is designed to provide an overview of the principles, operation, and use of basic ionizing radiation monitoring instrumentation. The instructor should provide each student with the opportunity to examine each piece of equipment. Time is not allotted in this lesson to allow a practical application demonstration of each instrument.

Time Allotted

1 Hour

Demonstrations

The instructor should briefly demonstrate the use of

1. ionization chamber
2. proportional chamber
3. Geiger-Mueller counter
4. scintillation detectors
5. film badges
6. pocket dosimeter
7. pocket ion chamber

The demonstration should include a brief description of the instruments, including

a. components of the instrument
b. primary use
c. range and type of radiation which can be monitored
d. meter readings, range, unit
e. adaptation required for different types of radiation
f. steps for use

Supervised Practice

Time is not allotted for supervised practice, but each student should be given an opportunity to examine the equipment.

Unit Activities--Instructor

Ionizing Radiation	Module 6 Unit 2

Lesson 3--Control of Ionizing Radiation

Classroom Presentation

Present a lecture concerning the monitoring and control of ionizing radiation, including such things as shielding requirements, facilities design, and decontamination procedure.

Time Allotted

2 Hours

Demonstrations

No demonstrations are required.

Supervised Practice

No supervised practice is required.

Unit Activities--Student	
Ionizing Radiation	Module 6 Unit 2

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 1--Principles of Ionizing Radiation

Classroom Activity

Attend a 2-hour lecture related to the physics and chemistry of ionizing radiation. By the end of the lesson, the student should have a basic understanding of the principles of ionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 3
the Industrial Environment--its Evaluation and Control		Chapter 29
PROBLEMS		
Practice Exercises		Section 6 Chapter 2

Unit Activities--Student	
Ionizing Radiation	Module 6 Unit 2

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 2--Monitoring Instrumentation

Classroom Activity

Attend a one-hour lecture on the principles, operation, and use of basic ionizing radiation monitoring instrumentation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 4
PROBLEMS		
Industrial Hygiene Engineering and Control		Section 6 Chapter 3

Unit Activities--Student	
Ionizing Radiation	Module 6 Unit 2

In order to complete the unit successfully, the student will be responsible for the following:

Lesson 3--Control of Ionizing Radiation

Classroom Activity

Attend a two-hour lecture on the monitoring and control of ionizing radiation.

Assignment

The student should review the following materials prior to attending class.

READING	SHORT COURSE	EXTENDED 1-HOUR
Industrial Hygiene Engineering and Control		Section 6 Chapter 5
PROBLEMS		

Facilities, Equipment, and Materials	
Ionizing Radiation	Module 6 Unit 2

Facilities

Lecture--Normal Classroom

Equipment and Materials

Educational

- Chalkboard
- Chalk
- Eraser
- 35 mm Projector with remote control
- Screen

Health and Safety

- Ionization chamber
- Proportional counter
- Geiger-Mueller counter
- Scintillation detector
- Film badges
- Pocket dosimeter
- Pocket ion chamber

Visuals

- Slide Series--Industrial Hygiene Engineering and Control Module 6, Unit 2

References Used in Class

<u>Industrial Hygiene Engineering and Control</u>

<u>the Industrial Environment--its Evaluation and Control</u>

"Threshold Limit Values for Chemical Substances and Physical Agents In the Workroom Environment with Intended Changes for 1976"

"Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure," Handbook 69

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
I. Ionizing Radiation--Introduction	If necessary, review with the students the differences between ionizing and nonionizing radiation
A. Atomic Structure	This section is provided as a review. It may be deleted at the instructor's discretion.
1. There exist over 100 elements; the basic ingredient in all materials.	
2. Atom--smallest particle of an element which possesses chemical properties of that element.	
3. Atom--composed of three fundamental particles.	Slide 6.2.1.1.--Components of an Atom
a. proton--positive charge (+1) and mass of 1 atomic mass unit (amu)	
b. neutron--no charge and mass of 1 amu	
c. electron--negative charge (-1); mass of 5.43×10^{-4} amu	
4. Protons and neutrons contribute most of mass and make up the nucleus.	
5. Electrons exist in orbits around the nucleus.	
6. Undisturbed atom will have equal numbers of protons and electrons--electrically neutral.	
7. Atom with surplus or deficit of orbital electrons--positively or negatively charged--called an <u>ion</u>.	
II. Radioactivity	
A. For a given number of protons, nuclear stability exists with a certain number of neutrons.	
B. Atoms with same number of protons, but different neutrons, are called <u>isotopes</u>.	Slide 6.2.1.2.--Nuclides of Hydrogen Use hydrogen as an example of isotope.
C. Radioactivity--Improper (unstable) combination of protons and neutrons in the nucleus.	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
D. Atoms will spontaneously transform to more stable state; radiation emitted in form of: 1. Alpha particles 2. Beta particles 3. Gamma radiation 4. Combination of the above.	
E. Alpha Particles	Slide 6.2.1.3.--Alpha Particles
1. Originate in the nucleus of radioactive atom. 2. Composed of 2 protons and 2 neutrons (helium nucleus). 3. Mass of 4 amu and a charge of +2. 4. When emitted, new element formed; atomic number decreases by 2 and atomic weight decreases by 4. 5. Energy of alpha dependent upon radionuclide source; may occur up to 10 MeV. 6. Cause more ionization than beta or gamma radiation, but travel much shorter distance. 7. Range. a. range short because of high mass and large charge	
b. general range of alpha particles in air is approximately 4 inches.	Ask students if there is a potential hazard with alpha particles if the range is short and stopped by paper.
c. can be stopped by a film of water, sheet of paper, or other paper-thin materials.	Slide 6.2.1.4.--Relative Penetrating Capability of Alpha Particles
8. Sources. a. radioactive decay b. e.g., ${}_{90}Th^{232}$, ${}_{92}U^{238}$	Refer to sample decay chain presented later.
9. Interaction with target--attract two electrons to form helium atom (direct ionization).	Slide 6.2.1.5.--Interaction of Alpha Particles

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
F. Beta Particles	
1. Originate in nucleus of radioactive atom.	Slide 6.2.1.6.--Beta Particle--Positron and Negatron
2. Electron emitted during radioactive decay.	
3. Can be positively or negatively charged.	
a. positron	
(1) positive beta particle	
(2) when emitted, atomic number decreases by one--proton becomes neutron	
(3) when colliding with electron, gamma radiation emitted	
b. negatron	
(1) negative beta particle	
(2) high speed electron	
(3) when emitted, causes atomic number to increase by one; neutron becomes proton	
(4) as negatron slows, X-radiation is formed	
4. Energy level.	
a. dependent upon radionuclide source	
b. 0.017 - 4 MeV	
5. Penetration capability.	
a. greater than alpha particles; smaller mass and charge	Slide 6.2.1.7.--Relative Penetrating Capability of Beta Particles
b. less than X- or gamma radiation	
c. range; e.g.,	
(1) air less than 6 feet in most cases	
(2) wood--1.5 inches	
(3) human body--0.1-0.5 inches	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
d. can be stopped by material of low atomic weight; e.g., aluminum	
6. Sources.	
a. radioactive decay b. e.g., $_{92}U^{232}$	Refer to sample decay chain.
7. Interaction with target--direct ionization.	Slide 6.2.1.8.--Beta Particle Interaction
a. generally causes ionization b. positron--formation of gamma radiation c. negatron--formation of X-radiation	
G. Gamma (γ) Radiation	Slide 6.2.1.9.--Gamma Radiation
1. Electromagnetic radiation. 2. Originates from nucleus but emission does not cause change in element properties. 3. Energy level.	
a. highest electromagnetic radiation to be discussed b. dependent upon radio-nuclide source c. 0.15 to several MeV	
4. Source.	
a. radioactive decay b. e.g., $_{92}U^{238}$ c. positron destruction.	Refer to sample decay chain.
5. Penetration.	
a. deep penetration; tremendous health problem b. No mass or charge c. e.g., half value layer for 1 MeV of gamma radiation is equal to 0.5 inches of steel	Slide 6.2.1.10.--Relative Penetrating Capability of Gamma Radiation

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
6. Interaction with target--indirect ionization. a. photoelectric effect--incident photons cause ejection of orbital electrons with energy equal to difference between photon energy and electron binding energy--X-radiation or electrons emitted as shell vacancies corrected b. Compton effect--photon gives up part of energy to orbital electrons--electron recoils and may be ejected; degraded photon created. c. pair production (1) high energy photon interacts with electric field surrounding charged particle (nucleus) (2) causes formation of electron and positron of equal energy (3) X- and gamma radiation formed when positron and negatron collide or slow H. Over forty elements in nature which undergo this process. I. Decay Process 1. Radioactive materials are unstable because of energy involved; e.g., a. repulsion of positively charged protons in a confined space b. interaction of neutrons with protons	Slide 6.2.1.11.--Gamma Interaction

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
2. Isotope releases energy in an effort to find more stable level.	
3. Depending upon type of emission, element may change; e.g.,	
a. alpha--new element b. beta--new element c. neutron--same element, new isotope d. gamma--same element	
4. Sample decay chain.	Slide 6.2.1.12.--Uranium-238 Decay Chain
a. radionuclides decay into other radionuclides b. radionuclides form "daughter" products c. total radioactivity may increase because of presence of "daughter" products	
5. Total of approximately 240 such radionuclides.	Inform students of the relative hazard of each. Slide 6.2.1.13.--Relative Hazard of Nuclides
6. Number of atoms decaying proportional to number of atoms present.	
a. constant for any radionuclide b. constant fraction disintegration per unit time c. e.g., half-life scheme ($T_{1/2}$); if $T_{1/2}$ is long, radiation released is small	Slide 6.2.1.14.--Half-Life Decay Series Describe half-life scheme to students.
III. Radiation--Other Sources	
A. Two other types of radiation formed from some type of atomic activity.	
1. X-radiation (electron movement). 2. Neutrons (fission).	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
B. X-Radiation	
1. High frequency electromagnetic radiation.	Slide 6.2.1.15.--Formation of X-Radiation
2. Originates outside of nucleus.	
3. Inner orbital electrons involved in X-radiation production.	
4. Principle	
a. high speed electrons (negatrons) slowed down	
b. electrons give up energy in the form of X-radiation	
c. energy released dependent upon	
(1) speed of electrons	
(2) characteristics of medium (striking target)	
5. Energy level--somewhat less than gamma radiation.	
6. Types of radiation.	
a. characteristic--produced in energetic transition between inner orbital electron levels	
b. bremmstrahlung (secondary) caused by interaction of electron with nucleus	
7. Sources.	
a. radioactive decay--emission from colliding negatrons	
b. X-ray machine	Slide 6.2.1.16.--X-Ray Machine
(1) components	
-cathode (electron source	
-anode (target)	
-potential difference between cathode and anode in vacuum	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
(2) electrons striking target dissipate energy in the form of X-radiation.	
8. Penetrating capability.	Slide 6.2.1.17.--Relative Penetrating Capability of X-Radiation
a. dependent upon wavelength of radiation	
b. short wavelength--"hard"	
(1) approximately 0.001-0.1 nm in length	
(2) penetrates several inches of steel	
c. long wavelength--"soft"	
(1) 0.1-1.0 nm in length	
(2) less penetrating than "hard" X-radiation	
d. range of penetration	
(1) expressed in terms of half-value layer (HVL)--reduces incident radiation by 0.5	
(2) dependent upon -energy of X-radiation -type of medium	
(3) e.g., HVL for "hard" X-radiation is several inches of concrete	
9. Interaction with target--same as gamma radiation.	
C. Neutrons	
1. Originate from nucleus.	Slide 6.2.1.18.--Formation of Neutrons
a. bombardment of light elements (Be, Li) with alpha particles or gamma radiation	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
b. fission of isotopes of uranium and plutonium caused by neutron bombardment produces more neutrons	Describe briefly the principle of chain reaction.
2. Has a mass of 1 amu and a charge of 0.	
3. Sources.	
a. nuclear reaction (described above)	
b. accelerators (1) Van de Graaf (2) Cockroft-Walton generator	At instructor discretion, the general principles and operation of an accelerator may be presented
4. Penetrating capability. a. dependent upon (1) energy level (2) characteristics of medium (3) type of collision	Slide 6.2.1.19.--Relative Penetrating Capability of Neutrons
b. mean free path (mfp) (1) average distance a neutron of given energy will travel (2) probability of interaction in 3 mfp = 0.95 (3) e.g., in human tissue, mfp = 0.25 to several inches	Review penetrating capability of each type of radiation.
5. Interaction with target. a. fast neutrons--collide with nuclei and lose energy (billiard ball-like collision) b. slow (thermal)--captured by absorber nuclei c. in either case, alpha, beta, or gamma radiation is emitted	Slide 6.2.1.20.--Neutron Interaction

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
d. because ionization is secondary to neutron interaction, calculation of neutron dose is difficult	
D. Summary	Slide 6.2.1.21.--Properties of Ionizing Radiation Review properties of five types of radiation discussed, including a. source b. description c. energy d. hazard e. necessary shielding (based upon penetrating capability)
IV. Units of Measure	The students should understand the terms presented. Emphasis should be placed on the concept of each term rather than the numerical value.
A. Units of Energy 1. Joule--standard unit of energy in physics. 2. erg--1.0 x 10^{-7} joules. 3. Electron volt (ev). a. energy unit of atomic and nuclear activity b. equal to kinetic energy acquired by an electron after being accelerated through potential difference of one volt 4. Energies encountered expressed as a. Kev--thousands of electron volts b. MeV--millions of elèctron volts c. e.g., energy of $_{55}Cs^{137}$ gamma radiation is 0.667 MeV.	Slide 6.2.1.22.--Units of Energy

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
5. Conversion-- 1.602×10^{-13} J/MeV 6. Energies associated with emission have been calculated and are available in reference manuals.	
B. Units of Activity	Slide 6.2.1.23.--Units of Activity
1. Activity--rate of radioactive decay in a given sample (dn/dt). 2. Curie (Ci). a. unit of activity b. disintegration (counts) per second (minutes) c. 1 Ci = 3.7×10^{10} 3. Unit of activity can be correlated to potential exposure.	
C. Exposure.	Slide 6.2.1.24.--Units of Exposure
1. Roentgen (R)--unit of exposure 2. Measures amount of charge produced in air by gamma or X-ray photon. 3. 1R = 2.58×10^{-4} coulombs/Kg air. 4. 1R produces 2×10^{9} ion pairs in air. 5. <u>Exposure rate</u>. a. time derivative of exposure b. expressed "R/hr"	
D. Absorbed Dose	Slide 6.2.1.25.--Units of Absorbed Dose
1. Energy imparted by ionizing radiation to matter per unit mass of absorber. 2. <u>rad</u>--standard unit of absorbed dose. 3. 1 rad = 10^{-2} joule/Kg	

Lesson Outline

Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
4. Dose rate. a. time derivative of absorbed dose. b. expressed "mrad/hr"	
E. Dose Equivalent	Slide 6.2.1.26.--Unit of Dose Equivalent
1. Measure of exposure and absorbed dose does not consider a. spatial distribution of absorbed energy b. type of ionizing radiation c. radionuclide source; e.g., certain radionuclides migrate to certain areas of the body	
2. rem. a. standard unit of dose equivalent b. takes into consideration the above-mentioned factors c. generally	
rem = rad x QF	Slide 6.1.2.27.--QF Values

