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NON-IONIZING RADIATION: HAZARDS AND CONTROLS. HELD IN SEATTLE, WASHINGTON ON FEBRUARY 24-28, 1997. NIOSH 583

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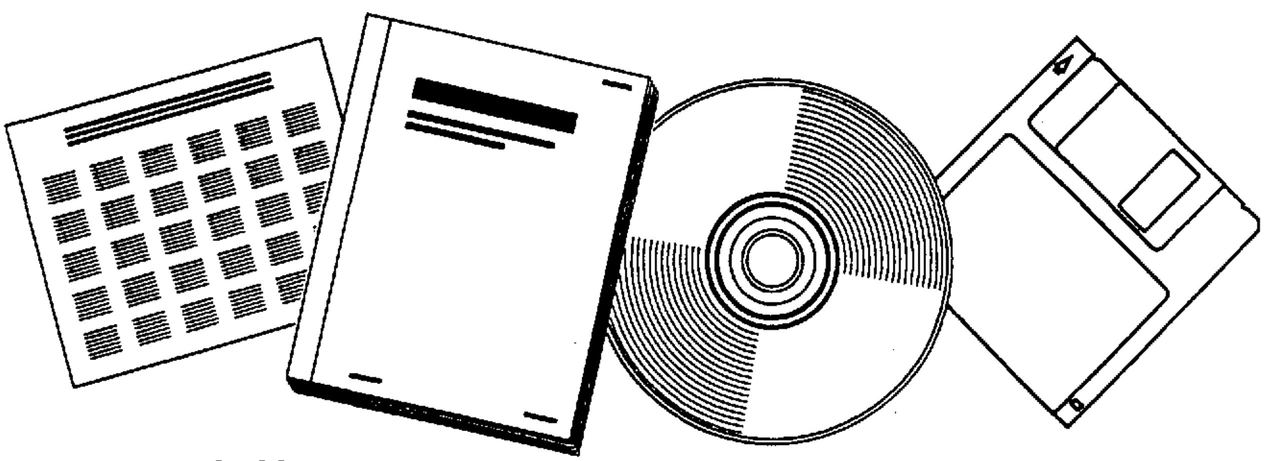

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

NIOSH 583

NON-IONIZING RADIATION: HAZARDS AND CONTROLS

February 24-28, 1997

University of Washington
Seattle, Washington

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16. Abstract (Limit: 200 words) This training course manual was developed to provide an introduction to nonionizing radiation, including both hazards and controls. Microwaves, ultraviolet, visible light, infrared and laser radiation were included. Electromagnetic fundamentals were reviewed, including the electromagnetic spectrum, waves and particle concepts, the photon concept, photoelectric effect, black body spectrum, production of electromagnetic radiation in atoms and molecules, electromagnetic radiation interactions and processes, and electromagnetic quantities and units. The microwave lesson plan provided an introduction to microwaves and then discussed various sources of microwave radiation, biological effects, microwave monitoring equipment, and control of microwave hazards. The lesson plan concerning ultraviolet, visible and infrared radiation discussed the fundamentals of the radiation, biological effects and hazards, standards and laws which regulate exposures, evaluation of hazards, and protection and control steps to be taken. The sections on lasers included the theory of operation, characteristics of lasers, laser hazards, control of hazards, evaluation of hazards, industrial uses of lasers, protective facilities and devices, operating procedures, training programs, medical surveillance, laws and regulations.

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NON-IONIZING RADIATION: HAZARDS AND CONTROLS

University of Washington

ACCREDITATION

This course has been approved for 5.0 CM points by the American Board of Industrial Hygiene.

Application for credit has been made to the Washington State Board of Registered Sanitarians.

Credit can be obtained for safety professionals by sending the course brochure and schedule to the Board of Certified Safety Professionals.

NON-IONIZING RADIATION: HAZARDS AND CONTROLS

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SUBJECT AGENDA/SCHEDULE
NIOSH583 (NON-IONIZING COURSE)

	MORNING	AFTERNOON
MONDAY	INTRODUCTIONS PRE-TEST EM FUNDAMENTALS (LECTURE)	CONCURRENT PROBLEM SESSION AND EM INSTRUMENTATION LAB.
TUESDAY	MICROWAVES - PRINCIPLES AND HAZARDS (LECTURE)	CONCURRENT PROBLEM SESSION AND MICROWAVE MEASUREMENTS LAB.
WEDNES- DAY	ULTRA-VIOLET, VISIBLE, AND INFRA-RED (LECTURE)	CONCURRENT PROBLEM SESSION AND ULTRA-VIOLET MEASUREMENTS LAB.
THURS- DAY	LASERS - PRINCIPLES AND HAZARDS (LECTURE)	CONCURRENT PROBLEM SESSION AND LASER SAFETY LABORATORY
FRIDAY	LASERS - PROTECTION AND ANSI STANDARD (LECTURE)	REVIEW, PROBLEM SESSION FINAL EXAMINATION COURSE EVALUATION

SUBJECT AGENDA/SCHEDULE
NIOSH 584 IONIZING RADIATION COURSE

	MORNING	AFTERNOON
MONDAY	INTRODUCTIONS PRE-TEST(IONIZING) IONIZING RAD. FUNDAMENTALS (LECTURE)	RADIATION LABORATORY INTRODUCTION FUNDAMENTALS CONCURRENT PROBLEM SESSION
TUESDAY	RADIOLOGICAL UNITS RADIATION SOURCES RADIATION INSTRUMENTATION (LECTURES)	CHARACTERISTICS OF GEIGER COUNTERS AND IONIZATION CHAMBERS (LABORATORY) CONCURRENT PROBLEM SESSION
WEDNES- DAY	BIOLOGICAL EFFECTS OF IONIZING RADIATION EXTERNAL SOURCES AND PROTECTION GUIDES (LECTURES)	RADIATION SURVEY LABORATORY AND CONCURRENT PROBLEM SESSION
THURS- DAY	INTERNAL RADIATION AND PROTECTION GUIDES RADIATION PROTECTION PROGRAM, AND PROTECTION PROGRAM EVALUATION (LECTURES)	RADIOGRAPHY (X-RAY MACHINE) SURVEY LABORATORY AND CONCURRENT PROBLEM SESSION
FRIDAY	LAWS AND REGULATIONS FOR IONIZING RADIATION (LECTURE) COURSE REVIEW	FINAL EXAMINATION COURSE EVALUATION

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ABSTRACT

This specialty course is an introduction to nonionizing radiation including sources, attendant hazards to personnel and the basic principles of control. Evaluation and control of laser and microwave sources are given special attention. The topical areas will include, The Electromagnetic Spectrum, Nonionizing Radiation Sources and Applications, Characteristics of Lasers, Laser Radiation Detection, Laser Hazards and Protection Standards, Laser Evaluation and Control, Measurement of Microwave Radiation, Microwave Hazards and Control, Microwave Oven Performance Standard, and Optical Radiation Hazards and Control. Using this information, the trainee should be able to: 1) identify a nonionizing radiation source and the type of radiation emitted, 2) determine the degree of the hazard to exposed personnel, and 3) apply the necessary protective procedures to reduce or eliminate the hazard to personnel. *The training course manual has been specially prepared for trainees attending the course and should not be included in reading lists of periodicals as generally available.*

LESSON PLAN NO. 13
ELECTROMAGNETIC FUNDAMENTALS

13	ELECTROMAGNETIC FUNDAMENTALS	OBJECTIVES	1

AT THE END OF THIS SESSION YOU WILL BE ABLE TO DEMONSTRATE YOUR KNOWLEDGE OF:

1. THE ELECTROMAGNETIC SPECTRUM
2. WAVE AND PARTICLE CONCEPTS OF RADIATION
3. ELECTROMAGNETIC RADIATION BY ATOMS AND MOLECULES
4. EM RADIATION INTERACTIONS & PROCESSES
5. EM QUANTITIES AND UNITS

13. ELECTROMAGNETIC FUNDAMENTALS

OBJECTIVES

At the end of this two hour presentation you will be able to demonstrate, in a problem session, your grasp of the following subjects:

1. The Electromagnetic Spectrum
2. Wave and Particle Concepts of Radiation
3. Electromagnetic Radiation by Atoms and Molecules
4. EM Radiation Interactions and Processes
5. EM Quantities and Units

This course begins with a review of Electromagnetic Radiation Fundamentals. This is material which you have studied in greater detail in your science courses at college. This review covers the facts you will need as background for the balance of the course.

USE OF UNITS IN CALCULATIONS

- **ALWAYS WRITE UNITS ALONG WITH QUANTITIES IN EQUATIONS.**
- **CANCEL UNITS AS YOU WOULD NUMBERS.**
- **THE ANSWER (IF IT IS CORRECT) WILL HAVE CORRECT UNITS.**
- **EXAMPLE:**

$$\text{DISTANCE (cm)} = \text{SPEED} \left(\frac{\text{cm}}{\text{sec}}\right) \times \text{TIME (sec)}$$

Before getting into the fundamentals of radiation protection phenomena, it is necessary to mention a few mathematical matters that will aid the student in his understanding.

First, an indispensable technique in problem solving is to write the units for each quantity in setting up equations. Then one may cancel and multiply units as though they were numbers. A correct formula will always have correct units. (However, the reverse is not always true!) For example, we know that speed times time is distance, and writing the units out shows this fact. Another example is: total radiant energy from a laser, in Joules, equals radiant flux or power, Φ, in Joules/cm^2, times the laser beam area in cm^2. Thus

$$H\ (\text{Joules}) = \Phi\ (\text{Joules/cm}^2)\ 4\pi\ [a(\text{cm})]^2$$

13	ELECTROMAGNETIC FUNDAMENTALS	MATHEMATICAL PRELIMINARIES	3

LOGARITHMS

- **DON'T BE "PSYCH'ED OUT"!**
- **LOGS ARE EXPONENTS; I.E., POWERS TO WHICH A BASE IS RAISED**
- **EXAMPLE: LOG_{10} 100 = 2, SINCE 10^2 = 100.**
- **"NATURAL LOG BASE" = e = 2.71828 . . .**
- **$\ln(e^x) \equiv x$ AND $e^{\ln x} \equiv x$**

Another mathematical concept that is useful in radiation protection is exponents, or, as they are sometimes called, logarithms. These terms frighten some people who were exposed to them long ago in high school without having had a chance to discover how useful they are.

An exponent is the power to which some number, or base is raised. If the number or base is ten, then the power is called the common logarithm of whatever value ten to this power has. Thus $10^2 = 100$, so the common log (or "log to base 10") of 100 is 2.0. It may be shown that the $\log_{10}$ of 200 is 2.30103, to 5 decimals. This means that $10^{2.30103} = 200$. Similarly, every number can be written as some power of 10. You can look up these powers or at least the decimal parts of them, in common log tables. Logs may be used in multiplication and division, but the era of pocket calculators has largely displaced them for day-to-day problem solving.

An exponential expression that is used a lot in radiation protection work involves the "natural logarithm base," denoted by e: e = 2.71828 . . . , an irrational (non repeating decimal) number. However, all the laws of logarithms also apply to use of the base e. A "natural log" of a quantity x, denoted "lnx", is the exponent of e so that $e^{\ln x} = x$. The exponential base e is used often, as it arises naturally in describing radiation absorption or shielding, or any situation where a rate of change of a quantity is proportional to the amount of that quantity. e^x is sometimes written exp(x).

13	ELECTROMAGNETIC FUNDAMENTALS	MATHEMATICAL PRELIMINARIES	4

"SCIENTIFIC" NOTATION

- **LARGE AND SMALL NUMBERS MORE EASILY WRITTEN USING POWERS OF TEN**
- **EXAMPLES: 4 MILLION = 4,000,000 = 4×10^6**
  ONE MILLIONTH = 0.000001 = 1×10^{-6}
- **ON CALCULATORS: "EE" OR "EEX" MEANS "ENTER EXPONENT" OF TEN.**
  THUS

  [3] [.] [7] [EE] [1] [0] = 3.7×10^{10}

In many technical areas, we need to work with very large or very small numbers. It is usually most convenient to express these numbers in what is called "scientific notation." This involves breaking the number up into its basic digits from one to ten and its multiplier expressed as powers of ten. Four million would be written 4×10^6: 42,600,000 would be written 4.26×10^7; etc. For very small numbers, we recall that ten to negative powers is the notation for the reciprocal. That is, one millionth is 10^{-6}, one thousanth is 10^{-3}, one tenth is 10^{-1}, etc. What is 10^0?

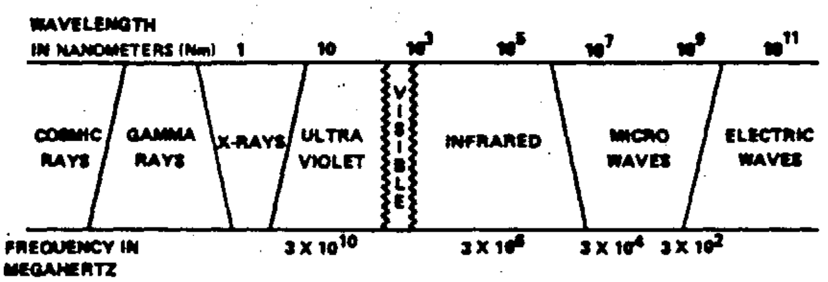
The convenience and utility of this notation is seen when one multiplies numbers in scientific notation. For example: the frequency of a microwave oven oscillator may be about 2.8×10^9 cycles per second. The velocity of the wave is 3×10^8 meters/second. The wavelength of the wave is

$$\left(3 \times 10^8 \ \frac{\text{meters}}{\text{sec}}\right) \div \left(2.8 \times 10^9 \ \frac{\text{cycles}}{\text{second}}\right) = 0.107 \text{ m}$$

Note the use of units. To multiply numbers in scientific notation we *add* the exponents and multiply the numbers.

In problem sessions in the course, you will have opportunity to use these concepts. If you have difficulties, ask the instructor; or, consult standard texts on algebra.

ELECTROMAGNETIC SPECTRUM



A. INTRODUCTION

1. Electromagnetic Spectrum

The familiar regions of the electromagnetic spectrum are radio, infrared, light, ultraviolet, X and gamma rays. Although these various emissions have different properties, they are similar in nature, being energy propagated as an electromagnetic wave. The speed of propagation is the same for all—approximately 3×10^8 m per second. They differ only in wavelength, frequency, and the amount of energy being propagated.

The wavelengths of known emissions range from approximately 150 kilometers (1000 Hertz) for long radio waves to 10^{-11} centimeters (3×10^{15} megaHertz) for high-energy x-rays.

Those portions of the spectrum referred to as microwave, infrared, and ultraviolet are important in the evaluation and control of non-ionizing radiation in industry.

The names which have been given to the various bands of electromagnetic spectrum refer primarily to the methods of generation and detection, rather than to a particular wavelength. For example, oscillation in an electrical circuit generates waves detected by a radio receiver, whereas an incandescent body emits infrared waves which in turn can be detected by a heat sensing instrument such as a bolometer.

There is no sharp division between the various types of emissions; however, through custom the spectrum has been divided into bands, the boundaries of which are somewhat arbitrary and ill defined.

The following definitions are customary: X- and gamma-rays, shorter than 1 nanometer (10^{-9} m); ultraviolet, 1—400 nm; visible, 400—700 nm; infrared, 700 nm—1,000,000 nm, i.e., up to 1 millimeter; microwaves 1 mm to 1 meter; radio waves 1 m to 10,000 m; electric waves, longer wavelengths. Other wavelength units in use include Angstroms, 10^{-10} m; and microns, 10^{-6} m.

ELECTROMAGNETIC ENERGY

WAVE CONCEPT

PARTICLE CONCEPT

2. Waves and Particle Concepts

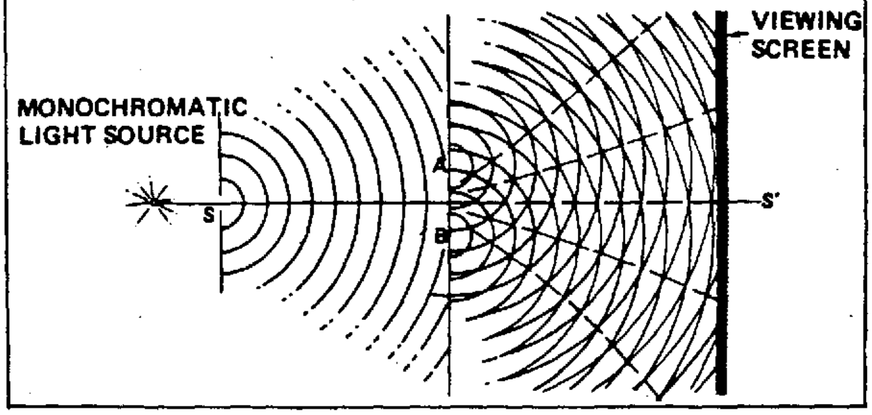
Many optical and radio phenomena can be explained by assuming that light consists of waves. Such phenomena are observed daily, for example, the effects of passing light through narrow openings, prisms or eyeglass lenses, or of reflecting light from various surfaces. However, other common phenomena involving light are more easily explained by assuming that light rays consist of small bundles of energy, called photons. For example, the operation of photocells, the emission of electrons from metal surfaces, or the detailed accounting for the distribution of colors in the sun's light spectrum are explained by the particle concept.

There seem to be two separate ways of understanding light, one in terms of waves and the other in terms of particles. This "duality" applies to all types of electromagnetic energy. Modern physics shows us that these two concepts — particles and waves — are not contradictory, but rather complementary.

In this course we shall deal briefly with both approaches. We shall start by considering the wave nature of light.

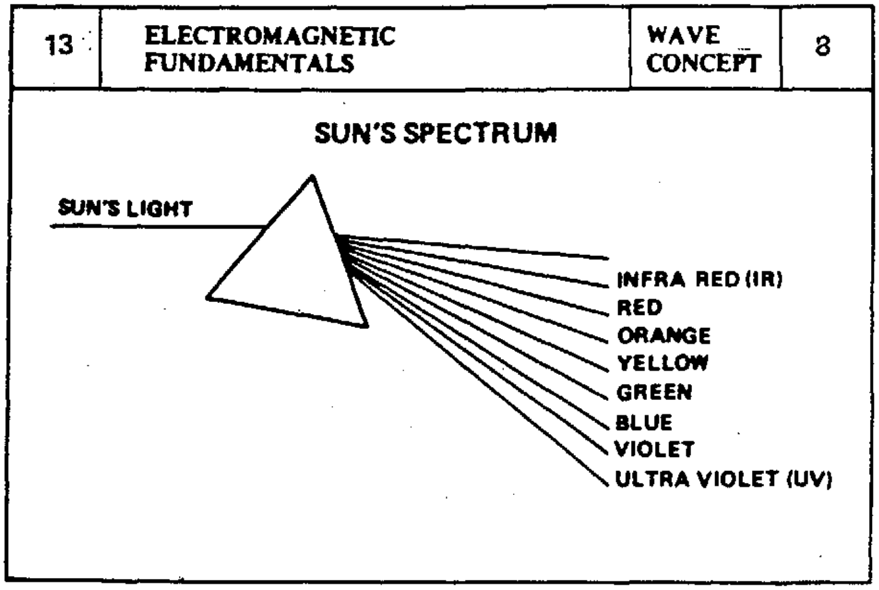
13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	7

DOUBLE SLIT DIFFRACTION



B. WAVE CONCEPT

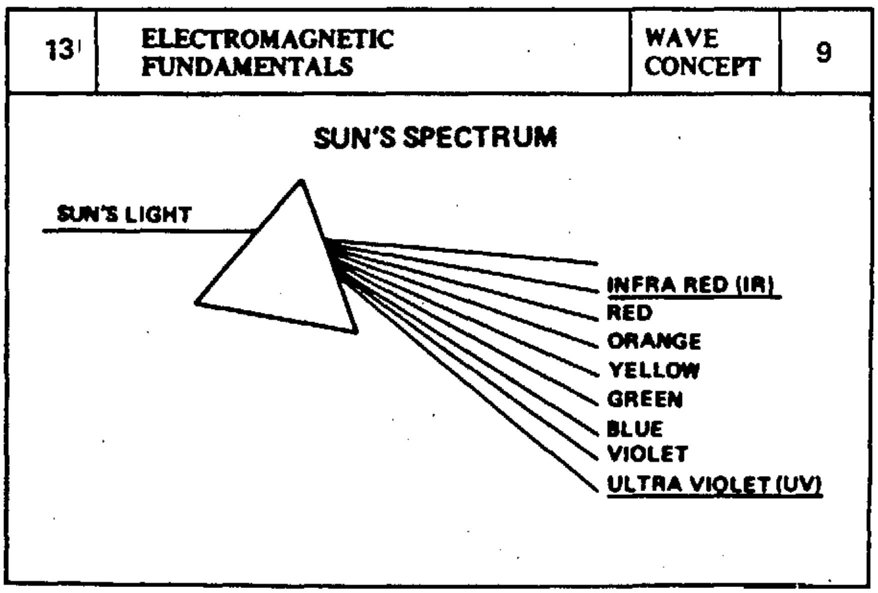
One of the early demonstrations of the wave nature of light was Young's two-slit diffraction experiment. Monochromatic light (of a single wavelength) was made coherent by passing it through an aperture, and this light was incident upon a barrier with two slit apertures, spaced a short distance apart. If light were propagating as particles, the screen should be dark. However, Young observed a succession of alternate light and dark bands, which he could explain in terms of the reinforcement and cancellation of the light waves emanating from the slits. This was considered conclusive proof in the 1800's for the wave nature of light.



1. Spectrum

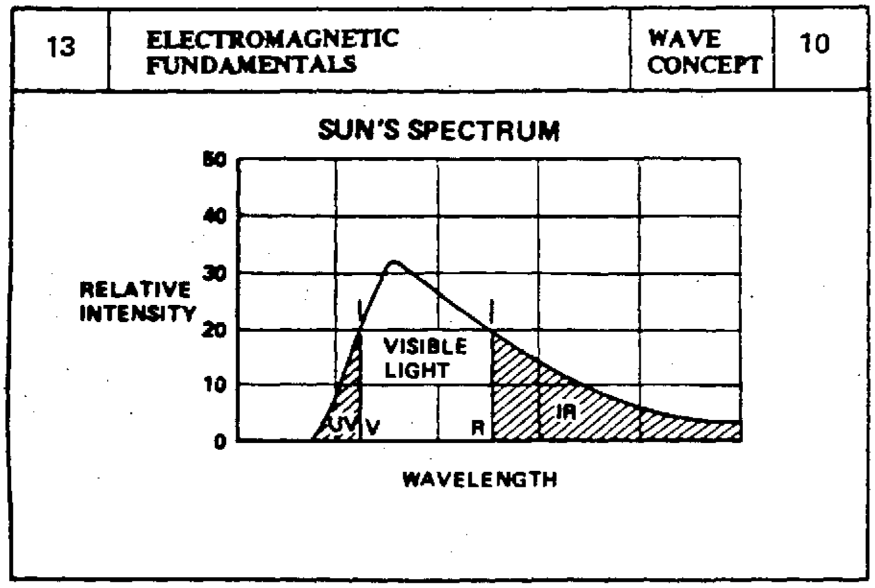
   a. Sunlight

   When a narrow beam of white light passes through triangular-glass prism, it is spread out in angle, with separated colors ranging from deep red to deep violet. This distribution of colors is called a spectrum. Normal white light, such as sunlight, consists of a mixture of all the colors in its spectrum.



If the prism we are using is made of a rather special kind of glass, and if we use some suitable detecting instruments other than our eyes, we would find that the spectrum of the sun's light extends both ways past the visible deep red and the visible deep violet. These invisible light regions are called, respectively, infra-red, or IR, and ultraviolet, or UV.

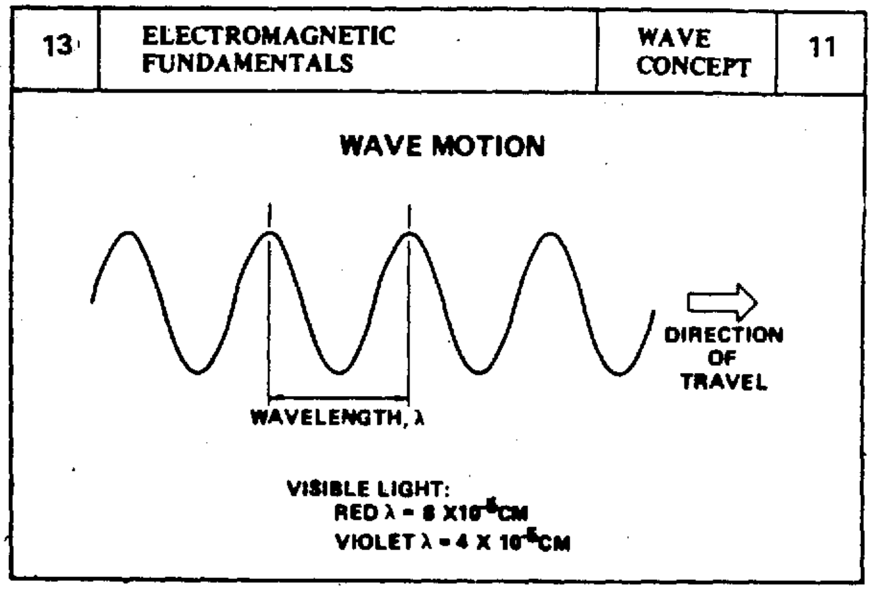
1. Spectrum



a. Sunlight (contd.)

The graph shows the intensity or light energy per unit wavelength of the sun's light in different parts of the spectrum. The horizontal axis against which intensity is plotted is the wavelength of the light.

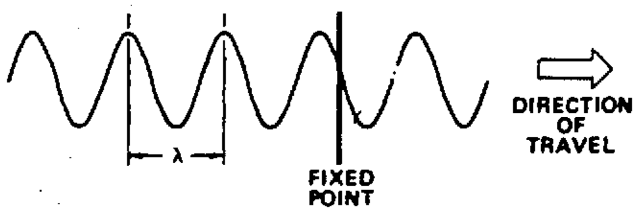
Notice that the portion of the spectrum which is visible to the eye has the greatest intensity and the maximum intensity is approximately in the middle of the visible wavelength range. Ultraviolet (UV) light, at the shorter wavelengths, is not visible to the eye. Likewise the infrared (IR) portion of the spectrum at the longer wavelengths, is not visible to the eye.



b. Wavelength

One of the reasons we think of light as wave motion is that it is possible to measure the wavelengths of light. The wavelength of any wave motion is the distance, along the direction of travel, between corresponding points of the successive waves. The usual symbol for wavelength is the lower case Greek letter lambda, λ. The wavelengths of visible light have been measured to range from about 4×10^{-5} cm for violet to 8×10^{-5} cm for red. The wavelength of ultraviolet light is therefore shorter than that of infrared.

WAVE MOTION



FREQUENCY = NUMBER OF WAVE CRESTS PASSING A POINT PER SECOND
= f OR ν (nu)

UNITS - CYCLES PER SECOND
= HERTZ (Hz)

1. Spectrum (contd.)

   c. Frequency

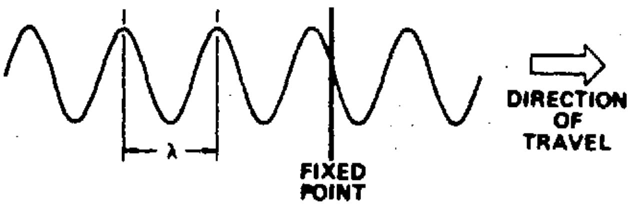
   The number of waves that pass a fixed point during an interval of time is known as the wave frequency. Frequency is normally measured as the number of wave crests that pass the fixed point in one second. Sometimes we speak of "cycles per second." It is now most common to call cycles per second by the single word "Hertz" (abbreviated Hz). One wave or one cycle passing a fixed point in one second would have a frequency of 1 Hz.

   The commonly used symbols for frequency are f and the lower case Greek nu (ν). The symbol f will be used here but ν appears often in handbooks and in reference texts.

   The period of a wave is the time it takes to pass a fixed point. Period, usually indicated by the capital letter T, is the inverse of frequency so that: $T = 1/f$.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	13

WAVE MOTION



- FREQUENCY, = f
- VELOCITY, V = λ x f (CM/SEC)
- VELOCITY OF LIGHT IN A VACUUM
  $C = 3 \times 10^{10}$ CM/SEC

1. Spectrum (contd.)

   d. Velocity

   If a wave passes a fixed point, having wavelength λ and frequency f, it must have a velocity given by the formula: V = λ x f.

   (This is derived from the fact that f waves each λ cm long pass the point each second.) The symbol for wave velocity is often V; however, the velocity of light in a vacuum is indicated by the lower case letter c.

   The velocity of light in a vacuum has been measured quite accurately, and is very close to 3×10^{10} cm/sec, or 3×10^{8} m/sec. Electromagnetic radiation has a velocity of c.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	14

LIGHT WAVE FREQUENCY

$$f = \frac{C}{\lambda_{\text{RED LIGHT}}} = \frac{3 \times 10^{10}\ \text{CM/SEC}}{8 \times 10^{-5}\ \text{CM}} = 3.75 \times 10^{14}\ \text{Hz}$$

$$f = \frac{C}{\lambda_{\text{VIOLET LIGHT}}} = \frac{3 \times 10^{10}\ \text{CM/SEC}}{4 \times 10^{-5}\ \text{CM}} = 7.5 \times 10^{14}\ \text{Hz}$$

$$C = 3 \times 10^{10}\ \text{CM/SEC} = f \cdot \lambda$$

   e. Velocity (and Frequency)

   Using the formula shown, and the wavelengths for light given earlier, the frequency of deep red light can be found to be:

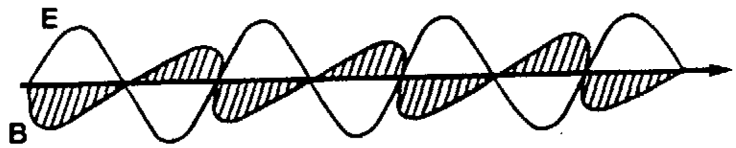
$$f_{red} = c/\lambda_{red} = \frac{3 \times 10^{10}\text{cm/sec}}{8 \times 10^{-5}\text{cm}} = 3.75 \times 10^{14}\ \text{Hz},$$

   and of deep violet light,

$$f_{violet} = c/\lambda_{violet} = \frac{3 \times 10^{10}\ \text{cm/sec}}{4 \times 10^{-5}\text{cm}} = 7.5 \times 10^{14}\ \text{Hz}$$

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	15

EM FIELD PROPAGATION



- CHANGING MAGNETIC FIELD (B) PRODUCES ELECTRIC FIELD (E)
- CHANGING ELECTRIC FIELD (E) PRODUCES MAGNETIC FIELD (B)
- RESULT IS E-M FIELD PROPAGATION VELOCITY PERPENDICULAR TO E- AND M-FIELDS
- VELOCITY DEPENDS ON E AND M PROPERTIES OF MEDIUM

2. Other Characteristics of Electromagnetic Waves

   a. EM Field Propagation

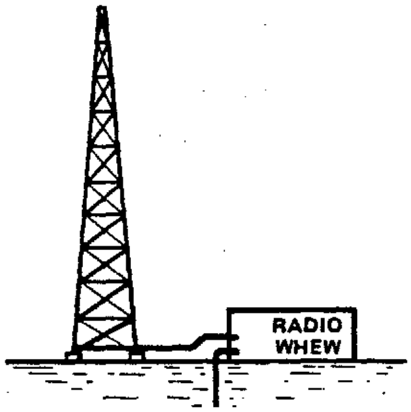
After considering the charts showing waves, it might be asked, of what is an elec-magnetic wave composed? That is, if the wave amplitude (same frequency and wave-length) were larger, what would there be more of? If we were dealing with water waves, amplitude would be wave height above the average water level. In the case of EM waves, the quantity that is varying periodically is the "electromagnetic (EM) field."

The EM field consists of two inter-related and interdependent entities, namely, an electric field and a magnetic field. A field is an entity in space that can exert a force; an electric field can exert a force upon an electric charge, e.g., upon an electron. A magnetic field can exert a force upon a moving charge or current. In the 19th centery, Maxwell developed the electromagnetic theory, based upon earlier discoveries, which states that (a) a changing (time-varying) magnetic field (B) induces a perpendicular electric field (E), and (b) a changing electric field (E) induces a perpendicular magnetic field (B). Thus the two fields produce one another and propagate as a single entity, the EM field, or EM waves, along a direction that is mutually perpendicular to the E and B fields, and with a velocity determined by the electric and magnetic properties of the medium of travel.

An electron in an EM field will feel an oscillatory force in the plane of the E-field. It will move up, then down, then up again as the varying E field moves past it.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	16

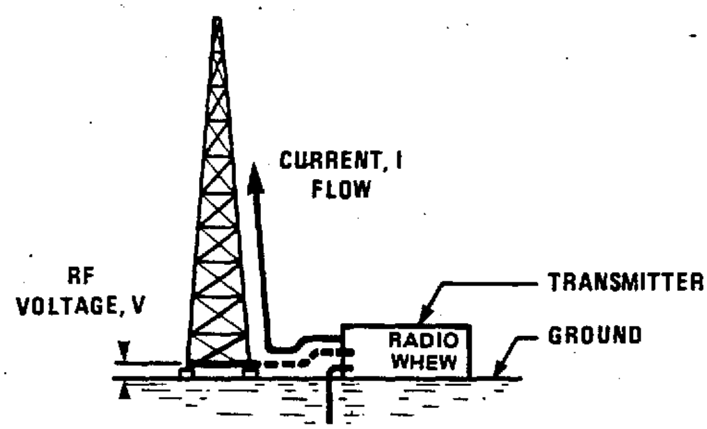
RADIO ANTENNA



As an example of the EM field quantities just described, consider a radio transmitting antenna and how it produces EM waves.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	17

RADIO ANTENNA CURRENT DRIVE

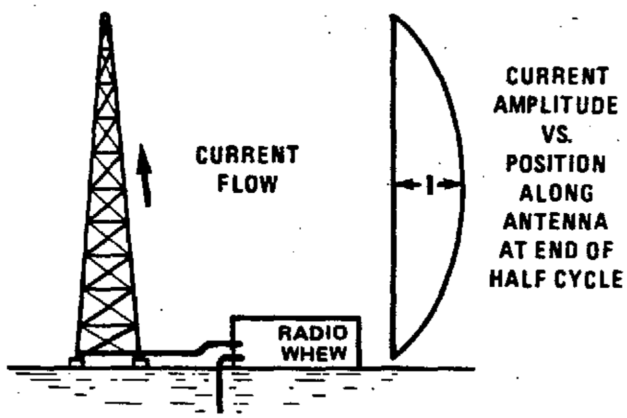


A transmitter, or power source, in the station produces an oscillatory radio frequency (RF) high voltage that is capable of driving large currents through an appropriate load. In this case the load is the antenna, a tall metal tower, insulated from the ground.