Practical Quality Factors
Radiation Type

	Rounded QF
X-rays, gamma rays, electrons or positrons, Energy > 0.03 MeV	1
Electrons or positrons, Energy < 0.03 MeV	1
Neutrons, Energy < 10 KeV	3
Neutrons, Energy > 10 KeV	10
Protons	10
Alpha Particles	20
Fission fragments, recoil nuclei	20

TOPIC	REMARKS
d. dose equivalents used in personnel dose monitoring; also basis for maximum permissible dose (MPD)	
e. example--	
Alpha source with reading of 0.05 mrad/hr.	Slide 6.2.1.28.--Calculation of Dose Equivalent--Question
Calculate rem value for the 8-hr period.	Slide 6.2.1.29.--Calculation of Dose Equivalent--Solution
<u>Solution</u>	
rem = rad x QF	
$\text{rem} = \frac{0.05 \text{ mrad}}{\text{hr}} \times \frac{20 \text{ mrem}}{\text{mrad}}$	
$= \frac{1.0 \text{ mrem}}{\text{hr}}$	
$\frac{\text{Exposure}}{8 \text{ hr}} = \frac{1.0 \text{ mrem}}{\text{hr}} \times 8 \text{ hr} = 8.0 \text{ mrem}$	
F. Fluence (Φ)	
1. Number of particles which enter a sphere of unit cross sectional area. 2. Expressed in terms of "particles per cm^2." 3. <u>Energy fluence (Ψ)</u>. a. sum of energy of particles b. expressed in terms of "MeV/cm^2"	Slide 6.2.1.30.--Fluence Inform the students that fluence and flux density are presented because they are often presented in the literature.
G. Flux Density (ϕ)	Slide 6.2.1.31.--Flux Density
1. Increment of particle fluence per unit time ($\phi = d\Phi/dt$) 2. Expressed "particles/cm^2/sec" 3. e.g., neutrons/cm^2/sec. 4. <u>Energy flux density</u>. a. time derivative of energy fluence b. expressed "$MeV/cm^2/sec$"	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
V. Biological Effects	Slide 6.2.1.32.--Biological Effects
A. Fundamental Property of Ionizing Radiation	
1. Transfers energy when passes through materials.	
2. Absorption of energy causes	
a. ionization (explusion of orbital electron)	
b. excitation to higher energy state of orbital electrons or nuclei	
3. Ions react with other atoms and molecules, causing potential changes.	
B. Energies Involved	
1. Energy involved in radiation very small.	
2. Lethal dose of radiation dissipates approximately 10^{-6} times the amount of energy dissipated by the cell itself during daily functioning.	
3. Thus, only 1 of $2.0 \times 10^{+7}$ molecules in the cell is actually affected by the radiation.	
C. Action of Radiation	Slide 6.2.1.33.--Action of Ionizing Radiation
1. Direct action--irradiation of critical molecules in cell causes death; e.g., DNA.	
2. Indirect action--irradiated water molecules form active products (H_2O_2 (peroxide), OH^-, O_2H^-), which react with other molecules causing cell damage or death.	
3. Indirect action more significant than direct action.	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
4. Generally, radiation causes a. cell death b. cell damage which prevents growth or causes formation of cell mutation c. cell function and ultimately body function reduced	
D. Relative Biological Efficiency 1. All forms of ionizing radiation produce some type of injury. 2. Production of tissue reaction dependent upon density of ionization in the radiation path; i.e., linear energy transfer. 3. Linear energy transfer. a. related to amount of energy transferred to medium per linear penetration b. e.g., alpha particle disseminates high energy over short penetrating distance ∴ high energy transfer 4. Particulate radiation (alpha, neutrons) produces more damage per energy absorbed; thus high relative biological efficiency (RBE). 5. Electromagnetic radiation causes more diffuse ionization.	
E. Types of Exposures	Slide 6.1.2.34.--Types of Exposure
1. External a. radiation permeates skin b. e.g., gamma and X-radiation	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
2. Internal. a. radiation source enters through (1) respiratory system (2) digestive system (3) open cut b. e.g., alpha particles c. radioactive source in body emitting radiation d. effective dose difficult to calculate 3. Biological effect the same, but internal exposure may be more devastating.	
F. Radiation Pathology 1. Response of individual to radiation depends on a. dosage b. amount and type of tissue irradiated; e.g., localized damage vs. whole body irradiation 2. Local exposure. a. causes damage to specific site or organ b. systemic changes may occur 3. Whole body radiation. a. dose greater than 100 rad causes systemic illnesses (acute radiation syndrome) b. signs/symptoms (1) nausea and vomiting (2) skin erythema (3) intestinal bleeding and diarrhea (4) gradual loss of hair	Slide 6.2.1.35.--Radiation Pathology

Lesson Outline

Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
c. because of cell damage, cerebral edema may occur and cause death within minutes to hours	
4. The following effects would be observed in man after acute whole body doses of penetrating radiation.	Slide 6.2.1.36.--Acute Radiation Syndrome
0-25 rad -no observable effect.	
25-50 rad -minor temporary blood changes.	
50-150 rad -possible nausea and vomiting along with reduce white blood cell count.	
150-300 rad -exaggeration of above symptoms plus diarrhea, malaise, and loss of appetite.	
300-500 rad -exaggeration of above symptoms, plus hemorrhaging and loss of hair (epliation). About 50% of the untreated exposed population will die at 450-500 rad level.	
Above 500 rad-most of the above symptoms will appear sooner and in more severe form. Survival chances diminish rapidly with higher doses.	
5. Long-term effects. a. cancer b. general body deterioration (early aging) c. loss of hair d. mutation of genes (deformed offspring)	Slide 6.2.1.37.--Long-Term Effects of Ionizing Radiation

Lesson Outline

Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
	Because of overlapping of the various types of ionizing radiation, the general industrial and medical uses will be discussed rather than the uses for each specific type of radiation. Students should be asked to describe 1. examples of uses of ionizing radiation 2. description of application and work environment they may be familiar with.
VI. Ionizing Radiation--Application A. Radioisotopes Available in 1. Naturally occuring radionuclides. 2. Nuclides produced by accelerators. 3. Fission products. B. Industrial Uses 1. Radiation gauges.	
a. radiation penetrates or is reflected off matter--can determine useful information if reading can be taken. b. because radiation level low, use is nondestructive	Ask students for uses of radiation gauges.
c. radiation gauges used to monitor automated product lines (1) determine sheet metal thickness (2) density of metals or fluids (3) moisture content	Slide 6.2.1.38.--Radiation Gauge Efficiency Briefly review data on slide to show students increased sensitivity radiation gauges.

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
d. types of gauges (1) transmission--monitors radiation penetrating substance (2) reflection--monitors radiation reflected	Slide 6.2.1.39.--Radiation Gauge--Schematic
e. type of ionizing radiation commonly used in gauges (1) X-radiation (2) gamma radiation $_{55}Cs^{137}$ (3) beta (negatrons) $_{38}Sr^{90}$ (4) neutrons	
2. Radiography and fluoroscopy.	Slide 6.2.1.39.--Radiation Uses
a. defined as production of a shadow image of the internal structure of an object	Ask students to give practical example of radiography.
b. type of radiation used (1) X-radiation (2) gamma radiation (3) neutrons	
c. radiography (1) shadow image recorded permanently on film (2) higher quality and better resolution than fluoroscopy	
d. fluoroscopy--shadow image presented temporarily on a screen	
e. used for quality control of a process, e.g., (1) welded joints (2) seams--pipelines, etc.	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
3. Static eliminator. a. primarily alpha emitter used b. used on sheet process--removes static c. unshielded source used d. must be shielded from personnel	Slide 6.2.1.40.--Radiation Uses
4. X-ray diffraction and fluoroscent analysis. a. planes in a molecular crystal lattice will diffract X-radiation in a set pattern b. can be used to determine crystal state of material c. can be used to determine actual content of material because of absorption and emission properties	Slide 6.2.1.41.--Radiation Uses
5. Electron beam equipment. a. electron beam evaporator (1) evaporates target substance (2) evaporates substance used as coatings on glass, plastic, etc. b. electron beam welder (1) similar to evaporator only higher energy levels (2) value -high spot intensity -welded parts not contaminated by atmosphere	Slide 6.2.1.42.--Radiation Uses

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
c. electron microscope (1) high resolution (2) used by metallurgists, solid state technologists (3) specialists required to operate equipment d. primary radiation danger--X-radiation	
6. Activation analysis. a. method of determining concentration of elements in a given compound b. element bombarded, and radiation emitted by excited nuclei is measured c. each radionuclide has distinct pattern of X- and gamma radiation emission	Slide 6.2.1.43.--Radiation Uses
7. Radioactive tracers--"tagging." a. basic uses (1) study basic physical phenomenon (2) measure yield in chemical separation (3) make volume determination (4) "tag" for products in transit b. e.g., (1) irradiate piston ring and monitor wear by autoradiography (2) flow of petroleum products through pipes tagged for volume determination	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
8. Fire detectors--function with ionization chambers requiring small radioactive source.	Slide 6.2.1.45.--Radiation Uses
9. Self-luminous compounds. a. illumination of dials b. process (1) compound of phosphor (zinc sulfide) and radionuclide prepared (2) bombardment of phosphor with ionizing particles causes the phosphor to scintillate causing it "to glow"	Slide 6.2.1.46.--Radiation Uses
10. Large radiation sources. a. radiation processing (1) use of ionizing radiation to produce biological or chemical effect (2) e.g., sterilization of medical supplies, synthesis of ethyl bromide b. thermoelectric generators (1) radiation used as heat source (2) thermoelectric converters convert heat to electricity (3) must be shielded because of gamma and X-radiation and neutrons produced c. nuclear explosives	Slide 6.2.1.47.--Radiation Uses
C. Agricultural Uses	
1. Used in basically two ways. a. irradiation	Slide 6.2.1.48.--Radiation Uses--Agricultural

TOPIC	REMARKS
b. radiotracers--isotopes same, whether radioactive or not	
2. Irradiation.	
a. makes use of modification of matter by radiation	
b. all types of radiation used in agriculture	
(1) alpha--to study cellular disposition	
(2) beta--evaluation of metabolic processes, pathways of fertilizer and nutrient disposition	
(3) X- and gamma radiation--similar uses as beta emitters; more problems because of higher energy levels	
D. Medical Uses	Slide 6.2.1.49.--Radiation Uses--Medical
1. X-ray applications	
a. development of film of outline of bones, teeth, and calcified structures	
b. injection or ingestion of X-ray opaque substances to provide outlines of organ--e.g., barium sulfate ingested to provide film of intestinal tract	
2. Irradiation--destruction of diseased cells; e.g., carcinoma.	
3. Use of radionuclides.	
a. radioactive isotopes of appropriate elements introduced and disposition traced throughout body or to specific organs	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

TOPIC	REMARKS
b. e.g., (1) radioactive iodine--thyroid (2) radioactive mercury--kidney (3) radioactive chromium--spleen	
E. General Hazards 1. Exposure to radioisotopes. 2. High voltages of equipment used to create radiation; e.g., X-radiation. 3. Extraneous radiation other than that of interest; e.g., radium ^{226} may be used as an alpha source, but precautions must be taken to evaluate and control extraneous gamma radiation.	Slide 6.2.1.50.--Radiation Hazards
VII. Maximum Permissible Dose A. Not known whether a minimum threshold exists under which no damage occurs. B. Cells can spontaneously repair damage of small doses; therefore, two small doses at a given interval of time are less damaging than a single equivalent dose.	
C. Maximum Permissible Dose Equivalents 1. Accepted standard. 2. Dose equivalent unit--rem.	Slide 6.2.1.51.--MPD Equivalents Review the MPD for each of the categories, including: A. Importance of using rem as unit of measure (relate to rad and Roentgen. B. Cumulative dosage over time. C. Variation of MPD by part of body. D. Emergency dose limits. MPD values included in textbook.

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

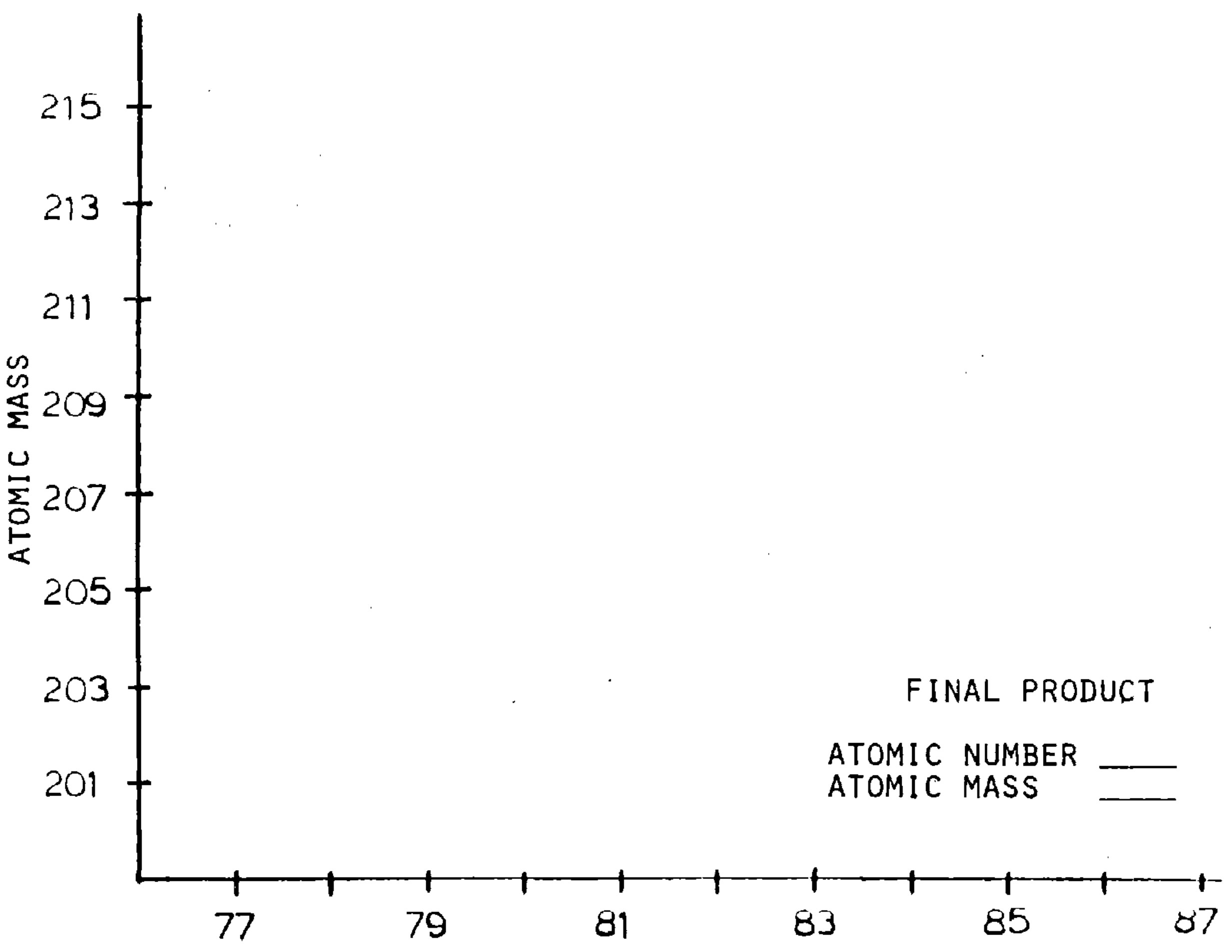
TOPIC	REMARKS
D. Maximum Permissible Concentration that would lead to exceeding MPD calculated by-- 1. Type of radionuclide. 2. Area of Exposure	Slide 6.2.1.52.--MPC Equivalents If available, show students NBS Handbook #69, "Maximum Permissible Body Burden and Maximum Permissible Concentration of Radionuclides in Air and Water for Occupational Exposure." Briefly describe use of handbook. Inform students MPD will be discussed further in later lesson.
VIII. Summary--Discussed Thus Far A. Atomic Structure B. Radioactivity C. Specific types of ionizing radiation 1. Alpha 2. Beta 3. Gamma 4. X-radiation 5. Neutrons D. Units of Measure E. Biological Effects F. Application/Hazards G. Maximum Permissible Dose	Slide 6.2.1.53.--Summary Review problem set and assign to students. Inform students when problems should be completed.