At the beginning of a RF cycle the transmitter starts to drive electric charges up the antenna, i.e., to inject current into the antenna. At this instant the transmitter, at the bottom of the tower, has no way of knowing that the electric charges it is pushing into the antenna will be able to go only as far as the top of the antenna, i.e., that there is not a complete circuit for current flow. A quarter cycle later, the current at the antenna base is flowing at a maximum rate, and then it begins to flow less until, at the end of a half RF cycle, the current at the base is zero again.

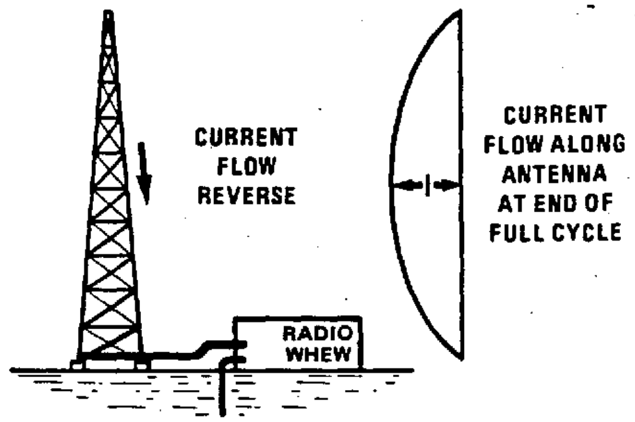
13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	18

RADIO ANTENNA CURRENT WAVE PATTERN



The charge pumped into the tower, meanwhile, has travelled up and found the open circuit, so the antenna is at this instant highly charged electrically. (The antenna was designed to be just the right length so that when the first electrons reach the top, the oscillator at the bottom has just completed its half cycle.) The current pattern along the antenna at this instant is shown; it looks like a half sine wave.

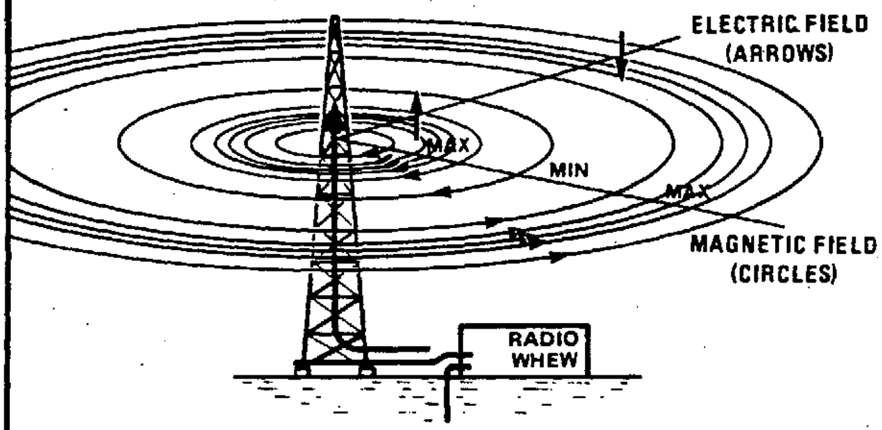
RADIO ANTENNA CURRENT WAVE PATTERN



As the oscillator-transmitter reverses its voltage for the second half of the RF cycle, the charges on the antenna flow back down, making a current in the opposite direction. This cyclic current flow process then repeats itself for each successive radio frequency cycle.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	20

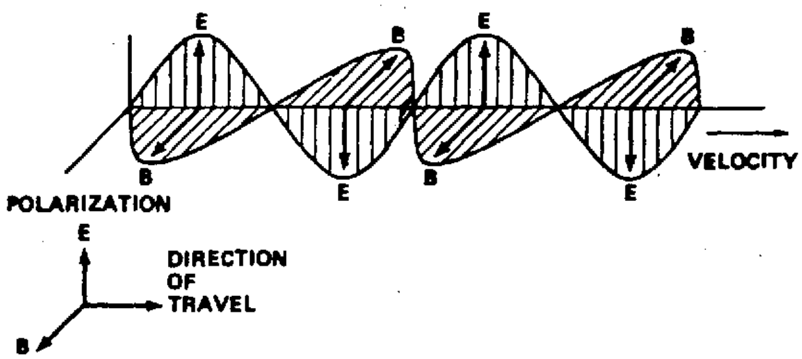
RADIO WAVE PRODUCTION AND PROPAGATION



Now consider the region around the antenna in which this time varying current is flowing. A current flow produces a magnetic field around the antenna as shown. It is changing "B" field ("B" usually is used to denote magnetic flux density, which is proportional to field strength). A changing B field, according to Maxwell's Laws, produces an "E" field ("E") usually refers to the Electric field strength). Another way to think of it is that charges on the tower cause an E-field, since they can exert forces on other charges near the tower, and since these charges are moving, the E field varies. These two ways of thinking about the process are equivalent. There result changing E and B fields from the process of driving the charges up and down the antenna tower. These fields propagate, as we discussed earlier, as radio waves away from the tower as indicated. The direction of the E-field is essentially that of the tower direction, in this case vertical.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	21

RELATIONSHIPS BETWEEN THE DIRECTIONS OF THE ELECTRIC FIELD, THE MAGNETIC FIELD AND THE DIRECTION OF PROPAGATION



b. Transverse Waves and Polarization — Near and Far Fields

At a long distance from the antenna, in what is called a "far-field" situation the E and B fields propagate as shown, mutually perpendicular to the velocity. This is called a "transverse" wave. The direction of the E-field is called the "polarization" of the wave, and what is shown is called a "plane polarized" wave. The E- and B-fields are in phase, i.e., are zero at the same points in space and time.

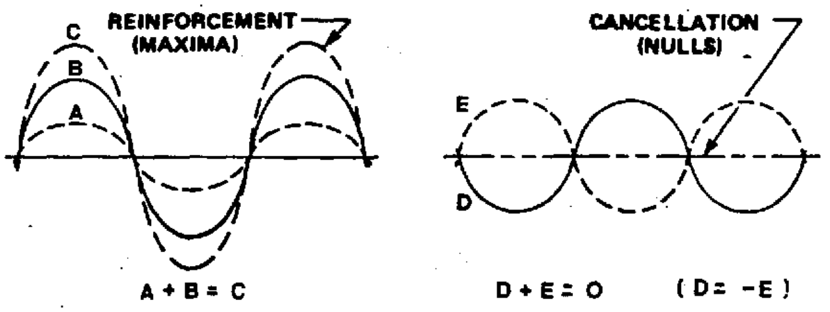
All EM waves need not be plane polarized. Radiation generated by incandescence or which has been scattered or reflected in certain ways may exhibit random polarization, with E field vectors oscillating in planes with all possible orientations. Such radiation is "unpolarized," and sunlight in the atmosphere is a common example. Some microwave antennas are designed to produce E fields that rotate in space, having what is called "circular" or "elliptical" polarization.

Compare the propagation of transverse waves shown in the above chart with the situation near the radio tower in the previous chart. Notice that at distances close to an antenna, the E field and B field are typically not well-established into perpendicular spatial nor in-phase time relationships such as those shown here. This is the so-called "near-field," to be discussed further later. Note that many industrial microwave hazard situations involve near-field phenomena, i.e., people may be exposed close to the radiation source.

13	ELECTROMAGNETIC FUNDAMENTALS	WAVE CONCEPT	22

SUPERPOSITION OF WAVES

- ADDITION OF WAVES OF THE SAME FREQUENCY & POSITION
- ADD DIRECTIONS & AMPLITUDES



c. Superposition of Waves

When EM waves (or any type waves) of the same frequency travel together in the same space and time frame, the resulting E-field at any point and time is found by adding the separate E-field vectors (magnitudes and directions) at that point and time. This is called superposition. This may lead to cancellation or nulls of fields at some places (zero E-field strength), and reinforcement of fields elsewhere, or maxima. If these nulls and maxima remain fixed in space, we have what is called a standing wave pattern. To superimpose, or add waves at an instant, they must: (a) have the same frequency, and (b) be at the same position in space.

d. Review of Wave Concept

At this point the student should review the first chart, Electromagnetic Spectrum, and the third chart, the Two Slit Diffraction Experiment, and gain some additional understanding of the wave nature of light. Note the wide extent of the EM spectrum, from very short to very long wavelengths. Can you explain the result of the diffraction experiment using the wave theory? (Hint: Think about superposition of waves.)

C. THE PARTICLE CONCEPT OF RADIATION

13	ELECTROMAGNETIC FUNDAMENTALS	PARTICLE CONCEPT	23

- EM RADIATION IS VIEWED AS PACKETS OF ENERGY CALLED PHOTONS
- THE ENERGY OF A PHOTON IS: (PLANCK'S CONSTANT) X (FREQUENCY)

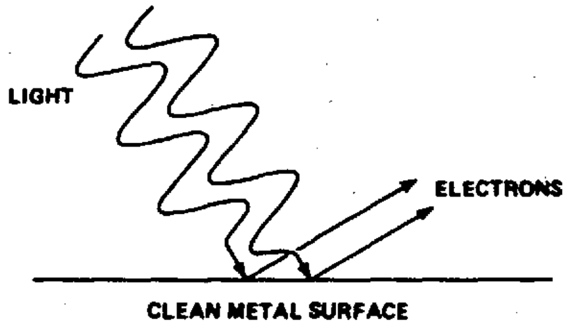
1. The Photon Concept

There are a large number of experiments that cannot be understood in terms of the wave model of electromagnetic radiation. Radiation in these cases is imagined to be propagated as discrete packets or photons. This is called the Quantum theory of electromagnetic radiation.

A fundamental relationship exists between the energy of a photon in the particle concept and its frequency in the wave concept. The energy of a photon (E) is equal to a constant (h) multiplied by the frequency (f). This constant is named in honor of Max Planck and has a numerical value of 6.63×10^{-34} joules/sec. The relation $E = hf$ is the basis for explaining certain physical phenomena such as the photoelectric effect.

13	ELECTROMAGNETIC FUNDAMENTALS	PARTICLE CONCEPT	24

PHOTOELECTRIC EFFECT



2. Photoelectric Effect

While many electromagnetic and optical observations are simply explained by considering EM radiation to consist of moving waves of self-propagating electromagnetic fields, there are other phenomena that seem to contradict the wave theory. Photoelectric effect is one such phenomenon. If light of a high enough frequency is made to shine on a specially prepared surface of a metal, electrons are emitted from that surface.

It is observed that the emitted electrons (called photoelectrons) have energy depend-upon only the wavelength of the incident light. More intense light produces more electrons, but they have the same energy. Also there is a threshold value of wavelength, characteristic of the metal, above which the photoelectric effect ceases.

The wave theory cannot explain these facts. The "quantum" theory developed (by Max Planck in the early 1900's) does explain them, as follows: (a) light is absorbed only in certain discrete amounts of energy

$$E = hc/\lambda,$$

called "quanta." (b) The observed kinetic energy (KE) of the photoelectron is equal to the quantum energy minus the work function, W, or energy required to pull an electron out of the metal surface. The formula is

$$KE = hc/\lambda - W.$$

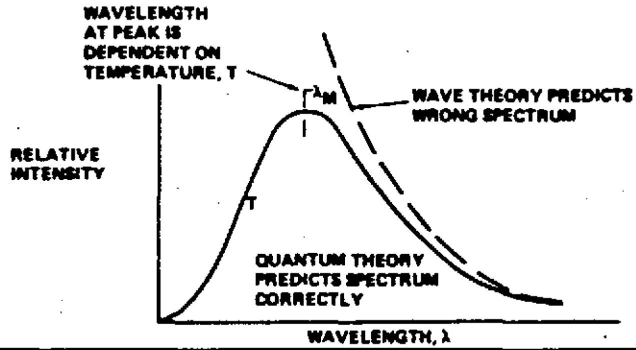
The bundle of energy absorbed is called a "photon," or quantum of light energy. The relationship between the light frequency, wavelength and its associated photon energy is

$$E_{photon} = hf = hc/\lambda,$$

where h is Planck's constant, 6.6×10^{-34} joule-seconds, and c is the velocity of light.

13	ELECTROMAGNETIC FUNDAMENTALS	PARTICLE CONCEPT	25

BLACK BODY RADIATION SPECTRUM



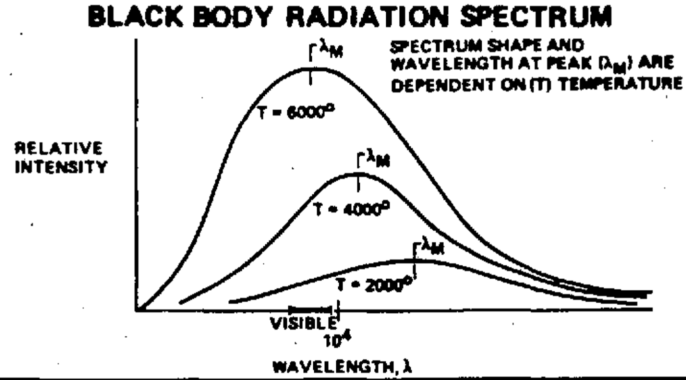
3. Black Body Spectrum

Another observation that cannot be explained with the wave theory of EM radiation is the detailed shape of the wavelength spectrum from a hot radiating object.

A surface that is so black that it absorbs all radiation coming to it, without reflecting any at all, is called a "black body." This is an ideal or theoretical concept. A black body will also radiate energy in the form of electromagnetic radiation and has a characteristic spectrum dependent upon the temperature of the black body.

13	ELECTROMAGNETIC FUNDAMENTALS	PARTICLE CONCEPT	26

BLACK BODY RADIATION SPECTRUM



The wave theory of electromagnetic radiation predicts that the intensity of black body radiation should increase at short wavelengths. This directly contradicts experimentally observed data for black body radiation in which the intensity has a maximum at some wavelength (depending on temperature) then falls off to zero intensity at short wavelengths.

Max Planck was able to derive a mathematical expression which correctly described the black body spectrum by assuming that energy is absorbed and reemitted in quanta or particles.

13	ELECTROMAGNETIC FUNDAMENTALS	PARTICLE CONCEPT	27

COMPLEMENTARITY

- WAVE - PHOTON DUALITY
- BOTH PICTURES VALID
  - EM RADIATION PROPOGATES AS WAVES
  - EM RADIATION INTERACTS WITH ATOMS AS ENERGY PACKETS OR PHOTONS

4. Complimentarity — Duality of Wave — Photon

The present understanding of EM radiation phenomena involves both photons and waves. This is difficult to explain in classical physical terms, but the modern quantum theory is capable of explaining most of the observed data.

Briefly, EM radiation is generated and absorbed at the atomic level as photons; it propagates as EM waves.

We will use this principle of the wave-photon duality or the complementarity principle, in considering some of the other phenomena of EM radiation.

Although quantum field theory has unified these conflicting pictures of the nature of radiation to some degree, we are left at the elementary level with the complementary wave-particle picture. Our choice of an appropriate mode of description will depend upon the particular experimental situation. In general, the wave picture is most useful for low energy, long wavelength radiation, such as radio, radar and microwaves. Both quantum and wave concepts are used in the optical region of the spectrum. High energy radiation such as x-rays and gamma-rays are most conveniently viewed as particle-like quanta.

D. PRODUCTION OF ELECTROMAGNETIC RADIATION IN ATOMS AND MOLECULES

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	28

MOLECULES AND ATOMS

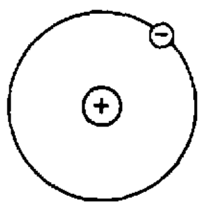
CHEMICAL SYMBOL	NAME OF MOLECULES	SCHEMATIC PICTURE SHOWING MOLECULE	CONSITUENT ATOMS
N_2	NITROGEN (ELEMENT)		2 NITROGEN ATOMS
H_2O	WATER (COMPOUND)		2 HYDROGEN ATOMS AND 1 OXYGEN ATOM
NaCl	SALT (IN A CRYSTAL)		1 SODIUM ATOM AND 1 CHLORINE ATOM

1. Atoms and Molecules

Atoms are the smallest particles of an element which maintain the properties of the element that cannot be further divided by chemical means. Atoms combine to form molecules; and these molecules may have chemical properties quite different from those of their constituent atoms. For example, water is composed of two atoms of hydrogen and one atom of oxygen. Hydrogen is a highly flammable gas and oxygen is a gas that supports combustion. The symbol for water is H_2O. Similarly, common table salt or sodium chloride (symbol NaCl), is composed of one atom each of sodium, a caustic metal and chlorine, a poisonous gas.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	29

HYDROGEN ATOM



- NUCLEUS
  - POSITVE, PROTON
  - HEAVY, 1.6 X 10^{-24} GRAM
- ELECTRON
  - NEGATIVE
  - LIGHT (1/1840 PROTON MASS)
  - ORBITING
- BOUND BY ELECTRICAL FORCES

Hydrogen – a simple atom. While we cannot divide atoms by chemical means, atoms do have internal structure. The simplest atom is that of hydrogen. Like all atoms, it has a massive positively charged nucleus. An equal negative charge, the electron, circulates around it in an orbital shell. The nucleus and electron are held together by electrical forces.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	30

ATOMIC STATES

GROUND STATE: LOWEST TOTAL ENERGY ARRANGEMENT

EXCITED STATE: HIGHER ENERGY, SHELL/SUBSHELL, ARRANGEMENT

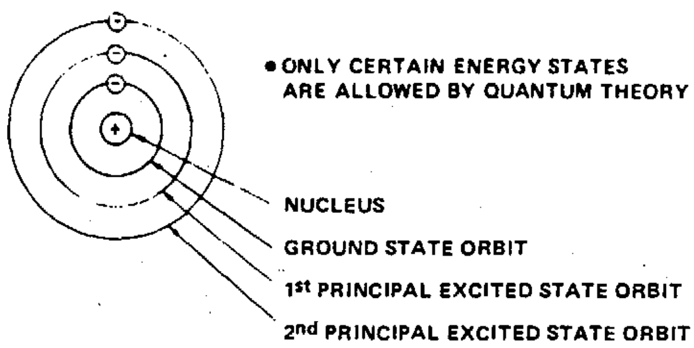
2. Atomic States

a. Ground State

Atoms normally exist in a state of minimum total energy called the "ground state." The state of an atom is determined by the orbital shell and subshells in which the electrons reside. They always tend to exist in the shells where they are bound as tightly as possible by electrical forces. (This is equivalent to the tendency of water to run downhill, to achieve its lowest energy in the force field of gravity.) Because shells and subshells can have only certain maximum numbers of electrons, all the atomic electrons cannot crowd into the lowest shell, but they do tend to be in the lowest energy, or tightest bound, arrangements allowed by the shell structure rules. This configuration is the ground state.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	31

TWO POSSIBLE EXCITED STATES OF A HYDROGEN ATOM

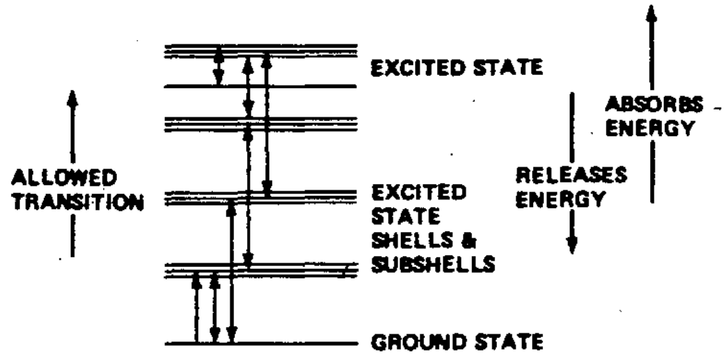


b. Excited States

When, for any reason, an atom absorbs energy, electrons may be transferred from one shell or subshell to another, or even knocked completely out of the atom.

When an electron is transferred into some subshell other than its normal lowest energy one, the atom is said to be excited or in an excited state. The atom then, as a whole, has more energy than it had in its ground state. The quantum theory predicts that atoms can have only certain discrete or quantized energies. That is, atoms can exist only in particular excited states.

ALLOWED TRANSITIONS BETWEEN STATES



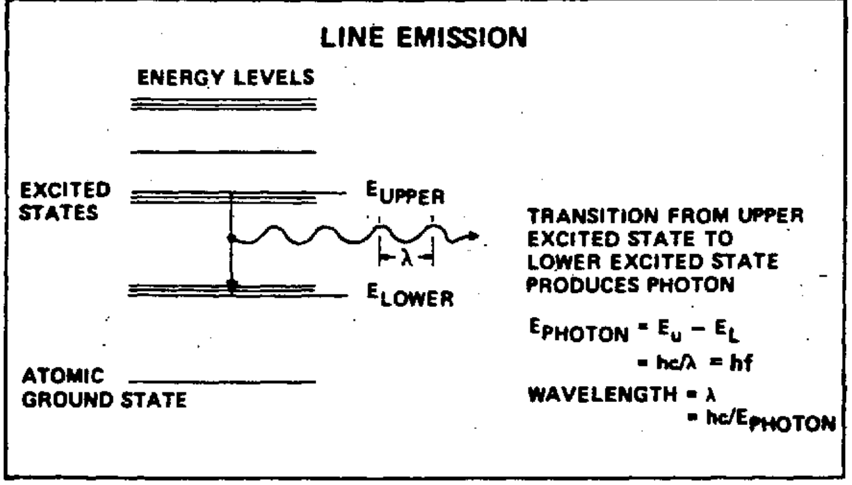
3. Transition Between Atomic States

An atom can exist in only one of its possible states at any given instant. Normally, of course, it tends to be in its ground state or lowest total energy configuration. However, it can be put into one of its many excited states by absorbing some energy from outside itself. In this process, an electron, usually an outer shell electron, jumps from its ground state to one of its other possible states. If the electron is completely removed from the atom, (free state) the atom is said to be ionized. There is a rearrangement of outer electron(s) in the various shells and subshell possibilities.

When electrons jump from one possible shell-subshell arrangement, or energy state, to another one, we say that an atomic transition occurs. Transitions may occur between many of the possible energy states, but according to quantum theory, not between all such states. In other words, there are some "forbidden transitions" of an atom.

Molecules are composed of a number of atoms bound together with electrical forces, resulting typically from the sharing of electrons by the atoms. Molecules have "ground" states, or states of lowest possible energy, and excited states, just as do atoms. However, in addition to electron orbit excitation states, molecules can have internal atomic vibrations and rotations as well. Vibrational and rotational states have generally low energy, but they may exist as substates (or splittings) superimposed on higher energy states. Transitions between closely spaced vibration or rotation states involve small energies, or long wavelength EM radiations.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	33



3. Transition Between Atomic States (contd.)

a. Line Emission

Whenever a transition occurs from an excited state of energy, E_U, to a less excited state of energy E_L, the energy difference between the two states is released in the form of electromagnetic energy as a photon. This is referred to as a single wavelength or line emission. It is a discrete, specific, quantity of energy, equal to $E_U - E_L$. If we measure the wavelength, λ, of the light we find

$$E_U - E_L = E_{photon} = hc/\lambda$$

where

h = Planck's constant
c = Velocity of light

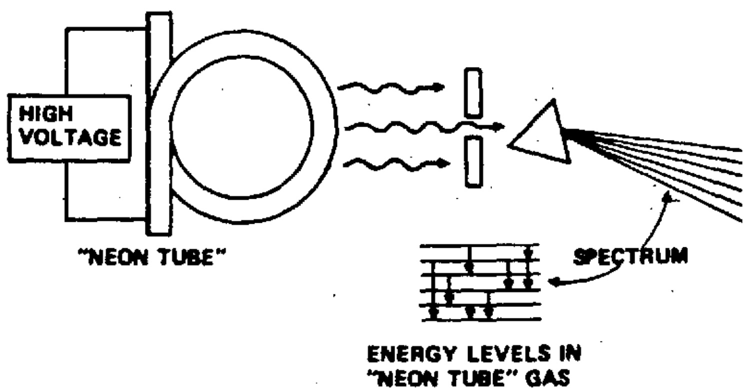
The photon energy released in a transition is related to the wavelength of the emitted light by the above formula. Here we see the wave particle duality again: light is emitted as a photon of specific energy but propagates as a wave with a specific wavelength.

Every transition allowed to an atom or molecule leads to some photon energy and thus to some discrete light wavelength.

A commonly used energy unit in work with atomic or molecular transitions is the "electron-volt," or 1.6×10^{-12} joule. It is the energy gained by an electron falling through a potential gradient of one volt.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	34

LINE EMISSION FROM EXCITED NEON ATOMS



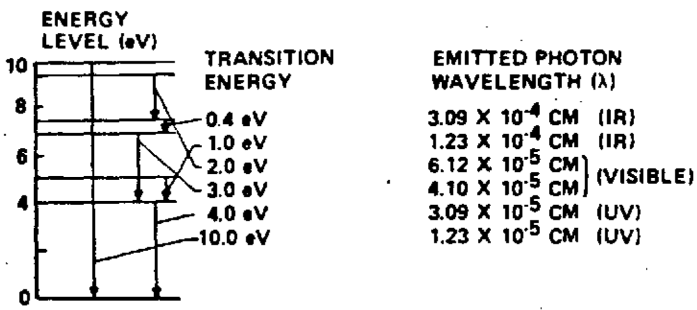
3. Transition Between Atomic States

a. Line Emission (contd.)

A typical "neon sign" has a tube containing gases through which electricity flows, exciting the atoms into many of their higher energy states. As these atoms rearrange their electrons to return to ground states, many different transitions occur, releasing photons. The photons emitted by a "neon tube" have a spectrum containing many discrete wavelengths, or lines, each corresponding to an atomic transition. This spectrum is characteristic of excited neon. The eye mixes these wavelengths to give the characteristic neon lamp color.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	35

ENERGY SPECTRUM



$E_{Photon} = hc/\lambda = hf$

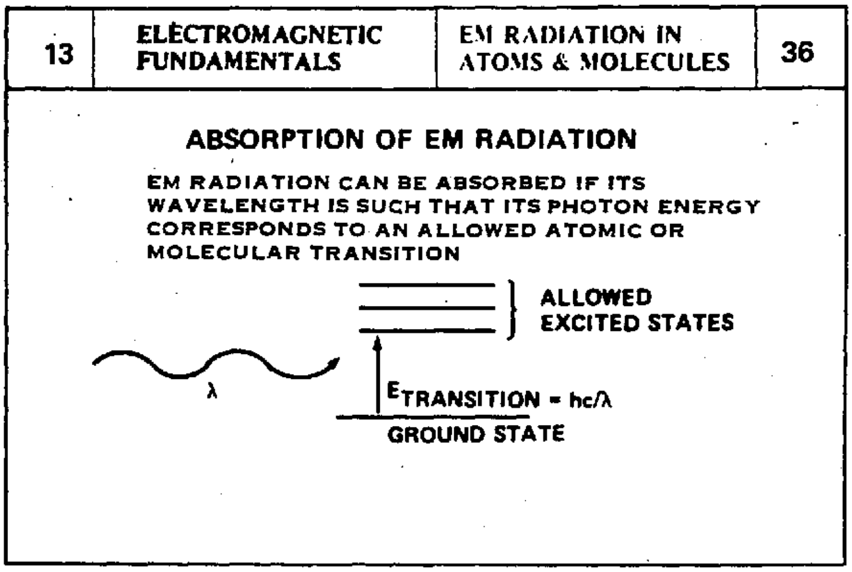
b. Energy Spectrum

The spectrum of EM radiation was given earlier in terms of wavelength and frequency. Because of the wave-photon duality, we can also relate wavelength or frequency to the energy of the associated photon. The chart shows this added information, using energy units of electron volts. Note the transition energy values for IR, visible and UV light, since these are the energies available in typical excited

3. Transition Between Atomic States

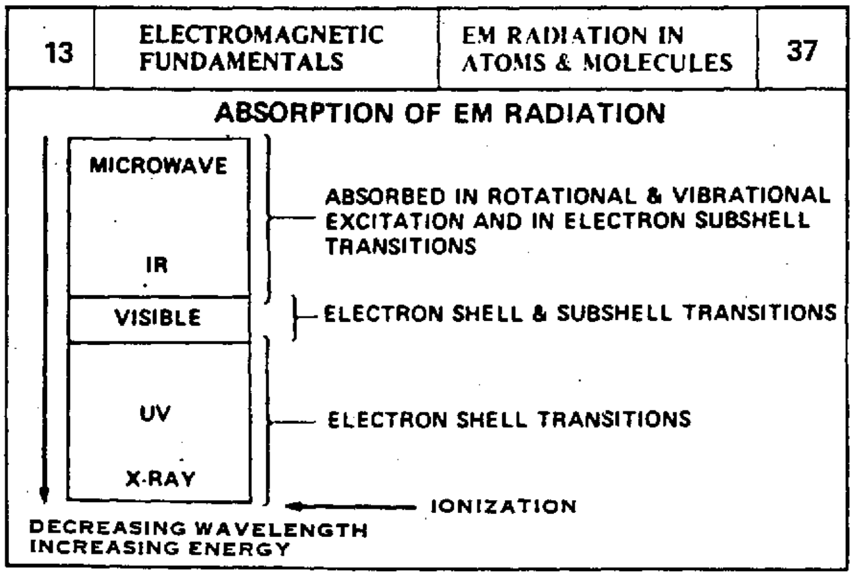
b. Energy Spectrum (contd.)

atoms encountered in much industrial hazard survey work with lasers, welding, or heat processing.The relationship between the scales is given by the formulas $E_{photon} = hc/\lambda = hf$.



4. Absorption of EM Radiation in Atoms and Molecules

We are now equipped to understand radiation absorption. Electromagnetic radiation impinging on a material can be absorbed if it has a wavelength such that its photon energy is just able to produce an allowed atomic or molecular transition. Typically, the atoms or molecules would be in their electronic ground states. At room temperatures, the molecules would also be vibrating and/or rotating. Impinging radiation capable of exciting these atoms or molecules into allowable excited states can and will be absorbed.



We find, experimentally, that materials absorb various wavelengths selectively from the spectrum. Microwaves and infra-red light is typically absorbed in exciting the vibrational and rotational states of molecules, or the closely spaced energy subshells of atoms.

4. Absorption of EM Radiation in Atoms and Molecules (contd.)

Visible light is absorbed in both vibrational and electronic transitions. Ultra violet and x-rays are typically absorbed in transitions from ground states to higher orbital electronic excited states or free electron states. Light is not absorbed which does not have the correct photon energy to cause allowable transitions to excited states. Such light is transmitted through or reflected by the material.

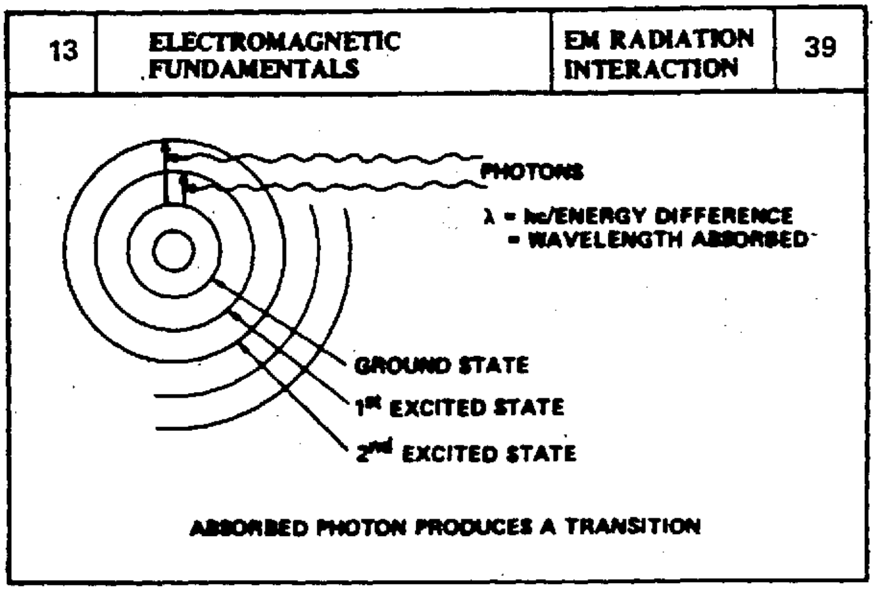
13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION IN ATOMS & MOLECULES	38

ABSORPTION OF EM RADIATION

- EACH MATERIAL HAS ITS CHARACTERISTIC ATOMIC OR MOLECULAR ABSORPTION SPECTRA
- ORDINARY GLASS ABSORBS UV, PASSES IR AND VISIBLE
- COLORED GLASS ABSORBS SELECTIVELY, PASSES CERTAIN WAVELENGTHS
- QUARTZ GLASS DOES NOT ABSORB NEAR UV
- ACRYLIC PLASTICS ABSORB FAR INFRARED

Every material has its characteristic atomic or molecular absorption spectra, determined by its excited state energy levels. For example, normal glass absorbs very little visible or IR. but absorbs UV light. Colored glass has small amounts of materials added that absorb specific wavelengths and allow others to pass. Red glass absorbs most colors except the reds. Quartz glass allows some UV light to pass.

E. E M RADIATION INTERACTIONS AND PROCESSES



1. Absorption and Attenuation Laws

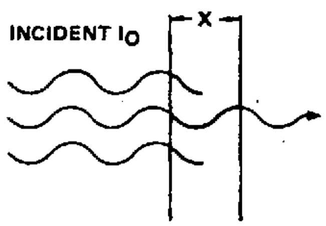
   a. Absorption by Atomic or Molecular Transition

   Just as transitions between excited states of atoms or molecules will produce photons of EM energy, so the inverse process is involved in absorption. Radiation, having a wavelength corresponding to an energy that will cause an allowed transition from a lower energy state to a higher one in atoms or molecules of a material, will be absorbed by that material. Since there are many possible excited states, there are generally many discrete wavelengths, λ, that can be absorbed. Molecules may absorb in closely spaced near-continuous bands.