Practice Exercises

Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

1. On the graph provided, chart the radioactive decay of radioisotope $_{85}Q^{215}$ if the following types of radiation are emitted in the sequence provided. What is the atomic number and mass of the element at the end of the emissions?

    1. Alpha particle
    2. Negatron
    3. Gamma radiation and alpha particle
    4. Positron
    5. Alpha particle



Practice Exercises	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 1

2. Given that a quantity of Uranium-238 is decaying at the rate of 2.6×10^5 disintegrations per second, what amount of Uranium (in curies) would emit this activity?

3. How many disintegrations per second would be expected from a Strontium-90 with an activity of 500 curies?

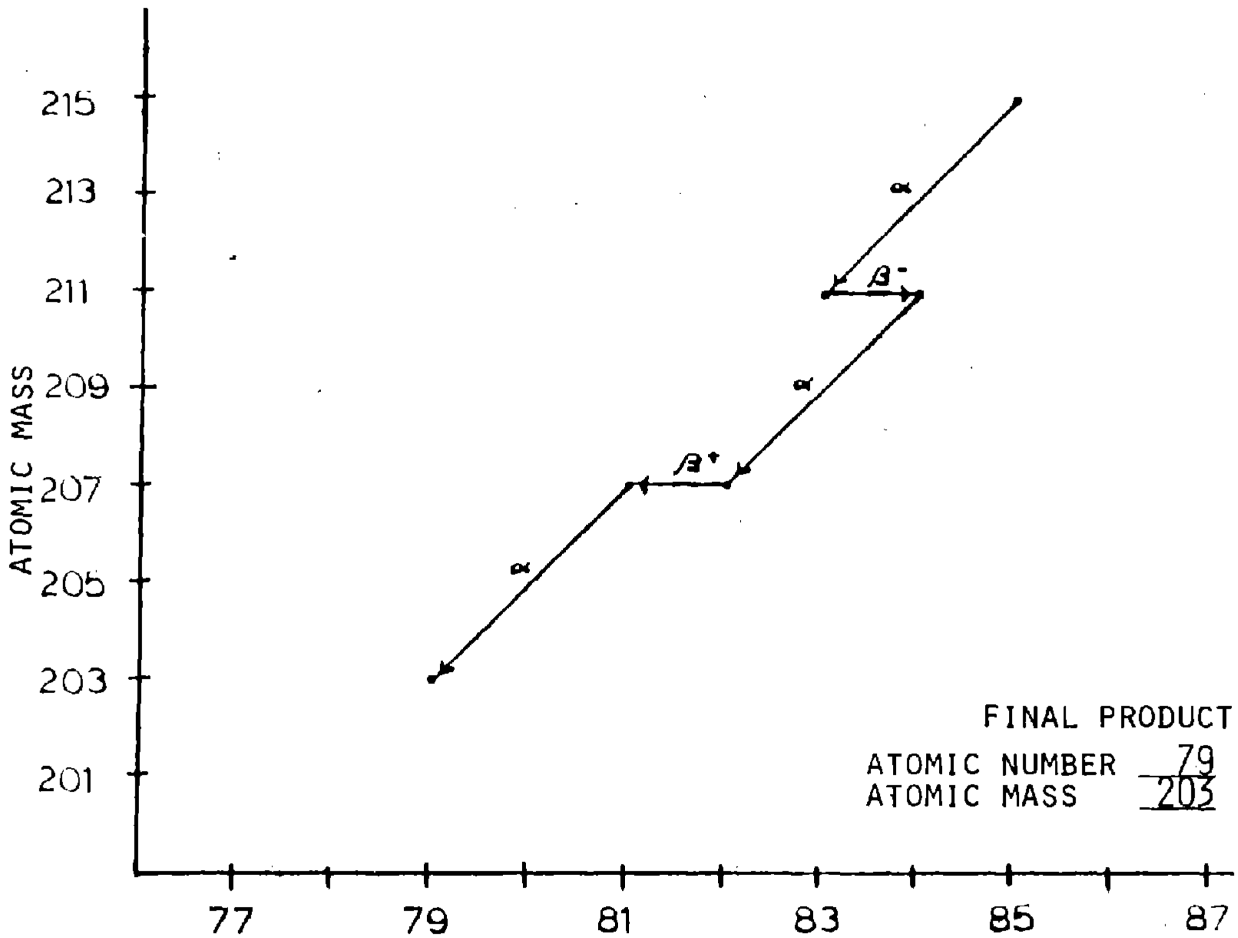
4. A beta emitter has a monitor reading of 150 mrads/hr at 0.5 cm. Calculate the dose equivalent. How many hours per week could an employee be exposed and not exceed the MPD for hand exposure over 13 weeks?

5. Assume that a radioactive source is emitting beta and gamma radiation and that monitoring equipment has indicated an absorbed and exposure rate of 2.5 mrad/hr and 12.0 mR/hr, respectively. How many hours per week could the employee remain working in this environment and not exceed the MPD value for whole body exposure over a period of 13 weeks?

1. On the graph provided, chart the radioactive decay of radioisotope $_{85}Q^{215}$ if the following types of radiation are emitted in the sequence provided. What is the atomic number and mass of the element at the end of the emissions?

    1. Alpha particle
    2. Negatron
    3. Gamma radiation and alpha particle
    4. Positron
    5. Alpha particle

    Solution:



2. Given that a quantity of Uranium-238 is decaying at the rate of 2.6×10^5 disintegrations per second, what amount of Uranium (in curies) would emit this activity?

Solution:

$$\frac{2.6 \times 10^5 \text{ disintegrations}}{\text{second}} \times \frac{\text{sec-curie}}{3.7 \times 10^{10} \text{ disintegrations}} = 7.027 \times 10^{-6} \text{ Ci}$$

3. How many disintegrations per second would be expected from a Strontium-90 with an activity of 500 curies?

Solution

$$500 \text{ Ci} \times \frac{3.7 \times 10^{10} \text{ dis}}{\text{sec-Ci}} = 1.85 \times 10^{13} \text{ disintegrations/second}$$

4. A beta emitter has a monitor reading of 150 mrads/hr at 0.5 cm. Calculate the dose equivalent. How many hours per week could an employee be exposed and not exceed the MPD for hand exposure over 13 weeks?

Solution

$$\text{rem} = \text{rad} \times \text{QF}$$

$$= \frac{150 \text{ mrad}}{\text{hr}} \times 1$$

$$= \frac{150 \text{ mrems}}{\text{hr}}$$

$$MPD_{hand} = 25 \text{ mrem/qrtr}$$

$$\frac{25 \text{ rems/13 wks}}{150 \times 10^{-3} \text{ rems/hr}} = 166.7 \text{ hours/13 weeks}$$

$$\frac{166.7 \text{ hours}}{13 \text{ weeks}} = 12.8 \text{ hours/week}$$

5. Assume that a radioactive source is emitting beta and gamma radiation and that monitoring equipment has indicated an absorbed and exposure rate of 2.5 mrad/hr and 12.0 mR/hr, respectively. How many hours per week could the employee remain working in this environment and not exceed the MPD value for whole body exposure over a period of 13 weeks?

Solution

$$QF_{(gamma)} = 1$$

$$QF_{(beta)} = 1$$

$$\therefore\ 12 \text{ mR/hr} \cdot 1 = 12.0 \text{ mrem/hr}$$

$$2.5 \text{ mR/hr} \cdot 1 = \frac{2.5 \text{ mrem/hr}}{14.5 \text{ mrem/hr}} \quad \text{- Total dose equivalent/hr}$$

For 13-week period

MPD = 3.0 for whole body exposure

$$\therefore\ \text{Total hours} = \frac{3.0 \text{ rem/13 weeks}}{14.5 \times 10^{-3} \text{ rems/hr}} = 206.9 \text{ hrs/13 weeks}$$

$$\frac{206.9 \text{ hrs}}{13 \text{ weeks}} = 15.9 \text{ hours/week}$$

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
I. Instrumentation--Introduction	
A. Radiation detection instruments operate on monitoring the effect of ionization; e.g., ions produced in a given volume of gas can be measured.	
B. No single instrument performs acceptably under all conditions and requirements.	
C. Radiation detectors most widely used include: 1. Ionization chamber. 2. Proportional chamber. 3. Geiger-Mueller counter. 4. Scintillation detector. 5. Photographic devices. 6. Solid state and activation devices.	
D. Prominent personnel monitoring devices include: 1. Film badges. 2. Pocket dosimeters. 3. Pocket ion chambers.	
E. Protection Measurements 1. Response of a detector due only to energy absorbed by detector itself. 2. Proper choice of detector can provide readings proportional to actual absorbed dose. 3. Generally, response of instrument is not <u>exactly</u> equivalent to the response of human tissue receiving the same energy--caused by secondary ionization factors. 4. However, may be assumed to be equal.	

TOPIC	REMARKS
F. Accuracy 1. Absorbed dose can rarely be determined directly; estimations must be acceptable. 2. MPD values conservative; can tolerate an accuracy of ±15%. 3. Accuracy of X- and gamma readings usually better than neutrons and particulate radiation. 4. Major efforts to increase accuracy should only be of concern if readings approximate MPD; e.g., care afforded exposed individual dependent upon dose received.	
II. Instrumentation	
A. Ionization Chamber Instruments 1. Principle a. ionizing radiation falls on chamber b. ions are formed in chamber from radiation c. primary ions are collected at the cathode and anode d. potential voltage difference is measured e. potential difference is proportional to quantity of ionizing radiation	Slide 6.2.2.1.--Ionization Chamber Demonstrate the ionization chamber instrument to the students. Be sure to discuss: A. Components of the instrument. B. Primary use. C. Range and type of radiation which can be measured. D. Meter readings; range, units. E. Adaptation required for different types of radiation. F. Steps for use.
2. Uses. a. measures relatively high level of radiation b. can measure both particulate and electromagnetic radiation c. responds to any ionization produced--difficult to discriminate between radiation types and specifically between particles of different LET	

TOPIC	REMARKS
3. Ionization chamber.	
a. usually 190-320 cm^3 in volume	
b. the larger the chamber, the greater the sensitivity and required operational voltage	
c. can be modified to measure all types of radiation	
d. usually open to atmosphere and requires corrections for ambient temperature and pressure	
e. sealed chambers may change because of leakage or absorption and adsorption on inside surface	
f. wall of chamber of critical importance--affects reading; thickness must approximate maximum range of ionized particles produced	Slide 6.2.2.2.--Ionization Chamber Wall Thickness Present information about wall thickness only to emphasize criticality of wall thickness.
g. chamber can be (1) air equivalent--measures exposure (2) tissue equivalent--simulates human tissue and is calibrated to measure absorbed dose.	Briefly describe the two types of chambers and advantages of each.
4. Advantages. a. simple, rugged device b. reliably determines absorbed dose or exposure	
5. Disadvantages. a. special design required to discriminate <u>well</u> between types of radiation b. must have general knowledge of radiation spectrum of interest	

Lesson Outline		
Monitoring Instrumentation		Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
B. Proportional Counter Instruments 1. Principle a. same as ionization chamber b. voltage increased such that secondary ionization occurs c. secondary ions contribute to ion current pulse (gas amplification d. amplification (10^3 - 10^4) increases sensitivity e. proportionality between counter current and energy fluence rate of radiation maintained 2. Uses. a. more useful in measuring particle radiation than photon radiation b. can measure alpha and beta and discriminate between the two types c. if chamber lined with boron film, thermal neutrons can be measured d. fast neutrons of low energy can also be measured e. spectrometry of low energy photon and alpha particle possible 3. Proportional counter chamber. a. choice of gas and wall construction dependent on purpose and type of measurement b. can be air or tissue equivalent c. by changing thickness of wall, one can get an indication of absorbed dose at various levels in human tissue	Slide 6.2.2.3.--Proportional Counter Demonstrate the proportional counter instrument to the students. Be sure to discuss: A. Components of the instrument. B. Primary use. C. Range and type of radiation which can be monitored. D. Meter readings; range, units. E. Adaptation required for different types of radiation. F. Steps for use.

TOPIC	REMARKS
4. Advantages. a. discrimination (1) gamma when counting neutrons (2) beta when counting alpha b. high sensitivity c. relative high accuracy and counting efficiency 5. Disadvantages. a. insulation requirements around components b. inaccuracies due to losses of absorbed energy; may decrease accuracy by 50%	
C. Geiger-Mueller (G-M) Counter	Slide 6.2.2.4.--G-M Counter
1. Used extensively as sensitive radiation detector. 2. Principle. a. similar to ionization chamber b. applied voltage increased such that secondary ionization occurs to all gas atoms in chamber c. because of secondary ionization (1) greatly increased sensitivity (2) response not generally related to type of ionizing event 3. Electrical pulse generated internally independent of type of ionizing event--response of detector cannot be related directly to either absorbed dose or exposure.	Demonstrate the G-M counter to the students. Be sure to discuss: A. Components. B. Primary use. C. Range and types of radiation which can be detected. D. Meter readings; range, units. E. Adaptations required for different types of radiation. F. Steps for use.

TOPIC	REMARKS
4. Uses. a. used to detect existence of low level radiation; e.g., 0-20 mR/hr b. under special conditions, can yield response proportional to exposure over limited ranges of photon energy c. primarily used to detect low energy beta and gamma radiation (1) separated if beta absorbing window used (2) three counts needed C_1--background C_2--windowless (gamma and beta) C_3--with window (gamma only) (3) calculate gamma = $C_3 - C_1$ beta = $C_2 - C_3 - C_1$ d. can measure gamma in the presence of neutrons 5. Characteristics. a. made in variety of shapes, sizes, and compositions--must be matched to use b. in general, sensitivity to beta dependent upon angle of incidence of radiation; i.e., G-M counter directional c. dead time--time required to initiate avalanche and for quenching to occur--may affect counter response	Briefly describe the role of "quenching gas."