   Among the molecular excited states are those where the energy is in vibration of atoms or rotation of the molecule. These have generally low excitation energy and hence are associated with long wavelength absorption and production.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	40

EM ABSORPTION LAW



TRANSMITTED I_T

$I_T(\lambda) = I_O(\lambda)e^{-k(\lambda)x}$

x = THICKNESS

$k(\lambda)$ = ABSORPTION COEFFICIENT FOR MATERIAL AT WAVELENGTH λ

ABSORBED ENERGY MAINLY HEATS MATERIAL

1. Absorption and Attenuation Laws (cont'd)

   b. Absorption Laws

   If there is a material x cm thick, upon which EM radition of some particular wavelength impinges with an intensity of I_O, then it can be shown that the radiation emerging from the other side of the material is given by the formula:

   $$I_T(\lambda) = I_O(\lambda)e^{-k(\lambda)x}.*$$

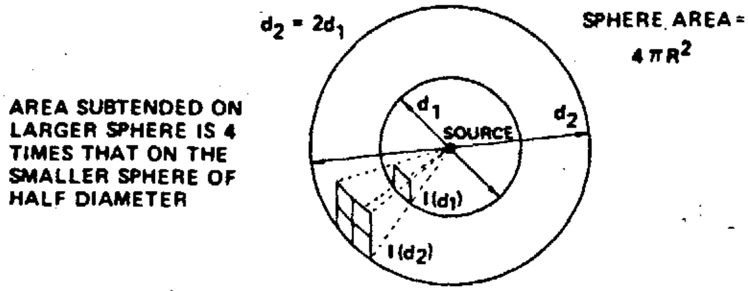
   $k(\lambda)$ is the absorption coefficient which has a different value for different wavelength radiation. For wavelengths at which no transition is allowed, for example, $k(\lambda) = 0$ and $I_T = I_O$.

   The EM radiation absorbed in the material is ultimately changed into other energy forms such as heat, that is, into molecular motion, including vibration and rotation. One common way of measuring the amount of EM radiation in a beam is by absorbing it in material of known absorption coefficient for the spectral range, and measuring the temperature change.

*This "exponential" absorption law results from the fact that a fixed fraction of the EM energy is absorbed per unit thickness.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	41

INVERSE SQUARE ATTENUATION



$$I(d_2) = I(d_1)\left(\frac{d_1}{d_2}\right)^2$$ INVERSE SQUARE LAW

1. Absorption and Attenuation Laws (contd.)

c. Inverse Square Attenuation

In addition to the absorption law just discussed, EM radiation generally obeys the inverse square law. At distances, d. far enough from the source so that the source appears small (or as a point), the intensity, I, varies according to

$$I(d_2) = I(d_1)\left(\frac{d_1}{d_2}\right)^2$$

which is the inverse square law. $I(d_1)$ is the intensity at distance d_1.

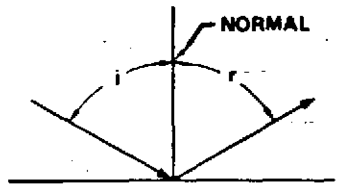
This can be seen from a consideration of a point source emitting energy in all directions, that is toward the surface of a sphere surrounding the point source.

Because the total radiated energy from a source gets spread out over larger areas as an EM wave expands. the energy flow per unit area depends on distance from the source according to the inverse square law.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	42

REFLECTION OF EM WAVES

ANGLE OF INCIDENCE (i) = ANGLE OF REFLECTION (r)



SURFACE OR INTERFACE

2. Reflection

   a. Basic Law of Reflection

EM radiation, if not totally absorbed or transmitted by a material, is at least partially reflected.

The basic law of reflection states that the angle of incidence equals the angle of reflection. Both angles are measured from a line or plane perpendicular to the plane which reflects the ray of radiation. Radiation generally will be reflected at any interface, or boundary, between different media in which it is traveling. The perpendicular line or plane is called the "normal" to the surface.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	43

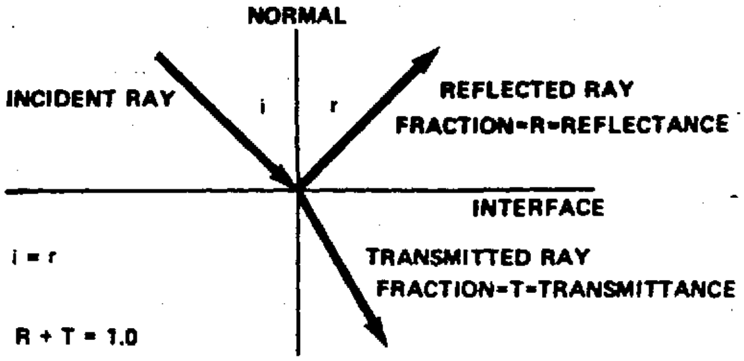
TWO TYPES OF REFLECTION OF EM RADIATION

SPECULAR	AND	DIFFUSE
• SMOOTH, SHINY, POLISHED SURFACE		ROUGH, RANDOMLY, ORIENTED, GRANULAR SURFACE

When discussing reflection phenomena at an interface it is customary to refer to specular and diffuse surfaces. A surface is specular if the sizes of surface imperfections and variations are much smaller than the wavelength of incident radiation. Examples of specular reflecting surfaces are polished mirrors, or shiny metal plates. When irregularities are randomly oriented and are much larger than λ then the surface is considered diffuse. In the intermediate region, it is sometimes necessary to regard the diffuse and specular components separately.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	44

SPECULAR REFLECTION



2. Reflection (contd.)

b. Specular Reflection

If light is incident upon an interface separating two transmitting media (at an air-glass-interface), some light will be transmitted while some will be reflected from the surface. Since no energy can be stored up at the interface, T + R = 1.00 where T and R are the fractions of the incident beam intensity which are transmitted and reflected. T and R are called the transmission and reflection coefficients respectively, or transmittance and reflectance. These coefficients depend not only upon the properties of the media and the wavelength of the radiation, but also upon the angle of incidence. Polarization of the incident radiation and the non-isotropic characteristics of crystalline media also affect transmission and reflection.

The EM energy not reflected at the interface is transmitted into the material. In the case of metals, this produces current flow, and the wave is usually absorbed in a very short distance. For longer wavelength EM radiation than IR, that is, in the microwave and radio frequency region of the spectrum, the depth of penetration where this induced current flows is called "skin depth", and is typically of the order of a tiny fraction of a wavelength.

In the case of non-metals, considerable EM radiation may be transmitted through the interface, and absorbed slowly in the material according to the exponential law.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	45

DIFFUSE REFLECTION OF EM WAVES

REFLECTED RAYS HAVE RANDOM DIRECTIONS IN THREE DIMENSIONS

REFLECTED INTENSITY IN ANY DIRECTION AT θ TO NORMAL } **= (INCIDENT INTENSITY) X (COS θ)**

2. Reflection (contd.)

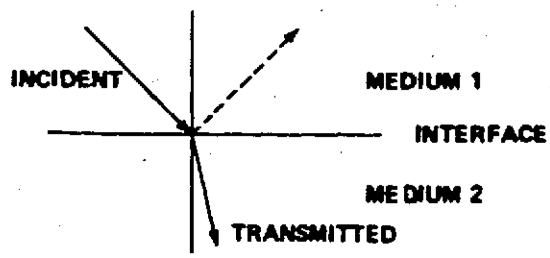
c. Diffuse Reflection

If surface irregularities are so great that an incident ray may be reflected in any random direction from a surface, we speak of the surface as diffuse. The radiant intensity I (radiant power per unit solid angle) will then vary with the cosine of the angle θ measured from a normal to the surface: $I = I_0 \cos \theta$
where I_0 is the radiant intensity in the direction perpendicular to the surface.

Many dull or rough surfaces reflect diffusely, for example a textured ceiling. The surface roughness, or distance between irregularities, should be of the order of the wavelength for diffuse reflection.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	46

SNELL'S LAW OF REFRACTION - I

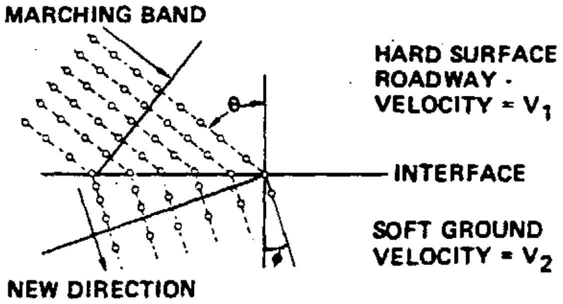


3. Refraction

   a. Snell's Law

   When an EM wave is incident upon an interface between two transmitting media, part of the wave may be reflected back into the first material and part transmitted across the interface into the second. Now, consider the transmitted wave. Because the two media at the interface typically have different optical properties, the velocity of the EM wave in one will be different from that in the other. This results in a change of direction of the wave as it crosses the interface. This is called refraction.

SNELL'S LAW OF REFRACTION - II



SIN θ /SIN ϕ = V_1/V_2 (SNELL'S LAW)

To see the effect of a velocity change on a wave crossing the interface, consider a marching band moving from a smooth hard roadway onto a rough, soft playing field. The band's velocity in the soft field, V_2, is less than the velocity, V_1, on the roadway, but the drummers keep everyone in step, that is, the "frequency" of the "waves" of musicians is constant. The band approaches the road-field interface at an angle, θ. The first musicians in the first rank, that step into the field are slowed by the soft ground, and as soon as the whole first rank is on the ground, they are marching in a different direction than their approach. Finally, the whole band is marching in this new direction. The original angle between the direction of the band and the line perpendicular to the interface, θ, and the final angle Φ, is given by
$\sin\theta / \sin\Phi = V_1/V_2$

This is Snell's law. This phenomenon is responsible for the bent appearance of a stick thrust into water.

INDEX OF REFRACTION

$$\frac{\text{LIGHT VELOCITY IN VACUUM}}{\text{LIGHT VELOCITY IN MEDIUM}} = \text{INDEX OF REFRACTION} = \eta \text{ OR } n$$

SNELL'S LAW $\sin\theta / \sin\phi = n$

θ = ANGLE OF INCIDENCE
ϕ = ANGLE OF REFRACTION

b. Index of Refraction

Refraction is the process whereby radiation proceeds between media having different radiative velocities. In refraction, the angles of the incident and refracted rays are not equal, but rather follow Snell's Law. Since the frequency of the radiation does not change, the wavelength in the medium with lower velocity must be shorter. For a particular EM radiation visible light, the ratio of the velocity of that light in some medium to that in a vacuum (free space) is called the index of refraction, usually symbolized by lower case Greek letter eta, η, or lower case English n.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	49

POLARIZATION

- POLARIZATION IS DIRECTION OF E-FIELD OF WAVE
- UNPOLARIZED LIGHT HAS RANDOM ORIENTATIONS OF E-FIELDS
- PLANE POLARIZED LIGHT HAS E-FIELD IN ONLY ONE DIRECTION
- REFLECTION AND REFRACTION CAN PRODUCE POLARIZED EM WAVES.

4. Polarization

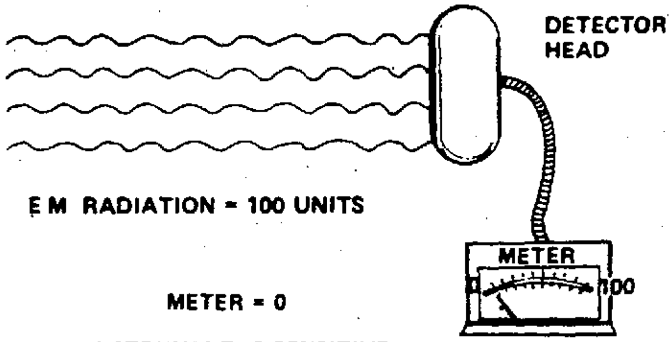
a. Definitions

Polarization of an EM wave refers to the direction of the electric field vector. Since EM radiation consists of transverse waves, this direction is 90° to the direction of travel of that wave, but the E-field vector may lie anywhere in the plane perpendicular to the direction of travel. If the E-fields of the wave are randomly distributed in all directions in this plane, the wave is said to be unpolarized. If the E-field is oriented in one particular direction, the wave is said to be plane polarized. Other types of polarization are possible.

Reflection and refraction of EM radiation in various materials can also produce polarization. An example is glare in sunlight reflected from a wet street or smooth metallic surface.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	50

POLARIZATION



E M RADIATION = 100 UNITS

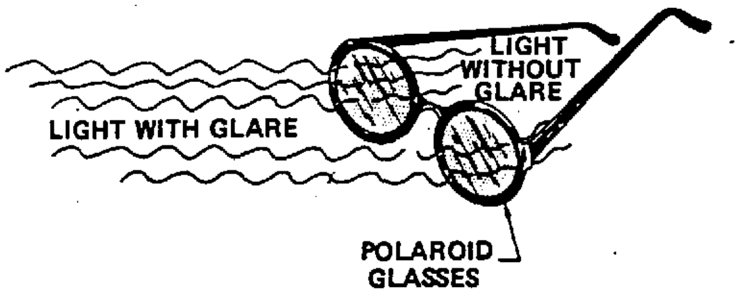
METER = 0

INSTRUMENT IS SENSITIVE TO POLARIZATION

Some monitoring and surveying EM radiation instruments are sensitive to field polarizations. When used in situations where the EM radiation refracts or reflects, it is possible to make erroneous readings unless one is alert to these polarization effects.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	51

POLAROID$_{(TM)}$MATERIAL



b. Polaroid Material

The most common method of producing polarized light, and of protecting the eyes against polarized glare, is by the use of Polaroid$_{Tm}$ sheet. This is a plastic material that has long chain molecules containing iodine (or other elements) to provide molecular-sized conductive lines. The E-field of the incident light is able to move electrons in these long molecules. The net effect of this electron current is to transmit polarized waves. Polaroid sheet can be made into protective panels, eyeglasses or goggles.

Tm = Trademark

As mentioned earlier, reflections of unpolarized EM waves from surfaces, crystals or grids at large angles (greater than arctan n) can produce polarized waves, with the direction of polarization parallel to the surface. Also, if the waves enter the surface of a crystalline material, then the refracted waves may be polarized. These facts are important for EM radiation hazard control. Since one may unexpectedly find polarized radiation, one must be careful in making measurements.

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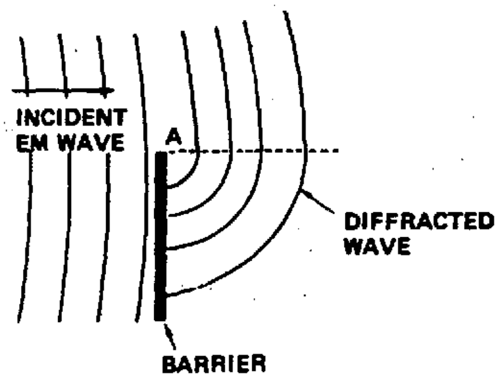
DIFFRACTION OF EM WAVES



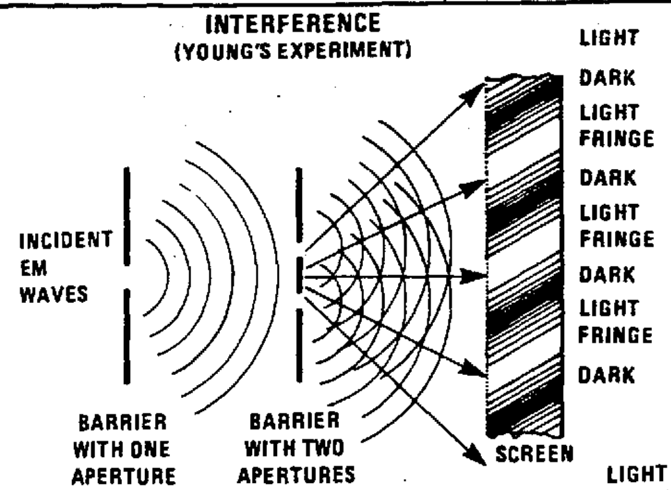
5. Diffraction

a. Huygen's Principle

When waves pass through an aperture, or past an edge of some barrier, they spread into the region which is not directly exposed to the incident waves. This is the phenomenon of diffraction.

To account for this bending of light rays, Huygen (in 1678) developed the principle that bears his name. It states that every point on a wavefront can be considered a new source of waves. As the waves approach a barrier, the point A on a wavefront just at the edge of the barrier can be thought of as a source of a new wavefront. The new wavefront expands spherically, and so light bends around the barrier.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	53



5. Diffraction (contd.)

b. Interference (Young's Experiment)

In one of the early experiments that demonstrates the wave nature of light, Young passed the light from a single source through two small apertures. On a screen he found. not two spots of light, but a pattern of dark and light lines. If one considers that each aperture is a source of a new wavefront, then it is apparent how this pattern arises.

Recall that waves may be superimposed to reinforce or to cancel depending upon the relative phases of the waves at any given point. Waves from aperture A reinforce waves from aperture B along certain lines as shown. They cancel along other lines. The phenomenon of reinforcement and cancellation is called interference. The reinforced light areas are called light fringes; the cancelled light areas are called dark fringes.