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
d. G-M counter should not be used if count rate > 1000 cpm	
(1) G-M counter energy dependent	
(2) increased radiation a decrease or blockage of meter reading	Ask the students how they could tell whether a G-M counter was inoperative or blocked.
(3) G-M counter may show "no field" when in fact field may be very high.	Answer--background radiation should cause at least one count every few seconds. If no counts are registered, the counter is either inoperable or blocked.
e. G-M counters should not be used for measurement of short, high intensity pulses; may cause meter blockage	
6. Advantages.	
a. sensitivity b. generally stable and rugged c. portable	
7. Disadvantages.	
a. readings cannot be directly related to absorbed dose or exposure b. meter may block and read "no field" in high radiation field c. directional sensitivity for beta radiation	
D. Scintillation Detector	Slide 6.2.2.5.--Scintillation Detector
1. Depends on light produced when ionizing radiation interacts with a phosphor or crystal capable of producing light.	Demonstrate the scintillation detector instrument to the students. Be sure to discuss:
2. Components.	A. Components of the instrument. B. Primary use. C. Range of radiation which can be monitored. D. Meter readings; range, units.
a. scintillator--photosensitive crystal	

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
b. photomultiplier c. electronic counting equipment 3. Principle. a. ionizing radiation falls on scintillation counter b. crystal is excited and emits light c. light produced registers on photomultiplier and converted to electrical impulses d. electrical impulses magnified and registered on microammeter e. number and size of pulses related to energy deposited in the scintillator 4. Uses. a. measures gamma radiation in presence of beta--NaI crystals b. measures beta in the presence of high energy gamma--thin plastic scintillators c. soft X-rays d. alpha particles--CsI:TL crystal--radioactive sample can be placed in scintillation chamber e. most useful--alpha and low-level gamma radiation 5. Advantages. a. very sensitive instrument b. monitor low energy source 5 mR/hr above background c. can be used as spectrometer; a mixture of several radionuclides can be quantitatively and qualitatively analyzed	Be sure to discuss--continued. E. Adaptation required for different types of radiation; e.g., phosphors. F. Technique for using instrument; i.e., steps for use.

Lesson Outline

Monitoring Instrumentation	Module 6 Unit 1 Lesson 2

TOPIC	REMARKS
d. discimination between different types and energies of radiation can be made by pulse shape or height analysis e. relatively high counting efficiency; e.g., alpha and beta approach 100%	
6. Disadvantages. a. photomultiplier and crystals relatively fragile b. scintillator photomultiplier and guides must be kept in light-tight case c. some crystals used are easily damaged by moisture and humidity	
E. Photographic Devices	Slide 6.2.2.6.--Film Badge
1. Designed to provide a reasonably accurate, permanent record of cumulative exposure. 2. Principle. a. radiation interacts with silver halide in photographic emulsion b. silver ions attracted to negatively changed sensitivity center on crystal c. silver ions reduced to free silver d. during processing, silver ions are removed; free silver stays e. quantity of silver is proportional to ionizing radiation	Show students a film badge. Describe its A. Components B. Primary use
3. Range of film, dependent upon: a. characteristics of emulsion b. filtration used c. processing techniques d. type and quality of exposing radiation	

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
4. Range usually 10^3:1.	
5. Uses.	
a. personnel monitors	
b. generally used to monitor beta, neutron, and gamma radiation	
c. only beta of energy greater than 0.2 MeV can penetrate film casement	
6. Properties.	
a. usually quite small	
b. require no power supplies	
c. special holders and packs devised for various parts of the body; e.g., wrists and fingers	
7. Processing.	
a. relatively expensive; not generally cost effective for less than 200 people	
b. change badges every 2 to 4 weeks but can be changed quarterly or weekly	Ask students for a potential problem in changing badges quarterly. Answer--Accidental exposure may go undetected for a long period of time.
c. calibration films must be included in each process because of emulsion differences	
8. Advantages.	
a. permanent record	
b. size and stability	
c. can discriminate between types of radiation	
d. can be used on large populations	
9. Disadvantages	
a. dependent upon direction of incident radiation	

TOPIC	REMARKS
b. cannot assess absorbed dose and dose equivalent to within ±20%-50% for simple radiation fields	
c. calibration and processing somewhat complex	
d. film emulsion reactive to water vapor	
F. Solid State and Activation Devices	
1. Any solid material which, when irradiated, exhibits a property whose response is a function of the energy absorbed may, in principle, be used as a radiation measuring device.	
2. Physical properties discussed include: coloration, photoluminescence, thermoluminescense, photoconduction.	
3. Thermoluminescent detectors.	Slide 6.2.2.7.--Thermoluminescent Detectors
a. useful in measuring X- and gamma radiation and high energy beta particles	Briefly demonstrate photo- and thermoluminescent devices to students.
b. principle	
(1) material exposed to radiation is ionized and "holes" develop in lattice structure	
(2) material then heated to provide recombination energy	
(3) as recombination occurs, light emitted	
(4) quantity of light emitted proportional to ionizing radiation exposure	
c. typical materials include	
(1) calcium fluoride	
(2) lithium fluoride	
(3) calcium sulfate	

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
d. advantages (1) can be quite small (0.01 - 1 gram) (2) rugged and durable (3) wide range (10 mR - 10^5R) (4) minimum error (±5% - 10%) (5) reusable e. disadvantages (1) device required to "read" detector--device heats detector and then reads light emitted (2) fading--room temperature causes loss of signal $CaSO_4$--30% decrease after 8 hours; 65% decrease after 8 days	
4. Photoluminescent devices. a. similar use as thermoluminescent devices b. principles (1) same as thermoluminescent device (2) except light emitted when glass exposed to ultraviolet light c. advantages (1) range (10mR-10^3R) dependent upon type of glass (2) portable and rugged (3) reusable in some instances d. disadvantages (1) device required to "read" detector (2) fading	Slide 6.2.2.8.--Photoluminescent Devices

TOPIC	REMARKS
5. Semiconductor device. a. exposure to radiation causes change to conductivity of material b. acts as solid ionization chamber c. used to measure alpha, beta, X-, and gamma radiation d. range: 10^{-6} - 10^{-4} R/hr e. problem: somewhat temperature dependent	
6. Chemical reaction detector. a. ionization radiation may cause chemical reaction b. e.g., Frick dosimeter ($FeSO_4$)	Briefly explain operation of chemical reaction detector. Because of the importance of personnel monitoring, this section reviews the major types of detection devices used for personnel monitoring.
G. Personnel Monitoring Devices	Slide 6.2.2.9.--Personnel Monitoring Devices
1. Film badges. a. designed to provide a reasonably accurate, permanent record b. can monitor whole body or parts of the body c. problem--film must be processed to determine exposure d. discussed previously (Section E)	
2. Pocket dosimeter. a. indicates accumulated exposure to radiation at any time b. can be read by the individual c. does not provide a permanent record of exposure	Demonstrate pocket dosimeter to students.

Lesson Outline	
Monitoring Instrumentation	Module 6 Unit 2 Lesson 2

TOPIC	REMARKS
d. principle (1) primarily an ion chamber (2) must be recharged to return register to zero	
e. can be worn similar to film badge	
f. usually prepared with radiation scale to 200 mR	
3. Pocket chamber.	Demonstrate pocket chamber.
a. similar in size and shape to a fountain pen b. indicates cumulative exposure c. principle similar to an ion chamber--change in charge d. is measured on a scale calibrated in mR. e. requires separate unit to read device f. as with pocket dosimeter, unit must be periodically recharged	
III. Choice and Use of Instruments	Slide 6.2.2.10.--Summary
A. Factors affecting the selection of instruments include: 1. Direction dependence of instrument.	
2. Response rate. 3. Susceptibility to environment interference. 4. Precision and accuracy of calibration. 5. Specific use. B. Generally accepted use.	Briefly review the primary use for each instrument discussed: A. Ionization chamber B. Proportional counter C. G-M counter D. Scintillation detector E. Photographic devices F. Solid state and activation devices G. Film badges H. Pocket dosimeters I. Pocket ion chambers

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
I. Identify Radiation Safety Problems	
A. Radiation cannot be seen, felt, heard, tasted, or smelled.	
B. Can be identified and measured by instruments; can be adequately controlled.	
C. Radiation exposure can be controlled: 1. Erection of barriers and warning signs. 2. Safe operational practices. 3. Operational procedures which minimize exposure times.	Ask students which factors must be evaluated when considering safe control of radiation.
D. Consideration for Safe Control	Slide 6.2.3.1.--Consideration for Safe Control
1. Type of work. a. processing feed materials for nuclear reactors. b. application of radioactive materials--luminous instrument dials c. radiation fields occurring with X-ray machine d. thickness gauges e. static eliminators f. radioactive tracers	Review from Unit 2, Lesson 1.
2. Sources of radiation. a. amount and type of radiation important	Slide 6.2.3.2.--Consideration for Safe Control
b. varying radioactivity of radioisotope per unit activity c. sealed sources (1) vary in size (2) problems arise in potential leaks	Slide 6.2.3.3.--Radioactivity of Radioisotope

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
d. radioisotopes (unsealed sources) (1) hazard varies by isotope (1) 1 to 2 Ci--high level hazard (3) radiation sources of 0.5 mCi should be shielded if gamma and neutron radiation involved e. radioactive metals (1) vary greatly in degree of hazard (2) may be held in hand if gloves worn (3) major problem--spread of loose material (e.g., flaking, grinding chips) (4) control--e.g., glove box	
3. Operational factors. a. required level of radiation protection and potential problems which might arise can be determined--factors include: b. area involved (sq. ft.), number of rooms, buildings c. number of employees potentially exposed to radiation and location d. chemical and physical states of radioactive material and its use e. incidents likely to occur f. nonradiation hazards involved; e.g., high voltage	Slide 6.2.3.4.--Consideration for Safe Control

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
g. nature of probable exposure (1) controlled or supervised release; e.g., disposal (2) accidental release not sensed by warning devices (3) violent release of dust, droplets, gases; e.g, fire, explosion (4) spread of contamination as a result of adherence to other materials	
h. inherent danger of the material i. probability of detection of harmful situation by routine surveys or monitoring j. possible effects of accidents on operation; e.g., loss of production, loss of space, clean-up costs	
4. Potential employee exposure. a. external radiation potential b. internal radiation potential; e.g., dust in air, water contaminated	Slide 6.2.3.5.--Consideration for Safe Control Actual calculation will be described in more detail later.
II. Authorization for Radionuclide Use A. Generally, use of radionuclides and radiation-producing instruments licensed.	
1. Federal--Nuclear Regulatory Commission 2. State--Health Department; e.g., X-ray machine	Slide 6.2.3.6.--NRC Established MPC Value Point out level of radionuclides required to necessitate licensing; e.g., small sealed sources do not require licensing.

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
B. License issued after applicant defines 1. Type of radionuclide. 2. Potential use. 3. Maximum quantities involved. 4. Training and experience of users. 5. Monitoring procedures to be used. 6. Laboratory facilities. 7. Handling equipment. 8. Disposal procedure. 9. Radiation protection program. C. For specific procedures, contact NRC or State Health Department	
III. Protection of Radiation Hazard A. Goal 1. Prevent overexposure from external radiation. 2. Minimize entry of radionuclides into the body (internal radiation). B. Three basic tools which can provide protection. 1. Time. 2. Distance 3. Shielding. C. Time 1. This element of protection is self-explanatory. 2. Radiation occurs at a rate of roentgens (or rads) per hour.	Inform students survey procedure will be discussed following the section on protection.
3. The shorter the time of exposure, the smaller the radiation dose received. 4. Work procedures should be reviewed carefully to minimize time.	Slide 6.2.3.7.--Time versus Radiation Exposure

Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
5. Second factor with respect to time is half-life. If exposure potential high, may wish to wait for radioactive <u>decay to occur</u>. a. loss of strength can be calculated if original activity and date of measure are known. b. decrease of activity of source is equal to $(1/2)^n$ where n = number of half-lives which have passed since last known measurement.	Concept of half-life previously discussed.
<u>Example</u> An isotope acquired from a national laboratory in June 1977 a surplus Co-60 source which had an exposure rate of 40 mR/hr at 10 cm in January of 1970. What is the exposure rate the user could expect in June 1977?	Slide 6.2.3.8.--Example--Calculation of Half-Life Effect
<u>Solution</u> June 1977 to January 1970 = 7.5 years Half-life of Co-60 = 5.3 years Half-life $= \frac{7.5}{5.3} = 1.415$ Using $(1/2)^n$ 1.415 half-lives $= (1/2)^{1.415} = 0.375$ Exposure rate (June 1977) = $40 \text{ mR/hr} \cdot 0.375 = 15 \text{ mR/hr}$	Slide 6.2.3.9.--Solution--Calculation of Half-Life Effect Note: Inform students that tables exist which calculate $(1/2)^n$ for values of n; such a table is found in the student's textbook.
D. Distance 1. Second tool of protection. 2. Radiation source is reduced by a factor of 1 divided by the square of the distance between the worker and the source--"inverse square law."	Slide 6.2.3.10.--Distance Versus Radiation Exposure

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
3. e.g., know that radiation level is 1.0 R/hr at one ft. If the worker is moved to distance of 5 ft., exposure would now be $\frac{1}{(5)^2} \cdot 1.0$ R/hr or 0.04 R/hr Solution Radiation level 1.0 R/hr at 1 ft. R = ? at 5 ft. $\frac{1.0 \text{ R/hr}}{(5)^2} = 0.04$ R/hr at 5 ft	Place example on chalkboard.
4. Important that the distance of measurement and the units of "inverse square law" are equivalent; i.e., if exposure level determined at X feet, distance must also be in feet.	
E. Shielding	
1. Attained by placing radiation absorbing barrier between source and employee to be protected.	
2. Selection of shielding dependent upon type and amount of radiation source radionuclides.	Slide 6.2.3.11.--Typical Shielding Materials
3. Location and shape of shield. a. must limit radiation in all directions which provide potential exposure to employees b. thickness of shielding required is relatively independent of distance from source or object	
c. to minimize size of shield, maximize protection, shield should be as close to source as possible.	Slide 6.2.3.12.--Shield Position

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
d. shields may be cylindrical or box-shaped, depending on local needs	
e. local shields often built of laid bricks, concrete blocks; concern (1) cracks between blocks -stagger cracks -grooved bricks (2) scattering of beam--incident radiation	Slide 6.2.3.13.--Shield Construction
f. highly radioactive sources may require remote control (1) require leaded glass (2) distance	Slide 6.2.3.14.--Typical Remote Control System
F. Gamma Radiation Shielding 1. Purpose--reduce exposure to acceptable level. 2. Gamma radiation--photon energy with high penetration capability. 3. Shielding must be high density. 4. Typical materials used include a. lead b. iron c. concrete 5. Amount of shielding required is discussed in terms of half-value layer (HVL). 6. HVL is the thickness of material required to decrease radiation by 0.5.	Shielding requirements will be examined by type of radiation.
7. Typical materials and their HVL. 8. Possible to calculate shield effect in terms of HVL; i.e., attenuation of shield is equal to $(0.5)^n$ where n = the number of HVL of the shield.	Slide 6.2.3.15.--Typical HVL Values