Interference phenomena between waves can occur for the entire EM spectrum. The patterns of EM wave intensity maxima and minima produced by interference are called diffraction patterns. One observes these maxima and minima in radio wave signal strengths around antennas, for example. It is a phenomenon to be aware of in monitoring or surveying, for one may find a low intensity at some point and think there is no hazard, whereas a few feet away (fractions of wavelengths) the intensity may be great due to a interference effect.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	54

SCATTERING OF EM WAVES

6. Scattering

   a. General

   If we pass light into a space filled with tabacco smoke, some of the incident light is observed emerging from the sides of the space, and some is transmitted through the space. The small particles of smoke reflect the light; scattered in all directions. This same scattering phenomenon is observable for all wavelengths in the EM spectrum.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	55

SCATTERING OF EM WAVES

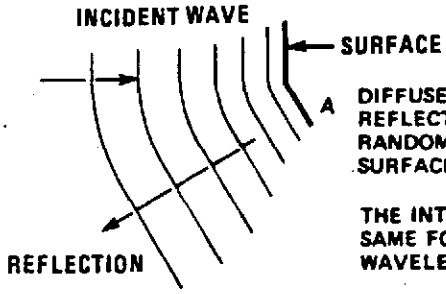
TWO TYPES OF SCATTERING

- **SCATTERING PARTICLES > WAVELENGTH (DIFFUSE)**
- **SCATTERING PARTICLES ≲ WAVELENGTH (RAYLEIGH)**

Two types of scattering can be distinguished. One, in which the size of scattering object is considerably larger than the wavelength of the incident radiation is called diffuse scattering. The other in which the size of the scattering object is comparable to or smaller than the wavelength is called Rayleigh scattering.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	56

DIFFUSE SCATTERING



DIFFUSE SCATTERING IS REFLECTION FROM MANY RANDOMLY ORIENTED SURFACES

THE INTENSITY IS THE SAME FOR ALL INCIDENT WAVELENGTHS

6. Scattering (cont'd)

   b. Diffuse Scattering

      From a large particle scatterer, A, the laws of reflection and diffraction apply. The reflected wave from any one surface is composed of many superimposed spherical wavefronts combining into a short segment of a plane wave. Since the particles in, say, smoke or other aerosols, are randomly oriented in space, the scattering of light from them is diffuse. That is, light is reflected, or scattered, in all directions, and the process is not wavelength dependent. White light is scattered as white light, unless the particles themselves are colored and thus absorb some wavelengths.

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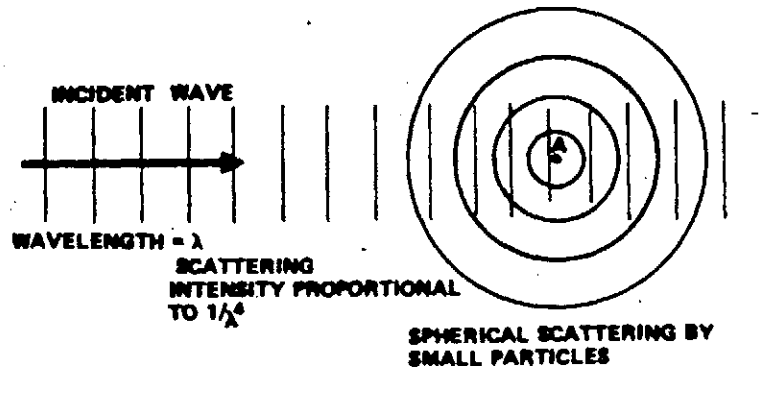
RAYLEIGH SCATTERING



6. Scattering (Contd.)

c. Rayleigh Scattering

If scattering particle is small compared to the wavelength, there is essentially no superposition into plane waves of the reflected wavefronts. The particle as a whole serves as a source of sperhical waves. In this case, there is a dependence of the amount of light scattered on the wavelength. This process is called Rayleigh Scattering. The longer wavelength waves are less efficiently scattered than shorter ones, because the particles present obstructions to the waves which are smaller for long waves than for short ones. The intensity of the scattered light is proportional to $1/\lambda^4$.

Molecules in a gas such as air, or in a transparent liquid, can act as Rayleigh-type scatterers for IR, visible, and UV wavelengths. They are, in fact, responsible for the deep blueness of clear water and of the sky. If it were not for the atmosphere, the sky would be black except where the sun, moon, or stars were located. (This is observed by astronauts.) Because of the air, the light from the sun is scattered in all directions high in the atmosphere. Since blue light scatters more, we observe blue sky from directions other than that toward the sun. At sunset, or sunrise, we look toward the sun across the edge of the earth through a large thickness of atmosphere, and the blue light is mostly all scattered out, leaving red light as the predominating color.

13	ELECTROMAGNETIC FUNDAMENTALS	EM RADIATION INTERACTION	58

SCATTERING OF EM WAVES

IMPORTANCE IN MONITORING AND HAZARD SURVEY

- **SCATTERED WAVE ENERGY IS NOT ABSORBED**
- **SCATTERING MAY PROVIDE A PROTECTION METHOD TO REDUCE INTENSITY IN SOME DIRECTION**

6. Scattering (contd.)

d. Importance

Scattering is important in monitoring and surveying of EM radiation hazards because the process can remove energy from direct beams without absorbing it. Scattered energy then appears in other directions where it could cause hazards. Also, scattering can be a protection method, to dilute the unwanted radiation by diffuse reflection into many directions where the intensity at any point may be relatively small, and within allowable limits.

F. EM QUANTITIES AND UNITS

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	59

FREQUENCY

- FREQUENCY
  - CYCLES PER SECOND = HERTZ (Hz)
    - KILO HERTZ (kHz) = 10^3 Hz
    - MEGA HERTZ (MHz) = 10^6 Hz
    - GIGA HERTZ (GHz) = 10^9 Hz

1. Generally Used Quantities

Frequency

The frequency of a wave or periodic motion is the number of waves that pass a fixed point in a unit time, such as one second. The unit of frequency is the Hertz, (Hz) or one cycle per second (CPS). Over the whole EM spectrum varicus multiples of Hertz are common, as follows:

Kilohertz (kHz) = 1,000 Hz
Megahertz (MHz) = 1,000,000 Hz
Gigahertz (GHz) = 1,000,000,000 Hz

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	60

WAVELENGTH

- METERS (m)
  - CENTIMETERS (cm) = 10^{-2} m
  - MILLIMETERS (mm) = 10^{-3} m
  - MICROMETERS (μm) = 10^{-6} m
  - NANOMETERS (nm) = 10^{-9} m
- ANGSTROM (Å) = 1×10^{-10} m

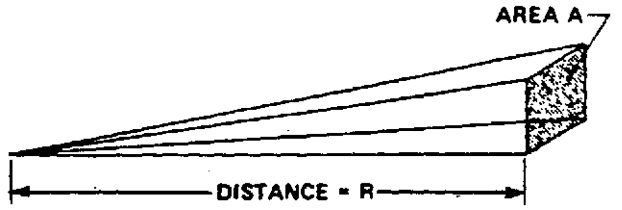
b. Wavelength

The wavelength of a wave or periodic motion is the distance between corresponding points of the wave, such as the distance between crests. The commonly used units are meters or multiples and fractions of a meter as follows:

meters	(m)		microns (or micrometers)	(μm)	= 10^{-6}m
kilometers	(km)	= 10^3m	nanometers	(nm)	= 10^{-9}m
centimeters	(cm)	= 10^{-2}m	Angstrom Units	Å	= 10^{-10}m
millimeters	(mm)	= 10^{-3}m			

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	61

SOLID ANGLE



SOLID ANGLE SUBTENDED BY AREA, A, AT DISTANCE R IS
$\Omega = A/R^2$ STERADIANS (sr)

(4π STERADIANS IN A SPHERE)

1. Generally Used Quantities (contd.)

c. Solid Angle

A concept used much in radiation work is the solid angle out of which radiant energy flows from a source, or into which this energy flows into a receiver. The unit of solid angle is the steradian, abbreviated sr. Solid angle is defined as the ratio of an area at some distance, R, from a source (or receiver), to that distance squared. Since the area of a sphere is $4\pi R^2$, by definition there are 4π steradians in the full solid angle surrounding a point. A hemisphere such as the sky above us. above the horizontal plane. contains 2π steradians. An area of 1 square centimeter at a distance of 1 meter subtends $(1 \times 10^{-2}m)^2/(1.0m)^2 = 10^{-4}$ sr.

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RADIANT ENERGY AND POWER

- ENERGY, Q, IN EM FIELD - ABILITY TO DO WORK OR HEAT MATERIAL

  UNITS: JOULES = WATT-SECONDS

- RADIANT FLUX, Φ, OR RADIANT POWER, P, THE TIME RATE OF ENERGY FLOW

  UNITS: WATTS (OR FRACTIONS)

d. Radiant Energy

Radiant energy is the energy in the EM waves. i.e., the ability of the EM wavefields to do work such as to move atoms or electrons and heat material. It is most commonly expressed in units of joules. or watt-seconds; a joule is 10^7 ergs. Total radiant energy is symbolized by the letter Q.

e. Radiant Flux, or Radiant Power

Radiant flux, or power is the time rate of flow of radiant energy, symbolized Φ or P. The unit used most commonly is Watts (W), or fractions of watts such as milliwatts (mW), microwatts (μW), or kilowatts (kW).

SOURCE OUTPUT UNITS

EMITTANCE INTENSITY RADIANCE

- EMITTANCE, W, IS POWER PER UNIT SOURCE AREA
  UNITS: WATTS/cm^2 OR WATTS/m^2
- RADIANT INTENSITY, I, IS POWER FROM SOURCE IN SOME DIRECTION PER UNIT SOLID ANGLE
  UNITS: WATTS/sr
- RADIANCE, L, IS POWER PER UNIT SOURCE AREA IN SOME DIRECTION PER UNIT SOLID ANGLE
  UNITS: WATTS/m^2 – sr

1. Generally Used Quantities (cont'd) .

The 3 quantities shown refer to source output.

f. Emittance

The energy per unit time, or power, being emitted by a radiating source, per unit area of the source, is called the source emittance. It is symbolized by W, and has units of Watts/cm^2 or Watts/m^2, or joules/cm^2-sec, or multiples thereof.

g. Radiant Intensity

Radiant intensity, I, refers to radiation source output, and is the radiant flux, or power, emitted from the source per unit solid angle in the direction of propagation. Units are watts per steradian, or multiples thereof.

h. Radiance and Luminance

Radiance refers to radiating source output, and is radiant power per unit area to source per unit solid angle in a direction of propagation. The units are usually Watts/m^2 sr, or Watts/cm^{2}sr, or multiples thereof. In radiometry its symbol is L, corresponding to the term "luminance" in photometry.

RECEIVER SURFACE

- RADIANT EXPOSURE, H, IS TOTAL ENERGY INCIDENT PER UNIT AREA OF SURFACE

  UNITS: JOULES/m^2 OR MULTIPLES

- IRRADIANCE, E, OR POWER DENSITY IS RATE OF RADIANT ENERGY FLOW PER UNIT AREA OF SURFACE

  UNITS: WATTS/m^2 OR MULTIPLES

1. Generally Used Quantities (contd.)

   i. Radiant Exposure

   Radiant exposure is the total energy per unit area incident upon a given surface in a given time interval. It is commonly expressed in units of joules/cm^2 or joules/m^2. This is also sometimes called "dose," and symbolized H.

   j. Irradiance or Power Density

   Irradiance, E. is radiant flux density, or the intensity of EM radiation present at a given point, the rate of flow of radiant energy per unit area. Its common units are Watts per square centimeter or meter. W/cm^2 or W/m^2, or multiples thereof.

Note: Radiant Exposure and Irradiance are terms used in laser hazard work; Energy Density and Power Density are corresponding terms used in microwave hazard work.

DECIBELS

- POWER RATIO UNIT COMPARING TWO SOURCES OF POWER LEVELS

- DECIBEL (DB) = 10 LOG_{10} (Pm/Ps)

  P_m = MEASURED POWER LEVEL
  P_s = STANDARD POWER LEVEL

- ZERO DB MEANS $P_m = P_s$

1. Generally Used Quantities (contd.)

   k. Decibel

An extremely common unit used in defining amounts of EM power is the decibel. Actually, the decibel (or bel, from which it is derived) is a unit of power ratio that compares two sources. However, if one power level is defined, at some standard number of watts or milliwatts, then another power can be expressed in decibels in comparison with the standard.

Let the standard be P_s, and let a measured value be P_m. Then ten times the base 10 logarithm of the ratio is the number of decibels, N, corresponding:

$$N_{(DB)} = 10 \log \frac{P_m}{P_s}$$

For example, if we choose 0.01 watt (or 10 milliwatts) as a standard power level, then a measurement of 40 decibels corresponds to a measured power of P_M; substituting in the defining equation

$$40 = 10 \log (P_m/.01)$$

Let both sides of the equation be exponents of 10:

$$10^{(40/10)} = 10^{\left(\log_{10} \frac{P_m}{.01}\right)} = P_m/.01$$

$$Pm = .01 \times 10^4 = 100 \text{ watts}.$$

Zero dB corresponds to the standard power level, since $10^0 = 1.0$

Decibels are used in radio-frequency, microwave, and acoustic power measurements. One must always be careful to note the standard power level, since different standards exist for different purposes.

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	66

SPECTRAL CHARACTERISTICS OF QUANTITIES

- ALL ENERGY AND POWER QUANTITES MAY BE EITHER : (1) SUMMED OVER SPECTRUM AS TOTALS
  OR (2) DEFINED OVER A UNIT WAVELENGTH RANGE AT A λ VALUE, THUS BEING A FUNCTION OF WAVELENGTH
- WAVELENGTH-DEPENDENT QUANTITIES ARE DENOTED BY SUBSCRIPT λ OR FUNCTION (λ)

2. Spectral Characteristics of Quantities

The quantities and units defined above were described in terms of total energy or total power, summed over an entire spectrum. They can also be defined in terms of the energy (or power) at a wavelength, λ. More properly, they are defined in terms of energy in a wavelength interval of the spectrum centered at the value λ. When so defined, these quantities become wavelength-dependent, and are designated by a subscript λ, or a parenthesis (λ) to show this functional relation. The name of the quantity is then preceded by the term "spectral" to indicate this. The units of spectral quantities have a per unit length (wavelength) in addition to those already given.

EM SPECTRAL QUANTITIES AND UNITS

- SPECTRAL RADIANT ENERGY, Q(λ): JOULES/WAVELENGTH UNIT
- SPECTRAL POWER, Φ(λ) : WATTS/WAVELENGTH UNIT
- SPECTRAL EMITTANCE, W(λ) : WATTS/m^2 – WAVELENGTH UNIT

NOTE: WAVELENGTH UNIT DEPENDS ON PART OF SPECTRUM INTEREST

2. Spectral Characteristics of Quantities (contd.)

   a. Spectral Radiant Energy

   Q (λ) is the EM energy at the wavelength, λ, per unit wavelength, usually expressed in units joules per nm, or joules per micron, for visible UV, or IR, or joules per meter for RF or microwaves.

   b. Spectral Radiant Flux

   Spectral power, Φ (λ) or P (λ), is the rate of flow of energy at λ per unit wavelength, with units of Watts/wavelength unit.

   c. Spectral Emittance

   W (λ) is the power being emitted per unit area of the source at a wavelength, λ, per wavelength unit. Typically its units are Watts/m^2-nm, or Watts/m^2 - μm. It is spectral emittance that is plotted as the ordinate of the blackbody spectrum.

EM SPECTRAL QUANTITIES AND UNITS (cont'd)

- SPECTRAL RADIANCE, L(λ) : WATTS/m^2-sr - WAVELENGTH UNIT
- SPECTRAL RADIANT EXPOSURE, H(λ): J/m^2 – WAVELENGTH UNIT
- SPECTRAL IRRADIANCE, E(λ) : WATTS/m^2 – WAVELENGTH UNIT

NOTE: WAVELENGTH UNIT DEPENDS ON PART OF SPECTRUM OF INTEREST

2. Special Characteristics of Quantities (contd.)

d. Spectral Radiance

L (λ) is radiated power per unit area of source per unit solid angle. per unit wavelength interval. Its units are Watts/m^2-sr-wavelength unit.

e. Spectral Radiant Exposure

H (λ) is the total energy per unit area over a time period which is within a unit wavelength interval at λ. It has units joules/m^2-wavelength unit. The wavelength unit depends upon the spectral region: μm or nm for visible IR, or UV; and cm or m for RF or microwaves.

f. Spectral Irradiance

E (λ) or Spectral Power Density, is the intensity of EM radiation in a unit wavelength interval at λ per unit area at a given point. Its units are Watts/cm^2-wavelength unit.