Lesson Outline

Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
9. Absorption of gamma radiation by shield is an exponential function; related by equation $I = I_o e^{-ux}$ where I = exposure rate after passing through shield I_o = initial exposure rate at shield u = absorption coefficient (cm^{-1}) x = thickness of shield (cm) a. u--function of photon energy of radiation and shielding material	
b. sample table	Slide 6.2.3.16.--Mass Attenuation Coefficients Adsorption coefficient calculated by dividing mass attenuation coefficient by the density of the shielding material.
Example How many cm would be required to reduce the exposure from a Co-60 source from 10 mR/hr to 2.5 mR/hr at the same distance? (HVL Co-60 = 1.1 cm Pb)	Slide 6.2.3.17.--Example--Calculation of HVL
Solution HVL Method $\text{Decrease} = \frac{2.5\ R/hr}{10.0\ R/hr} = 0.25$ $(0.5)^n = 0.25$ $n = \frac{\log 0.25}{\log 0.5} = 2\ HVL$ $2\ HVL \times \frac{1.24\ cm}{HVL} = 2.48\ cm\ Pb$	Slide 6.2.3.18.--Solution Calculation of HVL

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
Solution Continued I/I_o Method $I = I_o e^{-ux}$ $x = \frac{\ln (I/I_o)}{u}$ $I = 2.5$ R/hr $I_o = 10.0$ R/hr	Slide 6.2.3.19.--Solution--Calculation of HVL
Using table $u = \frac{0.060 \text{ cm}^2}{g} \times \frac{11.34g}{cm^3}$ $= 0.680$ $x = \frac{-\ln(2.5/10.0)}{0.680}$ $= 2.04$ cm Pb	Table used is a table of mass attenuation coefficients. Note: $\rho(Pb) = 11.34 \text{ gm/cm}^3$
Example	Present examples to students.
An unshielded source of Cs-137 has an exposure rate of 0.1 mR/hr. What would be the exposure rate if a 3 cm Pb shield were placed around the source? (HVL Cs-137 = 0.65 cm PB) (Cs-137 = 0.66 MeV)	Slide 6.3.2.20.--Example--Calculation of Exposure Rate
Solution HVL Method $\frac{3 \text{ cm Pb}}{0.65 \text{ cm Pb/HVL}} = 4.62$ HVL present Using table $(0.5)^{4.62} = 0.041$ New exposure rate $0.1 \text{ mR/hr} \cdot 0.041 = 4.1 \times 10^{-3}$ mR/hr	Slide 6.3.2.21.--Solution--Calculation of Exposure Rate

TOPIC	REMARKS
Solution Continued I/I_o Method $I = I_o e^{-ux}$ $I_o = 0.1$ mR/hr $x = 3$ cm Extrapolated from table $u = \frac{0.105\ cm^2}{g} \times \frac{11.34\ g}{cm^3}$ $= 1.19\ cm^{-1}$ $I = 0.1 \cdot e^{-(1.19 \cdot 3)}$ $= 2.82 \times 10^{-3}$ mR/hr	Slide 6.2.3.22.--Solution--Calculation of Exposure Rate
10. In prior example, calculated value for effect of shielding different: HVL Method = 4.1×10^{-3} mR/hr I/I_o Method = 2.82×10^{-3} mR/hr a. difference occurs because determination of HVL experimental and I/I_o empirical b. I/I_o formula does not account for a build-up phenomenon--a portion of scattered photons traveling through shield reach observer c. build-up factor dependent upon geometry of source, shield, and observer	
d. typical table of dose build-up factors e. new equation $I = BI_o e^{-ux}$ where B = build-up factor	Slide 6.2.3.23.--Build-Up Factors Explain factors. Table included in student's text.

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
Example Calculate the exposure rate for the previous example allowing for the build-up factor.	
Solution I_o = 0.1 mR/hr x = 3 cm Pb $\rho(Pb) = \frac{11.34\ g}{cm^3}$ $u = \frac{0.015\ cm^2}{g} \times \frac{11.34\ g}{cm^3} = 1.19\ cm^{-1}$ Using table for ux = 1.19 x 3 = 3.57 Cs-173 (MeV) = 0.66 MeV B = 1.79 $I = (1.79)(0.1)e^{-(1.19 \cdot 3)}$ $= 5.0 \times 10^{-3}$ mR/hr	Slide 6.2.3.24.--Solution--Calculation of Exposure Rate
11. Finally, it may be of value to project potential exposure rate at a given distance. To do so, must know a. relative energies of nuclides b. activity	
Formula $mR/hr = \frac{5000\ CEf}{d^2}$, where C = activity (mCi) E = energy (MeV) f = fraction of disinteration emitting E d = distance (cm)	Slide 6.2.3.25.--Formula--Calculation of Gamma Exposure

Lesson Outline

Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC

Note:

a. if d = ft, constant = 6

b. if more than one E is given off, each E · f must be calculated and a cumulative total of the exposure made.

12. Formula has two uses.

a. calculation of exposure rate of source being used

b. in emergencies, you can calculate approximate safe distances.

Example

A 50 mCi source of Co-60 is to be used in a new industrial process being used in your facility. What is the exposure rate of an unshielded source at 25 cm?

Solution

$$mR/hr = \frac{5000\ CEf}{d^2}$$

C = 50 mCi
E = 2.5 MeV
f = 1.0
d = d5 cm

$$mR/hr = \frac{5000 \times 50 \times 2.5 \times 1.0}{(25)^2}$$

= 1000 mR/hr at 25 cm

REMARKS

Slide 6.2.3.26.--Example--Calculation of Exposure Rate

Slide 6.2.3.27.--Solution--Calculation of Exposure Rate

Constants available in Table 7.5 in textbook.

Note: Inform the students that an equivalent calculation can be made using the gamma ray constant (Γ).

$$mR/hr = \frac{\Gamma A}{d^2} \quad \text{where}$$

A = amount (mCi)
d = distance

Same example.

Γ(Co-60) = 13.0
A = 50 mCi
d = 25 cm

$$mR/hr = \frac{13.0 \cdot 50}{(25)^2}$$

= 1.04 R/hr

= 1040 mR/hr

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
G. Gamma Radiation Protection	
1. Using time, distance, and shielding, minimum exposure can be maintained.	
2. Varying any one of these factors will increase or decrease exposure.	Briefly review a Practice Exercise that requires a use of all concepts presented.
3. The exposure level can be minimized such that it is below established standards.	
H. X-Radiation Shielding	
1. Radiation produced by X-ray machine has following components:	
a. useful beam--beam directed at object	
b. scattered radiation--incident radiation reflecting off target, walls, etc.	
c. leakage radiation--radiation that penetrates tube housing not part of useful beam	
2. Degree of shielding and protection required varies.	
3. X- shielding is based on same principles as gamma shielding.	
4. Direct calculation of HVL difficult because of factors such as	
a. complexity of X-ray spectrum	
b. dependence upon width of beam	
c. factors contributing to beam scattering.	
5. Generally, better to rely on calculated values based on experiments with similar design.	Slide 6.1.2.18.--HVL for Diagnostic X-Rays

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
6. Shielding designed to limit maximum exposure to 0.1R per week at specified dose points.	
7. Evaluation of exposure produced based upon:	Inform students that this is to shield personnel outside radiographic unit.
a. output (P)--output of direct beam b. workload (W)--degree of use of machine; expressed in mamp-min/wk c. use factor (U)--fraction of workload during which radiation under consideration is pointed in direction of interest d. occupancy factor (T)--factor of occupancy of area of interest e. distance from people	
8. If output, workload, use factor, and occupancy factor known, shielding required can be determined.	Inform students tables found in literature.
a. calculate output from tube (TO)	Slide 6.2.3.29.--Average Radiologic Output
b. calculate W x U x T	
c. attenuation = $\frac{MPD}{TO \cdot WUT}$	Put steps on chalkboard.
d. using table, find HVL required e. calculate shielding required	
Example Determine thickness of lead required on the wall of a radiographic installation with personnel working 12 ft from the source on the other side of the wall with the following conditions: Kvp = 70 W = 200 mamp-min/wk U = 1 T = 0.5	Slide 6.2.3.30 --Example--Shielding Requirements--X-Ray

TOPIC	REMARKS

Slide 6.2.3.31.--Solution--Shielding Requirements--X-Ray

Solution

a. Calculate tube output (TO) (from table)

at 1 ft and 70 Kvp

TO = 4.0 R/100 mamp-sec

at 12 ft

$$TO = \frac{4.0 \text{ R/100 mamp-sec}}{(12)^2}$$

$$= 0.028 \text{ R/100 mamp-sec}$$

b. Calculate W · U · T

W = 200 mamp-min/wk
U = 1
T = 0.25

$$W \cdot U \cdot T = \frac{200 \text{ mamp-min}}{\text{wk}} \times 1 \times 0.25$$

$$= \frac{50 \text{ mamp-min}}{\text{wk}}$$

c. Calculate attenuation

$$\text{att} = \frac{0.1 \text{ R/week}}{\frac{0.028\text{R}}{100 \text{ ma-sec}} \times \frac{60 \text{ sec}}{\text{min}} \quad \frac{50 \text{ ma-min}}{\text{wk}}}$$

$$= \frac{0.1 \text{ R/week}}{.84 \text{ R/week}} = 0.12$$

d. Calculate HVL needed

$$(0.5)^n = 0.12$$

$$n = \frac{\log(0.12)}{\log(0.5)}$$

$$n = \frac{-0.9208}{-0.3010}$$

$$n = 3.06 \text{ HVL}$$

e. Using Table 5.8 (in textbook)

$$3.06 \text{ HVL} \times \frac{0.15 \text{ mm Pb}}{\text{HVL}} = 0.459 \text{ mm Pb}$$

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
	Inform students that procedure is simplified in literature, but some information is required to work with tables: 1. output 2. workload (W) 3. occupancy factor 4. directional factor (U)
9. Determination of shielding requirement for incident radiation also calculated in same manner. I. Beta Shielding 1. Protection against beta radiation is less difficult because of short range of beta particles. 2. Range--thickness of material that no beta particles emitted from source can penetrate. 3. Range of the beta particles is a function of a. energy level of the beta particle b. absorbing material 4. Any shielding greater than range stops beta particles.	
5. From literature, range in unit density material (cm) can be found. 6. Then, unit density divided by the density of the shielding material = the required shielding.	Slide 6.2.3.32.--Properties of Commonly Used Beta Emitters
Example Calculate the minimum thickness of the wall of a glass test tube required to stop all beta particles from a P-32 source. (Glass = 2.3 gm/cm^3)	Slide 6.2.3.33.--Example--Shielding Requirements--Beta

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
Solution From table Range in unit density P-32 = 0.8 cm Maximum range in glass $\frac{0.8 \text{ cm-gm}}{\text{cm}^3} \times \frac{\text{cm}^3}{2.3\text{gm}} = 0.35$ cm glass	Slide 6.2.3.34.--Solution--Shielding Requirements--Beta
7. Important consideration--shielding materials must be light (small atomic weight); e.g., Al, H_2O, glass. a. beta converts to X-radiation which is more penetrating b. more likely with heavier compounds (Pb, iron)	
J. Alpha Particles 1. Alpha particles have limited range. 2. Alpha radiation cannot penetrate the layer of dead skin. 3. Danger--alpha emitter entering body--containment required; e.g., glove box, respirator.	Slide 6.2.3.35.--Glove Box
K. Neutron Shielding 1. Concepts of HVL and attenuation of coefficients described with gamma photons also apply to neutrons. 2. Most absorption materials for neutrons are high in hydrogen content (>20%). 3. Attenuation of hydrogen per energy level is prescribed in graph. 4. Attenuation for other medium. a. calculate hydrogen density in that medium b. multiply by attenuation coefficient	Slide 6.2.3.36.--Attenuation Coefficient of Hydrogen (beside item 3)

TOPIC	REMARKS
5. Calculate HVL by HVL = 0.693/attenuation coefficient	
Example Calculate the attenuation due to hydrogen in a water shield 1.5 cm thick, 8 MeV neutrons.	Slide 6.2.3.37.--Example--Attenuation Neutron Shielding
Solution Water is 11% H_2 by weight ∴ density (H_2) = 0.11 g/cm^3 From figure For MeV = 8.0, attenuation coefficient = 0.68 cm^{-1}/1gH_2/cm For water attenuation coefficient = 0.68 x 0.11 = 0.075 cm^{-1} $HVL = \frac{0.693}{0.075} = 9.24$ cm Number of HVL = $\frac{150}{9.24} = 16.2$ Attenuation = $(1/2)^n = (1/2)^{16.2}$ = 1.3×10^{-5}	Slide 6.2.3.38.--Solution--Attenuation Neutron Shielding
6. Can be used to calculate effect of shielding. 7. Neutron activity usually leads to emission of gamma radiation; therefore, neutron shielding requires gamma shielding. Problem beyond the scope of this text.	
L. Summary--Shielding 1. Discussed shielding for a. gamma b. X-ray c. beta d. alpha e. neutron	

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
2. Generally, all shielding serves some purpose; absorb radiation. 3. Design of shield depends upon attenuation and requirements. 4. Design of shield is more sophisticated than presented but general overview provided.	Ask for questions.
IV. Survey and Monitoring Procedures for Radiation Hazards	Slide 6.2.3.39.--Survey and Monitoring Procedures
A. Purpose 1. Indicate general level of radiation in working environment. 2. Monitor changing levels of radiation.	
B. Area Survey Includes 1. Initial examination of facility. 2. Laboratory operating procedures. 3. Personnel habits. 4. Types of sources. 5. Methods used in handling sources. 6. Radiation levels.	
C. Routine Surveys Should Be Scheduled 1. To detect inadequate shielding; e.g., cracks. 2. Excessive surface and airborne contamination. 3. Improper disposal of waste. 4. Emphasis placed on unlikely and remote areas.	
D. Routine measurements should be made at intervals during conduct of work for all steps and procedures, including 1. Time of procedure and exposure 2. Distance from source.	Give examples of how exposure level, distance from source, and time of exposure may vary for a given individual.

TOPIC	REMARKS
3. Variations in exposure throughout procedure. 4. Specific areas of the body receiving more exposure.	
E. Surface Contamination	Slide 6.2.3.40.--Surface Contamination
1. Evaluated by smear (wipe) test. 2. Determines amount of loose material may become airborne or transferred to personnel. 3. Specific surface area (100 cm^2) wiped off with clean cloth, paper, or tape. 4. Smear samples removed to low background area and reading taken. 5. If area size (100 cm^2) kept constant and equipment properly calibrated, readings can be quantified. 6. Corrective action taken as necessary.	
F. Air Monitoring	Slide 6.2.3.41.--Air Monitoring
1. Sample may be collected by standard procedure using filters, electrostatic precipitators, and impingers. 2. Care must be taken to insure appropriate particles of all sizes are collected. 3. Sample of 10 m^3 is usually adequate; grab sample may be performed if necessary. 4. Direct counting from surfaces where sample collected appropriate. 5. When counting alpha particles, correction factors must be determined for absorption of alpha by sample collecting filter.	

TOPIC	REMARKS
6. In some instances, naturally occurring radon and thoron may interfere with readings; when counting alpha, adjustment must be made.	
7. Values calculated to μCi/cc and compared with MPC for unrestricted areas.	
8. If concentration known, quantity of nuclide taken in by personnel can be calculated by determining exposure time and determining the product of the exposure time, concentration, and 10^7 cc/8 hrs.	
9. If nuclide source not known, arbitrary limit.	
a. 10^{-9} μC/cc--beta	
b. 10^{-12} μC/cc--alpha	
10. In any instance where air contamination is possible, respirators should be used until radiation level determined.	
G. Water Sample Analysis	Slide 6.2.3.42.--Water Sample Analysis
1. Sampled similar to air analysis.	
2. Sample required--100-500 mL.	
3. Sample evaporated and reading taken.	
4. Results compared to MPC values.	
5. If nuclide not known, qualitative tests can determine source.	
H. Personnel Monitoring	Slide 6.2.3.43.--Personnel Monitoring
1. Most direct method of calculating personnel exposure.	
2. Common equipment.	Previously discussed.
a. film badge	
b. pocket chambers	
c. pocket dosimeter	

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
3. Personnel monitor should be matched to type and energy level of radiation. 4. Should be used when 25% of MPD for 13-week period may be exceeded. 5. More than one should be used at any given time to insure adequate. 6. Location of personnel monitor critical; should be unshielded (e.g., clothing) at a point of maximum exposure. 7. Records should be maintained concerning cumulative doses received.	
I. Fixed Monitors	Slide 6.2.3.44.--Fixed Monitors
1. Sometimes used to give <u>continuous recording</u> of dose rate at fixed location. 2. Visible or audible alarms warn of high radiation level. 3. e.g., a. doorway--if clothing contamination possible b. monitor hands and shoes on change of shift c. radiographic area	
J. Control Design	
1. Warning systems for high exposure levels. 2. Interlock systems which minimize exposure.	
V. Facilities	Slide 6.2.3.45.--Facilities Design
A. Purpose--Provide adequate containment and allow for ease of cleanup.	

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
B. Design	
1. All surfaces should be smooth and nonporous; e.g., shelves, floors, sinks.	
a. unacceptable--uncoated wood, concrete, soapstone	
b. acceptable--tiles, polished stainless steel, plate glass	
c. ordinary paints, varnishes, and lacquers are not recommended.	
2. Dust-collecting surfaces should be eliminated.	
a. lights recessed	
b. pipes enclosed	
c. shelves covered by doors	
d. cove corners between wall and floor facilitate cleanup	
e. ceilings enclosed to prevent contamination of roof trusses	
3. Special piping and drainage systems should be plainly labeled if used for radioactive waste.	
4. Design of room and shielding should prevent radiation leakage; e.g.,	
a. construction of joints	Slide 6.2.3.46.--Room Construction
b. control for doors, pipes, conduits	
c. doorway maze	Slide 6.2.3.47.--Maze
	Describe purpose of maze.
5. Special equipment often required.	
a. e.g., long-handled tools; tongs, forceps	
b. remote control devices, lead glass windows	Previously displayed. (Slide 6.2.3.14.)

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
C. Special Consideration--Design 1. Hood. a. need to minimize airborne contamination from unsealed source b. airflow should be a minimum of 100 linear feet per minute; if highly toxic, 125-150 fpm is required c. hood should have own exhaust system	Slide 6.2.3.48.--Ventilation Hood
d. air contamination should be monitored e. airflow monitored for cross drafts and leaks in system f. exhaust system--development of exhaust system previously discussed in Ventilation; same principles apply	Actual calculation will be discussed later.
2. Glove boxes. a. offer sufficient protection for alpha and soft beta rays (e.g., H^3-C^{14}) b. prevent air contamination c. hermitically sealed ports into box for gloves d. air locks allow for inserting and removing samples e. for high energy beta and gamma, gloves replaced with remote mechanical manipulator f. frequently have exhaust ports and filters--exhaust volume usually 20-30 ft^3/min g. exhaust and inlet ports should be positioned so explosion will not direct at personnel and through ports	Slide 6.2.3.49.--Glove Box

Lesson Outline

Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
D. Posting the Area	
1. Areas of radioactivity should be posted if radioactivity present for longer than 8 hrs.	
2. Sign should bear--	Slide 6.2.3.50.--Radioactive Warning Sign--Symbol
a. three-bladed radioactive caution symbol (magenta or purple on a yellow background)	
b. statement based upon level of radioactivity	
3. Signs.	
a. CAUTION RADIATION AREA--potential dose of 5 mrem/hr or 100 mrem/week	Slide 6.2.3.51.--Radiation Warning Sign
b. CAUTION RADIOACTIVE MATERIALS--for levels exceeding those described on slide	Slide 6.2.3.52.--Radiation Warning Sign
(1) in room--sign (2) on container--label	Slide 6.2.3.53.--MPC Values for Radiation Warning Sign
c. AIRBORNE RADIOACTIVITY AREA--if airborne contaminants may exceed MPC for 40 hours	Slide 6.2.3.54.--Radiation Warning Sign
d. HIGH RADIATION AREA--if dose potential greater than 100 rem/hr	Slide 6.2.3.55.--Radiation Warning Sign
4. Post operating and handling instructions.	Slide 6.2.3.56.--Recommended Handling Procedures
E. Trays and Handling Tools	
1. Work that may result in contamination of table top should be performed in box.	
2. Tweezers and tongs should be used whenever possible to minimize exposure.	

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
VI. Storage and Disposal of Radionuclides A. Storage 1. Should be stored in designated areas--protect against fire, explosion, or flooding. 2. Should be in suitable containers, adequately shielded. 3. Radiation level should not exceed 5 mrem/hr at 1 ft in storage areas. B. Limited amounts of waste may be disposed of by 1. Release into atmosphere. 2. Tidal waters, sewers. 3. Burial. C. Special waste problems can be handled by commercially licensed firm. D. Release in Air 1. Limited by NRC. 2. Rule of thumb--concentration should not exceed MPC at point of discharge. 3. MPC used--Handbook #69. 4. Can calculate released radionuclides, including different nuclides at once.	Slide 6.2.3.57.--Storage and Disposal of Radionuclides
<u>Example</u> A radiochemist released 0.1 Ci of tritium through hood while performing a synthesis. Airflow rate was 100 ft/min with a 1 ft x 4.5 ft hood opening. Was MPC exceeded if averaged over 1 week?	Slide 6.2.3.58.--Example--Calculation of Air Contamination

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
Solution Flow rate for hood calculated to be $\frac{100\ ft}{min} \times 1\ ft, \times 4.5\ ft \times \frac{28,317\ cc^3}{ft^3} \times$ $\frac{480\ min}{8\ hr\ day} \times \frac{5.0\ days}{week} = \frac{3.06 \times 10^{10}\ cc}{week}$	Slide 6.2.3.59.--Solution--Calculation of Air Contamination Assume hood operates 8 hr/day, 5 days a week
From table (Handbook #69) MPC ($^3H = 2.0 \times 10^{-13}$ Ci/cc/wk) Therefore, maximum release $\frac{2.0 \times 10^{-13} Ci}{cc/wk} \times 3.06 \times 10^{10} cc = \frac{0.006\ Ci}{wk}$ ∴ MCP exceeded	
E. Liquid Disposal 1. Liquid radioactive wastes can be deposited in unrestricted water or sewer system.	
2. Levels established by NRC must be met. a. unrestricted--public drinking water b. restricted--sewerage system 3. Both daily and monthly MPC levels must be met by radionuclide. 4. Disposal may not exceed 1.0 Ci per year total.	Slide 6.2.3.60.--NRC Established MPC Levels
Example Determine how much I-125 and P-32 can be dumped into the sewer if water flow to the sewerage (based on water bills) is $1.2 \times 10^7\ ft^3/yr$.	Slide 6.2.3.61.--Example--Water Contamination

TOPIC	REMARKS
Solution	Slide 6.2.3.62.--Solution--Water Contamination

<u>Solution</u>

From table

MPC I-125 = 4.0×10^{-12} Ci/cc

MPC P-32 = 5.0×10^{-10} Ci/cc

Average daily water flow

$$\frac{1.2 \times 10^7 \text{ ft}^3}{\text{yr}} \times \frac{\text{year}}{365 \text{ days}} \times$$

$$\frac{2.8317 \times 10^4 \text{ cc}}{\text{ft}^3} = 9.31 \times 10^8 \text{ cc/day}$$

Daily Limits

I-125

$$\frac{4.0 \times 10^{-11}\text{Ci}}{\text{cc}} \times \frac{9.31 \times 10^8 \text{ cc}}{\text{day}} = \frac{37.24\text{mCi}}{\text{day}}$$

P-32

$$\frac{5.0 \times 10^{-10} \text{ Ci}}{\text{cc}} \times \frac{9.31 \times 10^8 \text{ cc}}{\text{day}} = \frac{0.466\text{Ci}}{\text{day}}$$

A maximum of 1 Ci per year for disposal of gross activity is set. Therefore, the number of daily disposals is limited.

F. Solid Wastes

1. Three methods for disposal.
   a. incineration
   b. burial
   c. commercial company
2. Incineration.
   a. good bulk-reducing method
   b. again, regulated by NRC
   c. rule of thumb--concentration released to unrestricted areas should not exceed limits specified for continuous exposure

TOPIC	REMARKS
d. when calculating release, concentration may be averaged over a maximum of one year	
e. ash left after incineration must also be treated as radioactive waste	
f. calculation of limits for released radioactivity identical to calculating release of air as previously described; must know (1) radionuclide(s) (2) airflow	
3. Burial.	
a. NRC rules fairly simple (1) allowed 12 burials per year (2) must be at least 6 ft apart and 4 ft deep (3) total quantity buried at any location may not exceed 1000 times figures on chart (Table 5.1 textbook) (4) if several nuclides buried, the sum of nuclide fractions cannot exceed one (1)	
b. state regulations may vary--be sure to check	
Example A user of radionuclides plans to dispose of 2 mCi of Fe-59, 10 mCi of Cr-51, and 20 mCi of I-125 by burial.	Slide 6.2.3.63.--Example--Burial Procedure

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
Solution From table Can bury 1000 times value Fe-59 = 10 mCi Cr-51 = 100 mCi I-125 = 1 mCi Would use of 1.0 Ci allowed $Fe\text{-}59 = \frac{2}{10} = 0.20$ $Cr\text{-}51 = \frac{10}{1000} = 0.01$ Could bury 0.79 x 1 mCi I-125 or 0.79 mCi Therefore, I-125 could not be disposed of by burial with the other nuclides or by itself.	Slide 6.2.3.64.--Solution--Burial Procedure
VII. Personnel A. Maximum exposure limits established. B. Personnel have responsibilities to minimize exposure. C. Training. 1. NRC has established training requirements for operators. 2. Each person potentially exposed to radioactivity should receive training in a. potential danger b. operational procedures which minimize exposure c. procedures in case of accidents D. Personal Protective Clothing 1. Special clothing which can be easily laundered or disposed of should be worn if contamination possible.	Slide 6.2.3.65.--Responsibilities of Personnel

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3
TOPIC	REMARKS
2. Degree of protection required is a function of a. quantity and type of radioactivity b. nature of operation c. design of laboratory 3. Sealed containers do not usually require protective clothing. 4. Garments. a. in general, protective clothing not required if MPD for most critical organ (Handbook #69) not exceeded b. serves to prevent contamination outside laboratory facility c. low level work--requires (1) laboratory coats or coveralls (2) simple cloth or plastic bags on shoes (3) rubber or plastic gloves d. medium level work--requires (1) coveralls (2) caps (3) gloves (4) shoe covers e. high level work--requires (1) multi-layer of coveralls, shoes, etc.; clothes should be sealed (2) self-contained breathing apparatus should be used (3) should not be encountered during normal operation	

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
5. Respiratory protection. a. required when concentration in air exceeds MPD values b. respirators vary (1) simple respirators filter particles (2) self-contained breathing apparatus c. limits of respiratory equipment (1) fit of mask (2) always 1-2% leakage (3) growth of beard may affect mask fit	Slide 6.2.3.66.--Typical Respirator
6. Shielding garments. a. used for close contact work with radiation of low penetrating power b. leather and rubber effective against most beta	
c. fabrics loaded with high atomic material (Pb) used for shielding X-radiation d. should <u>not</u> be used for high level beta and gamma radiation	Slide 6.2.3.67.--Lead Gloves
E. Personal Hygiene 1. Procedures minimize exposure. 2. Eating, smoking, storage of food and pipetting by mouth prohibited in radioactive areas. 3. Work with unsealed sources requires "wash up" before eating, smoking, or leaving work area. 4. Written procedures should include hygiene practices.	

TOPIC	REMARKS
F. Personnel Monitoring 1. Discussed previously. 2. As review, any personnel who potentially may be in an area of 25% of MPD should carry personal monitoring device; e.g., film badge, dosimeter.	
G. Medical Supervision	Slide 6.2.3.68.--Medical Supervision
1. Because of physical hazards, medical supervision essential. 2. Pre-employment examination. a. identify general physical condition b. quantity, if possible, of previous radiation exposures c. identify potential problems that may be magnified or potentially dangerous to employee in radioactive environment; e.g., (1) dermatological diseases (2) impairment of pulmonary ventilation (3) cataracts d. decision of employment and placement should consider these factors 3. Periodic medical examination. a. performed at appropriate intervals based upon (1) general health of employee (2) nature of work b. provide insight of any medical changes c. should not be used as reliable method for monitoring radiation hazard	

Lesson Outline	
Principles of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
d. examination should include review of occupational hazard records and assessment of exposure doses e. medical advice should be followed with respect to continued radiation exposure 4. Follow-up examination. a. desirable to have post-employment examination b. especially important if MPD exceeded c. provides (1) extended coverage for worker (2) adds to information on effects of radiation 5. Medical records. a. should include medical and radiation exposure history b. job assignments and hazards involved should be recorded c. records of personal dose and accumulative exposure	
VIII. Radiation Accidents	
A. Maximum effort should be made to minimize accidents; e.g., 1. Review operational procedures. 2. Check equipment. 3. For nonroutine or high-level operations, trial run should be performed. a. evaluate adequacy of procedure b. determine exposure time	Slide 6.2.3.69.--Radiation Accidents

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
B. Contamination Control 1. In event of accident, loose contamination should be minimized. 2. All spills cleaned up promptly. 3. Cleaning tools should not be removed from area without decontamination. 4. Level of contamination difficult to determine; therefore, minimize contamination.	
C. Monitoring for Contamination 1. Beta-gamma--G-M counter. 2. Alpha--proportional counter. 3. "Wipe" test often performed when contamination suspected.	This is a review for students.
D. Personnel Contamination and Decontamination 1. When employee's hands, body surface, clothing, shoes contaminated, loose contamination should be removed. 2. Care must be taken to minimize spreading of contamination. 3. Washing with mild soap or detergent good initial step. 4. May wish to follow up with: a. mild abrasive soap b. complexing solution c. mild organic acid 5. When hands involved, clipping fingernails may reduce contamination. 6. In any instance, medical personnel should be notified and the employee examined. 7. Because of potential medical treatment, a relatively accurate determination of the level of exposure is appropriate.	Inform the students that a more detailed presentation on decontamination may be found in the textbook.