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	69

ILLUMINATION UNITS

- LUMINOUS FLUX = RATE OF LIGHT ENERGY FLOW
  UNIT: LUMEN
- ILLUMINANCE = LIGHT POWER PER UNIT AREA
  UNIT: LUMEN/m^2, OR
  FOOT CANDLE = LUMEN/SQ FT

3. Illumination or Photometric Quantities

a. General

In the field of light intensity measurement, and illumination engineering, some of the EM quantities defined previously, while physically the same, have been given different names and units.

b. Luminous Flux

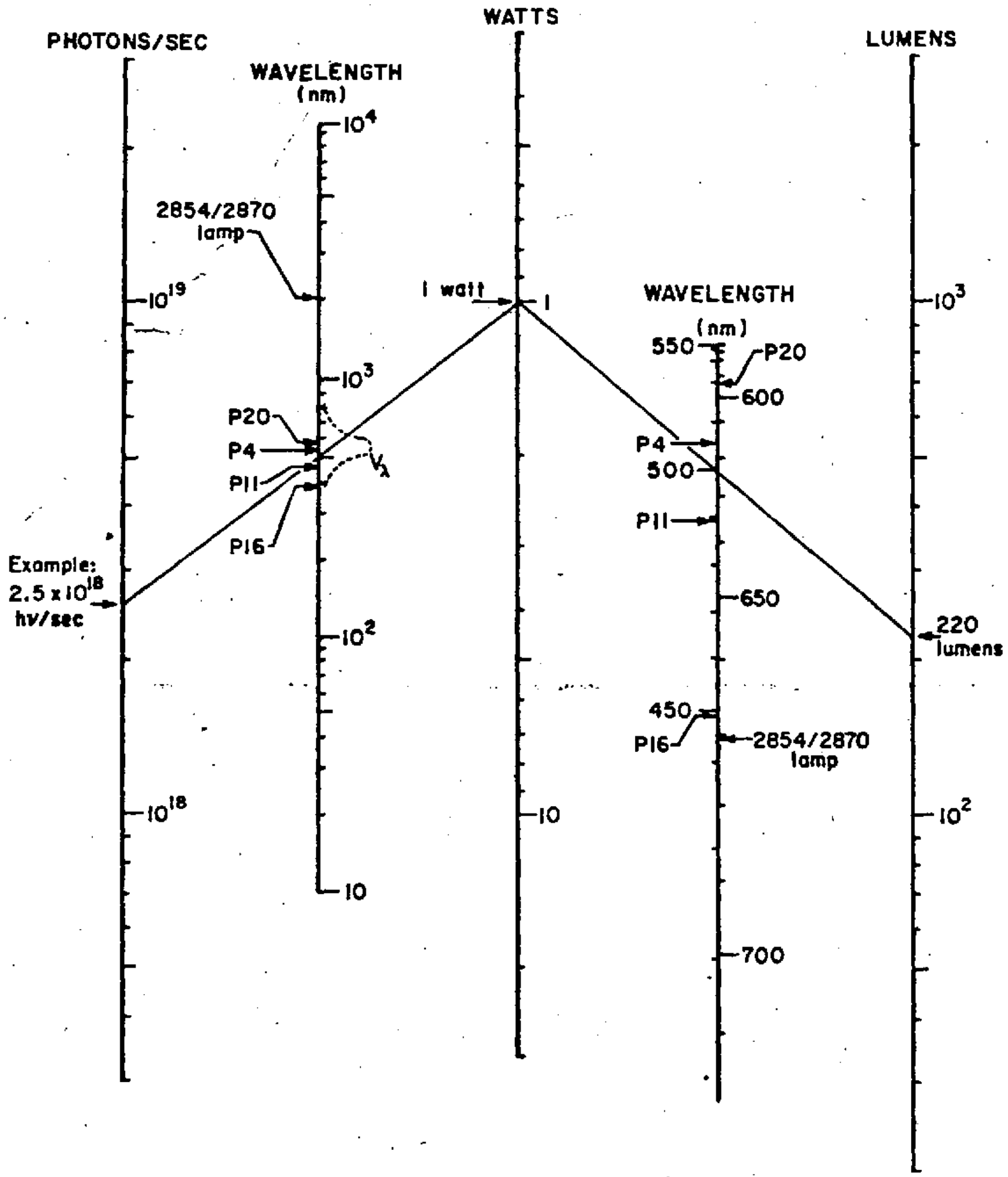
The rate of light energy flux, corresponding to radiant power. The illumination unit is the lumen, which is 1/680th of a watt.

c. Illuminance

Illuminance, corresponding to irradiance, is light power per unit area, with units lumens/m^2, also called lux. A unit of illuminance in common use is the foot candle, or lumens per square foot. This equals 10.76 lux.

FLUX CONVERSION NOMOGRAPH

PHOTONS/SEC = WATTS x 5.03×10^{15} x λ(nm)
LUMENS = WATTS x 680 x V_λ



Example: 1 watt of 500 nm radiation = 2.5×10^{18} hv/sec = 220 lumens

ELECTRON TUBE DIVISION ITT
3700 E. Pontiac St., Fort Wayne, Ind. 46803

ILLUMINATION UNITS

- LUMINOUS INTENSITY = CANDLE POWER = LIGHT POWER PER UNIT SOLID ANGLE

  UNIT: CANDELA = LUMEN/sr

- LUMINANCE = SOURCE OUTPUT

  UNIT: LUMEN/m^2 · sr = CANDELA/m^2

d. Luminous Intensity

Luminous intensity is sometimes called candlepower; it is luminous flux or light power per steradian solid angle. The unit of luminous intensity is the candela (cd), which is one lumen/sr. A candela is also defined absolutely in terms of a source of platinum at its solidification (or melting) point; such a standard incandescent source emits 60 candela/cm^2.

e. Luminance

Luminance refers to light source output, with units lumens per square meter per steradian; or candela/m^2. Another unit of luminance is the lambert, which is the light output from a diffuse source emitting one lumen/cm^2 in all directions.

MATERIAL PROPERTIES

- EMISSIVITY, ϵ, IS RATIO OF EMITTANCE OF MATERIAL TO EMITTANCE OF BLACK-BODY AT SAME TEMPERATURE.
- ABSORPTANCE, α, IS RATIO OF ENERGY ABSORBED BY MATERIAL TO THAT ABSORBED BY BLACK BODY.
- ϵ AND α ARE WAVELENGTH DEPENDENT.

4. Properties of Materials

a. General

Materials that emit, absorb, reflect, or transmit EM wave energy have properties that determine how they interact with this wave energy. These properties are usually wavelength dependent, and may also depend upon other physical parameters of the material, such as metallurgical state, temperature, etc. The properties are summed up in the several concepts discussed below.

b. Emissivity

The total emittance, W, or any real body is less than that of a theoretical black body. The ratio of the total emittance of a body to that of a black body is called the emissivity of the body, symbolized by the lower case Greek epsilon ϵ. For a black body, $\epsilon = 1$. For all other materials $\epsilon < 1$, although for carbon it is close to 1.0.

The same concept can be defined at specific wavelengths, λ. Thus, the spectral emissivity, $\epsilon(\lambda)$ of a body is the ratio of the spectral emittance of the body at wavelength, λ, to that of a black body at the same wavelength.

c. Absorptance

A black body also, by definition, absorbs all light indicent, whereas real bodies absorb somewhat less. Absorptance, α, of a material is the ratio of total incident energy absorbed to that absorbed by a black body. It is also spectrum-dependent, so we may write $\alpha(\lambda)$ as absorptance at a wavelength, λ.

A law of radiation, called Kirchoff's law, states that at a given temperature a body absorbs most strongly the radiation of that wavelength which it also emits.

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	72

ABSORPTION COEFFICIENT, k

- THE FRACTIONAL AMOUNT OF ENERGY ABSORBED PER UNIT DISTANCE OF MATERIAL TRAVERSED
- USED IN DETERMINING QUANTITY OF ENERGY TRANSMITTED THROUGH A MATERIAL

$E_x = E_0 e^{-kx}$ WHERE x = THICKNESS

k = ABSORPTION COEFFICIENT

E_0 = INCIDENT LIGHT INTENSITY

E_x = INTENSITY AT DISTANCE x

4. Properties of Materials

d. Absorption Coefficient

Absorption coefficient is not the same quantity as absorptance. Absorption coefficient is the fractional amount of energy absorbed per unit distance of material traversed. It has units of inverse length, and appears in the exponent of the attenuation formula

$$E_x = E_o e^{-kx}$$

where: E_o is incident light intensity, E_x is intensity at distance x and k is the absorption coefficient, which may be spectrum-dependent.

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	73

TRANSMITTANCE AND REFLECTANCE

- RATIOS AT AN INTERFACE
- TRANSMITTANCE = RATIO OF TRANSMITTED ENERGY TO INCIDENT = T
- REFLECTANCE = RATIO OF REFLECTED ENERGY TO INCIDENT = R
- T + R = 1.0

4. Properties of Materials

e. Transmittance

Transmittance is defined as the fraction of EM energy that is transmitted across an interface. It is symbolized by T. The transmitted fraction may be subsequently absorbed in the material.

f. Reflectance

Reflectance is defined as the fraction of the EM energy that is reflected at an interface, symbolized by R. Note that T + R = 1.

13	ELECTROMAGNETIC FUNDAMENTALS	EM QUANTITIES AND UNITS	74

OPTICAL DENSITY

- O.D. = $\log_{10} (E_o/E_t)$
  E_o = INCIDENT IRRADIANCE
  E_t = TRANSMITTED IRRADIANCE
- FOR THICKNESS X, IN MATERIAL WITH ABSORPTION COEFFICIENT k
  O.D. = k x/2.3

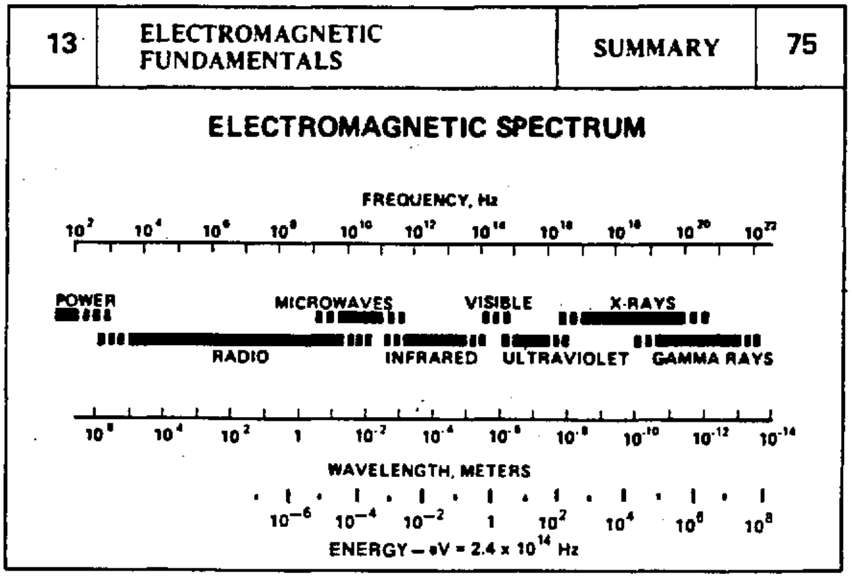
g. Optical Density

Optical density is defined as the logarithm of the incidence to the ratio of transmitted irradiance through a material. Symbolized O.D., it is

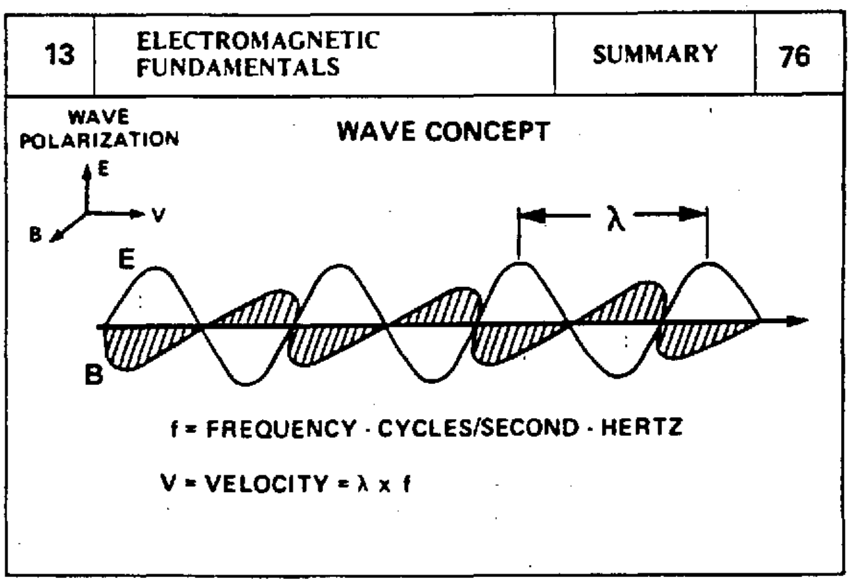
$$\log_{10}\left(\frac{E_o}{E_t}\right)$$

where E_o is incident irradiance, and E_t is transmitted irradiance. It is therefore a measure of attenuation and of absorption. It can be shown that the O.D. of a thickness x, of material with absorption coefficient k is kx/2.3.

G. SUMMARY



The electromagnetic spectrum includes several kinds of radiation of seemingly different character, but all are alike in that they are electromagnetic in nature and have the same speed in free space. The devices which produce electromagnetic radiation are quite different and produce radiation in overlapping regions. There is no upper or lower limit to the electromagnetic spectrum.



Electromagnetic radiation may be viewed as transverse waves with electric and magnetic fields at right angles propagating through different media with a certain wavelength and frequency. These waves may be superimposed on each other. Certain phenomenon can be best explained with this wave representation of electromagnetic radiation.

13	ELECTROMAGNETIC FUNDAMENTALS	SUMMARY	77

THE PARTICLE CONCEPT OF RADIATION

EM RADIATION CONSISTS OF ENERGY PACKETS CALLED PHOTONS

THE ENERGY OF PHOTONS EQUALS PLANCK'S CONSTANT MULTIPLIED BY THE FREQUENCY

$$E = hf = hc/\lambda$$

Electromagnetic radiation may also be reviewed as energy packets, or photons, which interact with matter in a quantized way. Certain other physically observed events are best described with this particle view.

The wave and photon descriptions of electromagnetic radiation are related to each other as follows:

$$E = hf = hc/\lambda$$

E = photon energy

h = Plank's constant

λ = wavelength of equivalent wave

c = speed of light

f = frequency

13	ELECTROMAGNETIC FUNDAMENTALS	SUMMARY	78

COMPLEMENTARITY

- WAVE - PHOTON DUALITY
- BOTH PICTURES VALID
  - EM RADIATION PROPOGATES AS WAVES
  - EM RADIATION INTERACTS WITH ATOMS AS ENERGY PACKETS OR PHOTONS

EM radiation is generated and absorbed in atomic and molecular processes as photons; EM radiation propagates as EM waves.

13	ELECTROMAGNETIC FUNDAMENTALS	SUMMARY	79

EM RADIATION IN ATOMS & MOLECULES

ATOMIC AND MOLECULAR STATES

TRANSITION BETWEEN STATES

ABSORPTION AND EMISSION OF EM ENERGY

Atoms consist of a nucleus surrounded by orbital electrons. The electrons tend to reside in the lowest total energy, or ground state, but may absorb electromagnetic radiation and enter a higher total energy, or excited state. From this excited state, the electron tends to radiate energy and then return to the ground state.

Molecules similarly may only exist in certain definite energy states. Absorption and emission may only occur between these states. In molecules, however, these levels are the vibrational and rotational states of the molecule.

EM Radiation can be absorbed by atoms and molecules only if it has the correct wavelengths, that is, the exact photon energies to raise atoms or molecules from an existing state to an allowable excited state.

Atoms and molecules have characteristic absorption and emission spectra because of this allowed forbidden behavior.

EM RADIATION AND PROCESSES

- ABSORPTION
- INVERSE SQUARE LAW
- REFLECTION, SPECULAR & DIFFUSE
- POLARIZATION & REFRACTION
- DIFFRACTION
- SCATTERING

EM energy is absorbed by materials according to an exponential law and ultimately appears mainly as heat.

Radiated energy per unit-area varies with the distance from the source according to the inverse square law.

EM waves reflected from surfaces are specular or diffuse.

EM waves moving into a medium with different optical properties are refracted according to Snell's law.

Polarization, reflection, and refraction can affect the measurement of EM radiation.

Diffraction is the spreading out of EM waves after they pass a barrier.

Scattering of EM waves can be a means of reducing energy intensity to safe levels.

13	ELECTROMAGNETIC FUNDAMENTALS	SUMMARY	81

FREQUENCY,	f [≡] Hz
WAVELENGTH,	λ [≡] M
SOLID ANGLE,	Ω [≡] Sr
RADIANT ENERGY,	Q [≡] WATT · SEC
RADIANT FLUX OR RADIANT POWER,	Φ [≡] WATT
EMITTANCE,	W [≡] WATT/Sr
EMITTANCE,	W [≡] WATT/m^2 (SOURCE)
RADIANT INTENSITY,	I [≡] WATT/Sr (SOURCE)
RADIANCE,	L [≡] WATT/m^2 · Sr (SOURCE)

13	ELECTROMAGNETIC FUNDAMENTALS	SUMMARY	82

RADIANT EXPOSURE,	H [≡] WATT·SEC/m^2
IRRADIANCE OR POWER DENSITY,	E [≡] W/m^2
DECIBEL,	db [≡] UNITLESS
EMISSIVITY,	ϵ [≡] UNITLESS
ABSORPTANCE,	α [≡] UNITLESS
ABSORPTION COEFFICIENT,	k [≡] 1/m
TRANSMITTANCE,	T [≡] UNITLESS
REFLECTION,	R [≡] UNITLESS
OPTICAL DENSITY,	O.D. [≡] UNITLESS

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LESSON PLAN NO. 14
MICROWAVES

14	MICROWAVES	OBJECTIVES	1

AT THE END OF THIS SESSION YOU WILL BE ABLE TO DEMONSTRATE YOUR KNOWLEDGE OF:

1. PROPERTIES AND SOURCES OF MICROWAVES
2. BIOLOGICAL EFFECTS OF MICROWAVES
3. MICROWAVE MONITORING EQUIPMENT
4. CONTROL OF MICROWAVES
5. REGULATIONS

OBJECTIVES

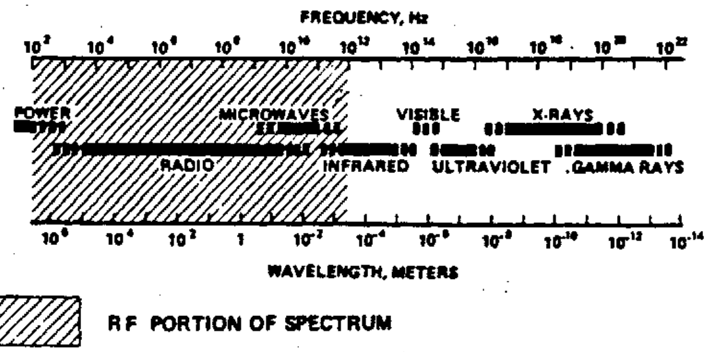
At the end of this two hour presentation you will be able to demonstrate, in a problem session, your grasp of the following subjects:

1. Properties and Sources of Microwaves
2. Biological Effects of Microwaves
3. Microwave Monitoring Equipment
4. Control of Microwaves
5. Regulations

A. INTRODUCTION TO MICROWAVES

14	MICROWAVES	INTRODUCTION	2

ELECTROMAGNETIC SPECTRUM



1. Electromagnetic Spectrum

The complete electromagnetic spectrum extends without definite upper or lower limits over a very large range of frequency. That portion of the spectrum with frequencies less than about 10^{12} Hertz is generally referred to as the Radio Frequency, or RF, Spectrum.

a. The Radio Frequency (RF) Spectrum

The R F Spectrum itself is divided into regions for convenience in discussing the various physical phenomenon observed. Broadcast radio waves are in the HF band; TV in the UHF and VHF bands.