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
E. Reporting Accidents	
1. NRC must be notified if specified levels exceeded.	
2. NRC must be notified <u>immediately</u> if	Slide 6.2.3.70.--Immediate Notification Criteria
a. whole body exposure of individual exceeds 25 rems	
b. skin exposure exceeds 150 rems	
c. exposure of hands, feet, ankles exceeds 375 rems	
d. release of radioactive materials exceeding 5,000 times the specified limits over a 24 hour period	
e. loss of one or more working weeks due to radiation accident	
f. damage to property in excess of $100,000	
3. 24-hour notification required if	Slide 6.2.3.71--24-Hour Notification
a. whole body exposure in excess of 5 rems	
b. skin exposure exceeding 30 rems	
c. exposure of hand, feet, ankles exceeds 75 rems	
d. release of radioactive materials exceeding 500 times the specified concentration limits over a 24-hour period	
e. loss of one or more working days due to radiation accident	
f. damage to property in excess of $1,000	

Lesson Outline	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
4. Reports filed should include: a. individuals exposed b. level of exposure c. nuclides involved d. concentration of nuclide released	
IX. Responsibility of Industrial Hygienist	Slide 6.2.3.72.--Responsibilities of Industrial Hygienist
A. In some instances, industrial hygienist has direct responsibility for radioactive sources. Responsibilities include: 1. Comply with all government regulations. 2. Insure adequate supervision and training of personnel working with radioactivity. 3. Maintain inventory of radioactive sources being used, including type and amount. 4. Review operational procedures to evaluate potential a. personnel exposure b. accidents causing a release 5. Periodically survey radioactive areas for radiation levels. 6. Evaluate laboratory facility for proper design, construction, shielding, posting and labeling, etc. 7. Design alternative plans for containment and decontamination in the event of an accident. 8. Monitor disposal of wastes. 9. Supervise the monitoring system, including personnel monitoring procedures.	

Lesson Outline

Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

TOPIC	REMARKS
10. Maintain accurate records, including a. personnel exposure b. radiation surveys c. instrument calibration d. waste disposal e. radiation incidents	
X. Summary--Discussed	Slide 6.2.3.73.--Summary
A. Identifying radiation safety problem	
B. Authorization for use	
C. Protection from radiation hazards	
D. Survey and monitoring procedures	
E. Facilities	
F. Personnel	
G. Storage and disposal	
H. Radiation accidents	
I. Responsibility of industrial hygienist.	
	Ask for questions. Assign Practice Exercises

Practice Exercises	
Control of Ionizing Radiation	Module 6 Unit 2 Lesson 3

1. Because of an accident, the shielding around a 500 mCi Co-60 source has been destroyed. What is the minimum distance to the source a person can approach if a 2.5 mR/hr level is not exceeded?

2. Determine the thickness of concrete required to reduce the intensity of a Co-60 (gamma radiation) to 1/100 its value when unshielded. (Note: HVL Co-60 = 6.6 cm concrete.) Use HVL method.

3. Determine the thickness of lead (Pb) required to reduce the dose rate from a 30 mCi Cs-137 source to 5 mrem/hr at 30 cm from the source. Use formula $I = BI_0e^{-ux}$.

4. A technician in a pharmaceutical company routinely handles

    1. 500 mCi of I-131
    2. 100 mCi of Au-198
    3. 25 mCi of K-42

    all stored together in a hood. When he works in front of the hood, his mean body position is 60 cm from the active materials.

    a. How long can the technician work in front of the hood per week without additional shielding?

    b. What would be the effect on permissible working time if the technician used tongs, extending the mean body distance to 150 cm?

5. An investigator is interested in releasing 200 mCi of Xe-133 through a hood. The air velocity into the hood is 150 ft/min through an opening 15 in high and 3 ft wide. Determine the permissible release rate so that the concentration in the effluent from the hood stack does not exceed maximum allowable concentrations averaged over a 24-hour period.

6. In a new process being introduced in your plant, an I-131 (gamma source) with an activity of 300 mCi will be used. In the process, the personnel will be a mean distance of 70 cm from the source and be exposed to the source for an average of 15 minutes per day. Because of the new process, it is possible that some of the material (I-131) may become airborne as particulate matter.

<u>Calculate</u>

   a. Potential exposure of unshielded source.
   b. Lead shielding required to reduce exposure to below MPD level.

7. Prepare a list of activities which should be performed to evaluate and control the radiation hazard being introduced.

1. Because of an accident, the shielding around a 500 mCi Co-60 source has been destroyed. What is the minimum distance to the source a person can approach if a 2.5 mR/hr level is not exceeded?

   Solution

   First, calculate the exposure rate at 1 foot

   $$\text{mR/hr} = \frac{6 \cdot C \cdot E \cdot f}{d^2}$$

   $$\text{mR/hr} = 6 \cdot C \cdot E \cdot f \text{ at 1 foot}$$

   $$= 6 \cdot 500 \cdot 2.50 \cdot 1$$

   $$= \frac{7500 \text{ mR/hr}}{1 \text{ hr}}$$

   Find 2.5 mR/hr

   $$ft^2 = \frac{7500}{2.5}$$

   $$ft = \left(\frac{7500}{2.5}\right)^{\frac{1}{2}}$$

   $$= 54.7 \text{ ft} \cong \underline{55 \text{ feet}}$$

   People should not be closer than 55 feet.

2. Determine the thickness of concrete required to reduce the intensity of a Co-60 (gamma radiation) to 1/100 its value when unshielded. (Note: HVL Co-60 = 6.6 cm concrete.) Use HVL method.

   Solution

   Using attenuation table,

   reduction by 0.01 requires 6.6 HVL

   $$\therefore 6.6 \text{ HVL} \times \frac{6.6 \text{ cm}}{\text{HVL}} = 43.56 \text{ cm concrete}$$

3. Determine the thickness of lead (Pb) required to reduce the dose rate from 30 mCi Cs-137 to 5 mrem/hr at 30 cm from the source.

   Solution

   Unshielded

   $$I_o \text{ mR/hr} = \frac{500CEf}{d^2}$$

   C = 30
   E = 0.662
   f = 0.85
   d = 30

(Solution Continued)

3. (Continued)

$$I_o = 93.78 \text{ mrem/hr}$$

$$I = 5 \text{ mrem/hr}$$

$$x = \frac{-\ln(I/I_o)}{\mu}$$

Using table for mass attenuation coefficient, calculate μ.

$$\frac{0.132 \text{ cm}^2}{\text{g}} \times \frac{11.34 \text{ g}}{\text{cm}^3} = 1.50 \text{ cm}^{-1} \qquad \text{Note: } \rho Pb = \frac{11.34 \text{ g}}{\text{cm}^3}$$

Initially

$$x = \frac{-\ln(I/I_o)}{\mu}$$

$$= \frac{-\ln(5/93.78)}{1.50}$$

$$= 1.95 \text{ cm Pb}$$

Using tables, calculate build-up factors.

$$\mu = 2.925$$

$$Pb = 0.662 \text{ MeV}$$

$$\therefore \quad B = 1.67$$

Finally,

$$I = BI_o e^{-ux}$$

$$x = \frac{-\ln(I/BI_o)}{\mu}$$

$$x = \frac{-\ln\ (5/98.73 \cdot 1.95)}{1.50}$$

$$x = \underline{2.4 \text{ cm Pb}}$$

4. A technician in a pharmaceutical company routinely handles

   1. 500 mCi of I-131
   2. 100 mCi of Au-198
   3. 25 mCi of K-42

all stored together in a hood. When he works in front of the hood, his mean body position is 60 cm from the active materials.

a. How long can the technician work in front of the hood per week without additional shielding?

b. What would be the effect on permissible working time if the technician used tongs, extending the mean body distance to 150 cm?

Solution

a. mR/hr (I-131) $= \dfrac{5000 \cdot 500 \cdot E \cdot f}{(60)^2}$

$= 694.4\ E \cdot f$

$= 694.4 \times 0.3725$

$= 258.66$ mR/hr

.0116	$E_1 = 0.723$	$f_1 = 0.016$
.0439	$E_2 = 0.637$	$f_2 = 0.069$
.2985	$E_3 = 0.364$	$f_3 = 0.82$
.0165	$E_4 = 0.284$	$f_4 = 0.058$
.0020	$E_5 = 0.08$	$f_5 = 0.025$
.3725		

mR/hr (Au-198) $= \dfrac{5000 \cdot 100 \cdot E \cdot f}{(60)^2}$

$= 138.88 \cdot E \cdot f$

$= 138.88 \cdot 0.4004$

$= 55.61$ mR/hr

.0022	$E_1 = 1.088$	$f_1 = 0.002$
.0068	$E_2 = 0.676$	$f_2 = 0.01$
.3914	$E_3 = 0.412$	$f_3 = 0.95$
.4004		

mR/hr (K-42) $= \dfrac{5000 \cdot 25 \cdot E \cdot f}{(60)^2}$

$= 34.72 \cdot E \cdot f$

$= 34.72 \cdot 0.2742$

$= 9.520$ mR/hr

.0006	$E_1 = 0.31$	$f_1 = 0.002$
.2736	$E_2 = 1.52$	$f_2 = 0.18$
.2742		

Total Exposure

I-131	=	258.66 mR/hr
Au-198	=	55.60
K-42	=	9.52
		323.78 mR/hr

(Solution Continued)

4. (Continued)

Total Body Exposure

3.0 rems/13 wk

$$\frac{3.0 \text{ rems}}{13 \text{ week}} = 0.231 \text{ rems/week}$$

Total hours/week

$$\frac{0.231 \text{ rems}}{\text{wk}} \times \frac{\text{hr}}{0.324 \text{ rems}} = 0.71 \text{ hrs/week, with no shielding, 60 cm--mean distance}$$

b. $$\text{mR/hr (I-131)} = \frac{5000 \cdot 500 \cdot 0.3725}{(150)^2} = 41.39 \text{ mR/hr}$$

$$\text{mR/hr (Au-198)} = \frac{5000 \cdot 100 \cdot 0.4004}{(150)^2} = 8.90 \text{ mR/hr}$$

$$\text{mR/hr (K-42)} = \frac{5000 \cdot 25 \cdot 0.2742}{(150)^2} = 1.52 \text{ mR/hr}$$

Total Exposure (150 cm)

I-131	=	41.39 mR/hr
Au-198	=	8.90
K-42	=	1.52
		51.81 mR/hr

Total hours per week

$$\frac{0.231 \text{ rems}}{\text{week}} \times \frac{\text{hr}}{0.0518 \text{ rems}} = \frac{4.46 \text{ hrs}}{\text{week}}$$

An increase in distance by a factor of 2.5 is equivalent to a 625% decrease in exposure (inverse square law).

5. An investigator is interested in releasing 200 mCi of Xe-133 through a hood. The air velocity in the hood is 50 ft/min, through an opening 15 in high and 3 ft wide. Determine the permissible release rate so that the concentration in the effluent from the hood stack does not exceed maximum allowable concentrations averaged over a 24-hour period.

Solution

$$\frac{\text{total flow of hood}}{\text{24-hr period}} = \frac{150\ \text{ft}}{\text{min}} \times 1.25\ \text{ft} \times 3\ \text{ft} \times \frac{1440\ \text{min}}{24\ \text{hr period}} \times \frac{2.83 \times 10^{4}\ \text{cc}}{\text{ft}^{2}}$$

MAC (Xe-133) = 0.3×10^{-6} µCi/cc (from table)

$$\text{Maximum release for 24-hour} = \frac{0.3 \times 10^{-6}\ \mu\text{Ci}}{\text{cc}} \times \frac{2.292 \times 10^{10}\ \text{cc}}{24\ \text{hour}}$$

$$= 6876.0\ \mu\text{Ci/24 hours (permissible rate)}$$

$$= 6.876 \times 10^{-3}\ \text{Ci/24 hrs}$$

Note: To release 0.2 Ci Xe would require

$$\frac{0.2\ \text{Ci}}{6.876 \times 10^{-3}\ \text{Ci/24 hrs}} = \underline{29\ \text{days}}$$

Self-Test	
Nonionizing and Ionizing Radiation	Module 6

1. Define the following terms:

   a. Photon ____________________

   b. Wavelength ____________________

   c. Frequency ____________________

2. Rank the following regions of the electromagnetic spectrum from highest to lowest frequency and indicate whether they are a form of ionizing or nonionizing radiation.

Rank	Region	Ionizing	Nonionizing
____	a. Ultraviolet	____	____
____	b. Radio frequency	____	____
____	c. Infrared	____	____
____	d. Visible	____	____
____	e. Gamma	____	____
____	f. X-Radiation	____	____

3. Describe the primary difference between ionizing and nonionizing radiation.

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   ____

4. List a source and biological effect for each of the following types of radiation.

	Source	Biological Effect
a. Ultraviolet	____________	____________
	____________	____________
		____________
b. Infrared	____________	____________
c. Radio Frequency	____________	____________
	____________	

Self-Test	
Nonionizing and Ionizing Radiation	Module 6

5. Describe the operation of a klystron unit. (Draw a diagram.)

Self-Test	
Nonionizing and Ionizing Radiation	Module 6

6. Describe the operation of a typical laser unit. (Draw a diagram.) Describe the potential hazards of a laser unit.

7. What is the power density (W/cm^2) of a laser unit with

   a. power output--0.5 Joules
   b. pulse length--10^{-4} seconds
   c. focal size--0.5 mm^2

8. List at least three (3) hazards associated with ultraviolet radiation.

9. Why is it necessary for ultraviolet measurements to approximate the actinic curve?

10. Describe the procedure used to determine the effective irradiance of an ultraviolet wide band source.

11. List three (3) factors which affect the accuracy of ultraviolet source measurement.

12. Briefly describe the effect of time and distance upon exposure to electromagnetic radiation.

13. What is the beam intensity of a laser at 135 cm with

    a. power output--0.5 watts
    b. beam divergence--0.80 milliradians
    c. beam diameter--2.0 cm

14. For each class of laser, describe the criteria for classification and at least one example of an operational requirement.

Class	Criteria	Operational Requirement
I	____________	____________
	____________	____________
II	____________	____________
	____________	____________
III	____________	____________
	____________	____________
IV	____________	____________
	____________	____________
V	____________	____________
	____________	____________
	____________	____________

15. What is the difference between the "near" and "far" fields of radio frequency radiation?

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16. Calculate the radius of the "near" field for radio frequency radiation, given the area of the antenna is 100.5 cm^2 and the wavelength is 10.5 cm.

Self-Test	
Nonionizing and Ionizing Radiation	Module 6

17. List at least five (5) causes of potential radio frequency hazard.

18. List at least two (2) types of detectors used for measurement of nonionizing radiation, their use, and basic prinicple of operation.

19. Define the following terms:

    a. Atom

    b. Proton

    c. Neutron

    d. Electron

    e. Isotope

    f. Radioactive Decay

    g. Half-Life ($T_{1/2}$)

Self-Test	
Nonionizing and Ionizing Radiation	Module 6

20. Complete the following table:

	Type of Radiation Particle/Photon	Charge +,-,0	Atomic Weight amu	Penetrating Capability	Source (Machine, Decay)
Alpha					
Beta					
Photon					
Negatron					
Gamma					
X-radiation					
Neutron					

21. Define each of the following units of measure:

    a. Curie ______________________________

    b. Roentgen ______________________________

    c. rad ______________________________

    d. rem ______________________________

22. Calculate the dose equivalent for an alpha source with a reading of 150.0 μrads at 10 cm, and the maximum exposure time which would not exceed 0.23 rems/week.

23. Describe the difference between an internal and external radiation hazard. Give an example of each.

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Self-Test

Nonionizing and Ionizing Radiation	Module 6

24. List at least four (4) uses of ionizing radiation in the industrial setting.

25. List at least three (3) hazards associated with radiation use.

26. Describe the principle of operation of the G-M counter and the characteristic difference between the G-M counter, proportional counter, and ionization chamber.

27. Describe the principles of operation of the
    a. Scintillation detector
    b. Photographic device
    c. Thermoluminescent device

28. What is the primary difference between a pocket dosimeter and pocket ion chamber?

Self-Test	
Nonionizing and Ionizing Radiation	Module 6

29. Describe the purpose of shielding and an example of an appropriate shielding material for each type of ionizing radiation.

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30. Briefly describe the steps which can be taken to control

   a. Alpha ______________________________________

   b. Beta ______________________________________

   c. Gamma ______________________________________

31. Describe the procedure necessary to analyze

   a. Surface contamination ________________________

   b. Air contamination ____________________________

   ____

   c. Water contamination __________________________

   ____

32. List five (5) potential design problems which may exist in a facility using radiation.

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Nonionizing and Ionizing Radiation	Module 6

33. What steps should be taken if a person has been splashed with a solution containing a gamma/beta emitter?

Self-Test (Answers)

Nonionizing and Ionizing Radiation	Module 6

1. Define the following terms:

   a. Photon *Quantum of energy*

   b. Wavelength *Distance from peak to peak of a wave*

   c. Frequency *Number of vibrations/cycles per unit time.*

2. Rank the following regions of the electromagnetic spectrum from highest to lowest frequency and indicate whether they are a form of ionizing or nonionizing radiation.

Rank		Region	Ionizing	Nonionizing
3	a.	Ultraviolet		*x*
6	b.	Radio Frequency		*x*
5	c.	Infrared		*x*
4	d.	Visible		*x*
1	e.	Gamma	*x*	
2	f.	X-Radiation	*x*	

3. Describe the primary difference between ionizing and nonionizing radiation.

   Ionizing radiation has an energy level high enough to cause removal of electrons from atoms of absorbing materials; whereas, nonionizing radiation may cause electron excitation but cannot cause electron ejection.

4. List a source and biological effect for each of the following types of radiation.

		Source	Biological Effect
a.	Ultraviolet	*Sun*	*Erythema*
		Welding operation	*Conjunctivitis*
			Keratitis
b.	Infrared	*Molten material*	*General heating*
c.	Radio Frequency	*Telecommunication*	*General heating*
		Instruments	

5. Describe the operation of a klystron unit. (Draw a diagram.)

The operation of a klystron is relatively simple. A stream of high speed electrons is produced at the cathode. The electrons travel towards the anode; and as they pass through the accelerating grid, they increase their speed. In the buncher cavity, the electrons are modulated by a microwave field into bunches. When the bunched electrons pass the catcher grid, the electrons slow down and microwave radiation is released and the microwaves are removed by the coaxial cable. Finally, the electrons are captured at the anode. The specific radiation released is dependent upon the dimensions of the tube, the dimensions of the cavity, and the velocity of the electrons.

For diagram, see Figure 6.1.6 in textbook.

6. Describe the operation of a typical laser unit. (Draw a diagram.) Describe the potential hazards of a laser unit.

As an example, the ruby laser is discussed.

The ruby laser is excited by optical pumping which lifts the system from the ground state of the chromium ion to one of the wide adsorption bands. These absorption bands are optically wide in comparison to the sharp photon wavelength later emitted.

Once the absorption bands are excited, they quickly drop to a lower energy level by a radiationless transition. This lower energy level is actually split into two levels which are close together in energy. One of them is very long lived with a life of T = 3 milliseconds. One photon can be emitted by each state. The longer wavelength photon, which comes from the long-lived state, is more numerous. It is these photons which are emitted in a rapid pulse much shorter than the lifetime of the state which gives the high power of the ruby laser.

The ends of the ruby crystal act as the optical cavity. Once the critical level is reached, the presence of photons stimulates emission of other photons, and chromium ions return to their ground state again. Simultaneous emission of the photons forms the coherent light. This light is then transmitted through the transmissive mirror-like end of the ruby crystal tube. The entire sequence described requires approximately one-thousandth of a second. The coherent wave is produced because the critical level of photons required for stimulated emission is reached.

For diagram, see Figure 6.1.7 in textbook.

Self-Test (Answers)	
Nonionizing and Ionizing Radiation	Module 6

7. What is the power density (W/cm^2) of a laser unit with

   a. power output--0.5 Joules
   b. pulse length--10^{-4} seconds
   c. focal size--0.5 mm^2

$$\textit{power density} = 5.0 \times \frac{1}{10^{-4}} \times \frac{1}{.05 \times 10^{-2}} = \frac{10^{-6} W}{cm^2}$$

8. List at least three (3) hazards associated with ultraviolet radiation.

   1. Direct exposure--erythema

   2. Ozone production

   3. Carcinogenic catalyst

   4. Vitreus humor fluorescences

   5. Decomposition of chlorinated hydrocarbons.

9. What is it necessary for ultraviolet measurements to approximate the actinic curve?

   Specific wavelengths of UV spectrum have a relative effectiveness with respect to affecting man (e.g., erythema causing). Measurements should reflect and weight exposure according to the effect on man (actinic curve).

10. Describe the procedure used to determine the effective irradiance of an ultraviolet wide band source.

    1. Narrow band measurements taken

    2. Calculate E_{eff} using formula $E_{eff} = \Sigma E_\lambda S_\lambda \Delta\lambda$

    3. Compare to TLV levels

11. List three (3) factors which affect the accuracy of ultraviolet source measurement.

    1. Instrument must matc : spectral range of UV source.

    2. Water vapor in atmosphere.

    3. Solarization or aging of lens

    4. Directionality of meters and probes

12. Briefly describe the effect of time and distance upon exposure to electromagnetic radiation.

    Time--Exposure directly related to time of exposure; as time decreases, exposure decreases.

    Distance--"Inverse square law"

13. What is the beam intensity of a laser at 135 cm with

    a. power output--0.5 watts
    b. beam divergence--0.80 milliradians
    c. beam diameter--2.0 cm

$$I = \frac{E}{[(\pi/4)(a + \phi l)]^2} = \frac{0.5\ W}{[(\pi/4)(2.0 + 135(8.0 \times 10^{-4}))]^2}$$

$$= 0.18 W/cm^2$$

14. For each class of laser, describe the criteria for classification and at least one example of an operational requirement.

Class	Criteria	Operational Requirement
I	*Incapable of producing injury*	*None*
II	*May be viewed directly for short periods*	*Control beam direction* *Posting signs*
III	*Cannot be viewed directly*	*Eye protection* *Controlled area*
IV	*Cannot be viewed directly or exposure to reflected beam*	*Restricted area; fail safe system*
V	*Class II, III, IV encased to prevent emission of hazardous radiation.*	*Laser encasement*

15. What is the difference between the "near" and "far" fields of radio frequency radiation?

The "near" field has energy carried by magnetic and electric vector and may reflect interference of source with waves. "Far" field is primary an electric vector.

16. Calculate the radius of the "near" field for radio frequency radiation, given the area of the antenna is 100.5 cm^2 and the wavelength is 10.5 cm.

$$r = \frac{A}{2\lambda}$$

$$r = \frac{100.5\ cm^2}{2(10.5\ cm)} = 4.786$$

Self-Test (Answers)

Nonionizing and Ionizing Radiation	Module 6

17. List at least five (5) causes of potential radio frequency hazard.

    1. Improper installation--Poor location, inadequate shielding

    2. Unauthorized operating personnel

    3. Ignoring operating defects; failing interlocks

    4. Lack of personnel attention to operation

    5. Poor maintenance schedule

    6. Poor engineering design

18. List at least two (2) types of detectors used for measurement of nonionizing radiation, their use, and basic principle of operation.

    1. Thermopile--UV radiation monitoring, absorption of UV radiation causes increase in temperature and increase in voltage production.

    2. Photon devices--e.g., laser beam measure; absorption of photons converted to voltage difference, current, etc.

19. Define the following terms:

    a. Atom *Smallest particle of an element which possesses the chemical properties of that element.*

    b. Proton *Particle which is found in nucleus; has a charge of +1 and a mass of 1 amu; determines chemical property of atom.*

    c. Neutron *Particle found in nucleus; has no charge and a mass of 1 amu.*

    d. Electron *Particle found outside nucleus of an atom; has -1 charge and a mass of 5.34 x 10^{-4} amu.*

    e. Isotope *Atoms with same number of protons but different number of neutrons.*

    f. Radioactive Decay *Spontaneous transformation of atom to reach lower, more stable energy level.*

    g. Half-Life ($T\frac{1}{2}$) *Time required for 0.5 of isotopes present to decay to a new element.*

20. Complete the following table:

	Type of Radiation Particle/Photon	Charge +,-,0	Atomic Weight amu	Penetrating Capability	Source (Machine, Decay)
Alpha	*Particle*	*+2*	*4*	*Very small*	*Decay*
Beta Photon	*Particle*	*+1*	*0*	*Medium*	*Decay*
Negatron	*Particle*	*-1*	*0*	*Medium*	*Decay*
Gamma	*Photon*	*0*	*0*	*Deep*	*Decay*
X-Radiation	*Photon*	*0*	*0*	*Deep*	*Machine*
Neutron	*Particle*	*0*	*1*	*Medium*	*Fission*

21. Define each of the following units of measure:

a. Curie *Unit of activity; 3.7 x 10^{10} disintegration/second*

b. Roentgen *Unit of exposure for X- and gamma radiation*

c. rad *Unit of absorbed dose*

d. rem *Unit of dose equivalent = QF x rad (R); takes into consideration various biological effectiveness*

22. Calculate the dose equivalent for an alpha source with a reading of 150.0 µrads at 10 cm, and the maximum exposure time which would not exceed 0.23 rems/week.

$$rem = 20 \times 150.0 \times 10^{-6} \text{ rads}$$

$$= 30 \times 10^{-4} \text{ rems}$$

$$time = \frac{30 \times 10^{-4} \text{ rems}}{0.23 \text{ rems/40 hours}} = 0.52 \text{ hours or } 31.2 \text{ minutes}$$

23. Describe the difference between an internal and external radiation hazard. Give an example of each.

a. *Internal--hazard which is being emitted from within body; e.g., alpha emitter absorbed through respiratory tract.*

b. *External--hazard which penetrates the skin; e.g., gamma radiation*

Self-Test (Answers)	
Nonionizing and Ionizing Radiation	Module 6

24. List at least four (4) uses of ionizing radiation in the industrial setting.

1. radioactive tracers

2. radiation gauges

3. luminescent dials

4. radiographic analysis (X-ray)

5. electron beam equipment

6. activation analysis

25. List at least three (3) hazards associated with radiation use.

1. Direct exposure

2. High voltages of associated equipment

3. Presence of toxic substance formed because of radiation

26. Describe the principle of operation of the G-M counter and the characteristic difference between the G-M counter, proportional counter, and ionization chamber.

Ionizing radiation falls on chamber; ions formed in chamber from radiation, high voltage causes avalanche of ionization of all atoms in chamber; sequence registered on meter.

Difference: Meter reading not proportional to radiation present.

27. Describe the principles of operation of the

a. Scintillation detector *Radiation interacts with phosphor causing production of light; light production measured with photomultiplier.*

b. Photographic device *Film sensitive to various types of radiation; developed exposure proportional to radiation present.*

c. Thermoluminescent device *Crystalline material exposed to radiation; causing "holes" in lattice structure; material then heated; electrons recombine and light is emitted; quantity of light emitted proportional to radiation present.*

28. What is the primary difference between a pocket dosimeter and pocket ion chamber?

The pocket chamber requires a separate unit to be read; the pocket dosimeter does not.

Self-Test (Answers)	
Nonionizing and Ionizing Radiation	Module 6

29. Describe the purpose of shielding and an example of an appropriate shielding material for each type of ionizing radiation.

Shielding absorbs the radiation and reduces the exposure; e.g.,

Alpha--any airtight enclosure

Beta--aluminum

Gamma--lead

Neutron--water

30. Briefly describe the steps which can be taken to control

a. Alpha *Enclosure--glove box*

b. Beta *Glove box, shielding, distance, decrease exposure time.*

c. Gamma *Shielding, distance, decrease exposure time.*

31. Describe the procedure necessary to analyze

a. Surface contamination *Smear test*

b. Air Contamination *Air sampling along with calculation of contaminant concentration*

c. Water contamination *Water sampling along with calculation of contaminant concentration*

32. List five (5) potential design problems which may exist in a facility using radiation.

1. Porous surfaces

2. Dust collecting areas

3. Leakage around shielding

4. Hood design problems

5. Inadequate drainage systems for liquids

33. What steps should be taken if a person has been splashed with a solution containing a gamma/beta emitter?

If personnel contamination is suspected, first identify the contaminated areas with survey meter. Do not use decontamination methods which will spread localized material or increase penetration of the contaminant into the body (e.g., by abrasion of the skin). Decontamination of wounds should be accomplished under the supervision of a physician.

Irrigate any wounds profusely with tepid water and clean with a swab. Follow with soap or detergent and water (and gentle scrubbing with a soft brush, if needed). Avoid the use of highly alkaline soaps (may result in fixation of the contaminant) or organic solvents (may increase skin penetration by contaminant).

Use the following procedures on intact skin:

a. *Wet hands and apply detergent.*
b. *Work up good lather, keep lather wet.*
c. *Work lather into contaminated area by scrubbing gently for at least 3 minutes. Apply water frequently.*
d. *Rinse thoroughly with lukewarm water (limiting water to contaminated areas).*
e. *Repeat above procedures several times, gently scrubbing residual contaminated areas with soft brush, if necessary.*
f. *If the radiation level is still excessive, initiate more powerful decontamination procedures after consultation with the radiation protection office.*

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