Microwave radiation is generally considered to range from 100 MHz - 300 GHz. As such it is far removed from the ionizing classes of radiation such as X- and gamma-rays, and is thus classified as non-ionizing radiation.

14	MICROWAVES	INTRODUCTION	3

R.F. SPECTRUM BANDS

BAND DESIGNATION		FREQUENCY
ELF	EXTREMELY LOW FREQUENCIES	0– 3 KHz
VLF	VERY LOW FREQENCIES	3 - 30 KHz
LF	LOW FREQUENCIES	30 - 300 KHz
MF	MEDIUM FREQUENCIES	300 - 3000 KHz
HF	HIGH FREQUENCIES	3 - 30 MHz
VHF	VERY HIGH FREQUENCIES	30 - 300 MHz
UHF	ULTRA HIGH FREQUENCIES	300 - 3000 MHz
SHF	SUPER HIGH FREQUENCIES	3 - 30 GHz
EHF	EXTREMELY HIGH FREQUENCIES	30 - 300 GHz

1. Electromagnetic Spectrum (Continued)

b. Radio-Frequency Spectrum Band Designations

The RF spectrum band limits are shown above. These limits are not strictly adhered to, but are commonly accepted. Microwaves extend approximately from the middle of the VHF to the center of the EHF bands.

14	MICROWAVES	INTRODUCTION	4

MICROWAVE SPECTRUM BANDS

BAND DESIGNATION	FREQUENCY (MHz)	WAVELENGTH (CM)
P	225 - 390	133- 77
L	390 - 1550	77 - 19
S	1550 - 3900	19 - 7.7
C	3900 - 6200	7.7 - 4.8
X	6200 - 10,900	4.8 - 2.8
K	10,900 - 36,000	2.8 - 0.83
Q	36,000 - 46,000	0.83 - 0.65
V	46,000 - 56,000	0.65 - 0.54

c. Microwave Band Designations

The microwave region itself is divided into bands. Although these are a convenient form of nomenclature, they have no official status and there is not always agreement as to the frequency limits associated with each band. These bands are important to the radiation monitor because radiation in the different bands may be measured in different ways or using different equipment.

14

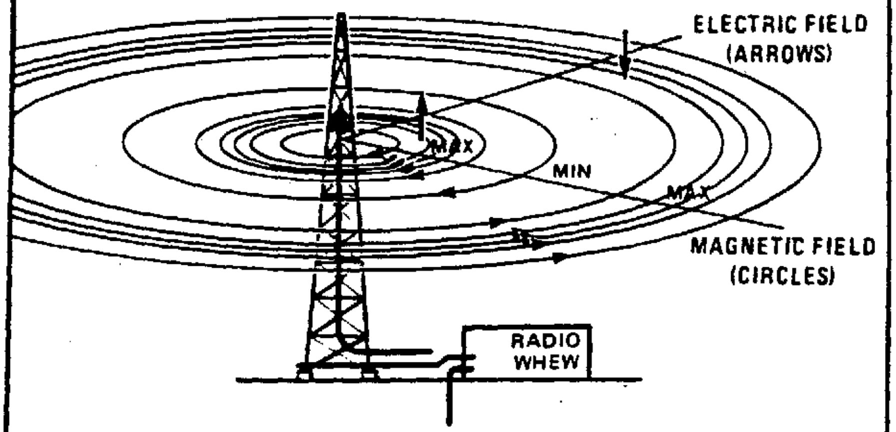
4A

(U) TABLE 1. COMPARISON OF COMMONLY USED BAND DESIGNATIONS

IEEE DESIGNATIONS	INTL FREQ DIVISION	ITU DESIGNATIONS	JCS/ECM BANDS	EXPANDED	WAVEGUIDE MANUFACTURERS
Millimeter 40 - 300 GHz	EHF 30 - 300 GHz	Band No 11 30 - 300 GHz	L&M Band 40 - 100 GHz	220 GHz	G - Band 140 - 220 GHz
Ka Band 27 - 40 GHz			K - Band 20 - 40 GHz		D - Band 110 - 170 GHz
K - Band 18 - 27 GHz					
Ku Band 12 - 18 GHz	SHF 3.0 - 30 GHz	Band No 10 3.0 - 30 GHz	J - Band 10 - 20 GHz	18.0 GHz	F - Band 90 - 140 GHz
X Band 8 - 12 GHz			I - Band	10 GHz 8.0 GHz	W - Band 75 - 110 GHz
C - Band 4 - 8 GHz			H - Band G - Band	6.0 GHz 4.0 GHz	E - Band 60 - 90 GHz
S - Band 2 - 4 GHz			F - Band E - Band	3.0 GHz 2.0 GHz	V - Band 50 - 75 GHz
L - Band 1.0 - 2.0 GHz	UHF 300 MHz - 3 GHz	Band No 9 300 MHz - 3 GHz	D - Band 1.0 - 2.0 GHz		U - Band 40 - 60 GHz
UHF 300 - 1000 MHz			C - Band B - Band 250 - 500 MHz		Q - Band 32 - 50 GHz Ka Band 26.5 - 40 GHz
VHF 30 - 300 MHz	VHF 30 - 300 MHz	Band No 8 30 - 300 MHz	A - Band 0 - 250 MHz		K - Band 18 - 26.5 GHz
HF 3.0 - 30 MHz	HF 3.0 - 30 MHz	Band No 7 3.0 - 30 MHz			

14	MICROWAVES	INTRODUCTION	5

RADIO WAVE PRODUCTION AND PROPAGATION



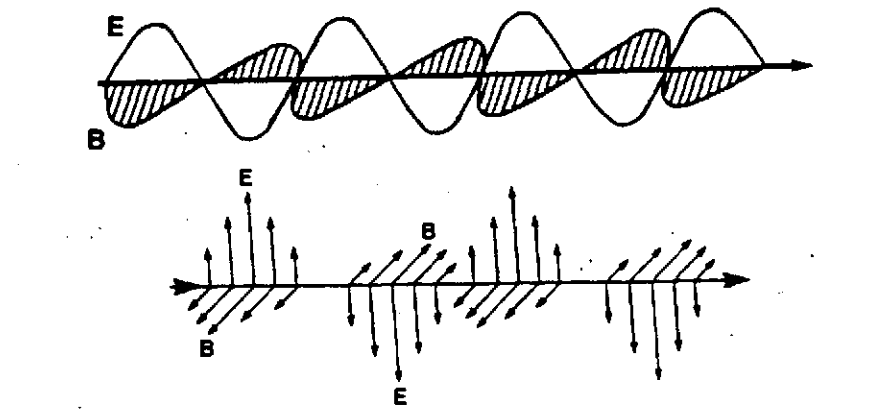
2. Properties of Microwaves

a. EM Field Generation and Propagation

An electric current in an antenna or other conductor made to oscillate at a certain frequency produces electric and magnetic fields in the vicinity of the antenna which propagate away from the antenna at the frequency of the current oscillation.

14	MICROWAVES	INTRODUCTION	6

ELECTROMAGNETIC FIELD



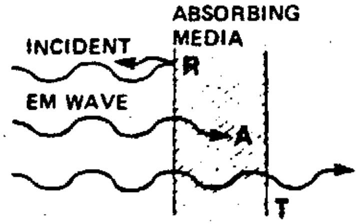
b. The Electromagnetic Field

Recall that an electric field is something that exerts a force on an electric charge. An E-field thus has both magnitude and direction, that is, it is a vector quantity. A magnetic field, B-field, is also a vector quantity.

At large distances from the source, the electric and magnetic field waves are transverse, meaning that they are at right angles to the direction of travel. They travel at a speed depending upon the medium, which is the velocity of light (3×10^8 m/s in vacuum.)

14	MICROWAVES	INTRODUCTION	7

ABSORPTION OF EM ENERGY



- ABSORPTION DEPENDS ON DIELECTRIC AND CONDUCTIVE PROPERTIES OF ABSORBING MEDIUM
- ENERGY NOT REFLECTED OR ABSORBED IS TRANSMITTED THROUGH MATERIAL

2. Properties of Microwaves (Continued)

c. Absorption of Electromagnetic Energy

The EM energy incident upon a material surface may be reflected or transmitted at the surface. That which is transmitted may be absorbed in the material or pass through.

As EM waves interact with atoms or molecules, they can deposit energy if their frequency (or wavelength) is such as to be able to cause a transition between the various energy states of the atoms or molecules. Microwave frequencies have too low an energy to ionize atoms, but they can excite molecular vibration or rotational states, or free electron states of metals. Because of the nature of these states, the absorption of EM energy depends upon the material composition as well as upon frequency, that is, the dielectric and conductive properties of the material.

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REFLECTION AND DIFFRACTION

EM WAVES REFLECTED BY SURFACES
- **SURFACE ELECTRON INTERACTION**
- **REFLECTION MAY POLARIZE WAVES**

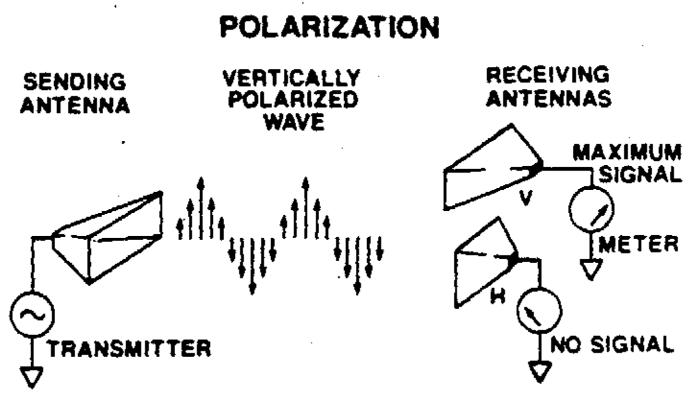
EM WAVES DIFFRACTED IN PASSING THROUGH APERTURE
- **INTERFERENCE PATTERNS**
- **FREQUENCY AND APERTURE DEPENDENCE**

2. Properties of Microwaves (Continued)

d. Reflection and Diffraction

Reflection—EM waves are reflected by those surfaces where they can interact with atomic electrons. These surface electrons are set into vibration and re-emit the wave which we observe as the reflection. Because of this, the reflected waves are at least partially polarized.

Diffraction—EM waves passing through apertures or past barrier edges are diffracted, or bent, to form interference patterns. This effect depends upon frequency and aperture sizes and spacings. Nulls and maxima are observed as a result of superposition. Many microwave antennas operate using the principle of superposition. Thus, waves emitted from different parts of the antenna add in phase in the direction the antenna is pointing, and cancel in most other directions.



2. Properties of Microwaves (Continued)

e. Polarization

A microwave antenna concentrates the microwave energy into a shaped radiation field. This field is made up of an electric field (E-field) and a magnetic field (B-field). In free space, these two fields are at right angles to each other and move through space at the speed of light. The polarization of an antenna is defined as the orientation of the electric field vector of the radiated field.

A receiving antenna acts as a conductor upon which the incident E-field wave can "induce" current (electrons) to flow. Therefore, antennas designed to receive a given direction of polarization may be insensitive to a 90° cross-polarized wave.

For maximum transfer of energy, a receiving antenna must have the same polarization as the transmitting antenna. That is not to say that antennas which are not of the same polarization cannot be used together. In the case where the antennas are not the same, the energy transferred depends on the exact polarization of each antenna. For example, if the transmitting antenna is circularly polarized and the receiving antenna is linearly polarized, then the receiving antenna only detects half of the energy beamed at it. Each combination must be analyzed as a separate case.

14	MICROWAVES	INTRODUCTION	10

BASIC MICROWAVE QUANTITIES AND UNITS

- POWER DENSITY – WATTS/cm^2
- ENERGY DENSITY – JOULES/cm^3 OR WATT SEC/cm^3
- POWER RATIO – DECIBEL
- ABSORBED POWER DENSITY (W/kg) (SPECIFIC ABSORPTION RATE, SAR)

2. Properties of Microwaves (Continued)

f. Microwave Quantities and Units

The quantities and units commonly used in microwave hazard survey work are power density, in units of watts/cm^2; energy density, in units of joules/cm^3; and power ratio, in decibel units. Power density is the rate at which EM energy is present on a unit of space. Decibels are a logarithmic measure of power level ratio, where one power level P_m, a measured value, is compared with another, P_s, a conventional standard. Then, the number of decibels is

$$dB = 10 \log_{10} P_m/P_s$$

As an example of the use of the decibel unit, consider a meter reading of 20 dB over a reference (standard) power density value of 10 mW/cm^2. The meter is actually sensing a power density level of 1.0 W/cm^2, since

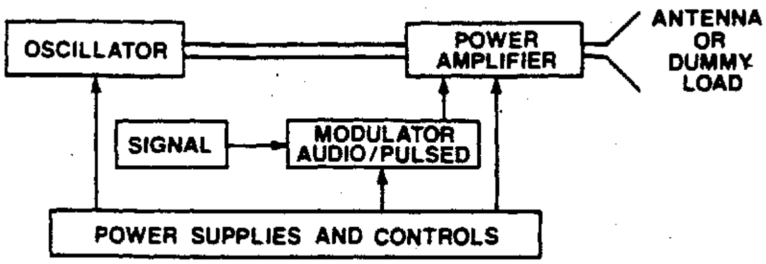
$$20 \text{ dB} = 10 \log_{10} \left(\frac{1.0 \text{ Watt/cm}^2}{10 \text{ mW/cm}^2} \right)$$

The student should verify this calculation.

The quantity of interest in biological effects of microwaves is the amount of power being absorbed at different points within the body. The rate of energy (power) absorption per unit mass of tissue at a point is called "absorbed power density," or "Specific Absorption Rate," abbreviated "SAR". Typically the SI units "Watts/kg" are used for the quantity SAR in the literature.

14	MICROWAVES	INTRODUCTION	11

GENERATION OF MICROWAVES
OSCILLATOR-POWER AMPLIFIER



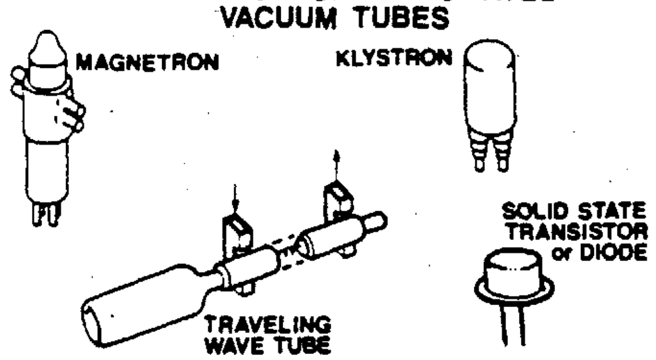
3. Generation of Microwaves

    a. Oscillator — Power Amplifier

    Equipment to generate microwave radiation generally includes an oscillator and power amplifier, an antenna or load, a means of modulating the RF, power supplies, controls, interconnecting cables, waveguides, wave coupler and, perhaps, an enclosure to contain the EM energy.

    A dummy load is often used instead of an antenna while the RF or microwave source is being tuned or tested, to avoid broadcasting or beaming of the RF energy into the environs.

GENERATION OF MICROWAVES
VACUUM TUBES



3. Generation of Microwaves (Continued)

b. Vacuum Tube

Power amplifiers for microwave production are generally vacuum tube devices of different configuration.

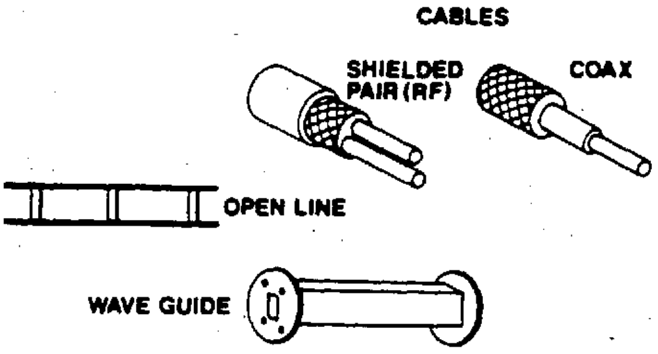
MAGNETRON. This type of tube is used for both high and low power generation at microwave frequencies. The magnetron is a vacuum diode on which a magnetic field is imposed. Electrons emitted by the cathode are influenced by the DC electric field and the magnetic field prior to reaching the anode.

The electrons are constrained by the fields to move past gaps (resonant cavities) in the anode and their kinetic energy is coupled into these cavities as RF field energy.

KLYSTRON. Klystrons are designed either as an oscillator or amplifier in the microwave region. All klystrons operate on the principle of velocity modulation. A beam of electrons is formed in an electron gun, then sent through a gap of a resonant cavity. A high frequency voltage signal across the cavity gaps alternately accelerates and decelerates the beam electrons. As a result, the electrons form into bunches along their axis of travel. A second resonant cavity is positioned so as to extract energy from these bunches of electrons as they pass through it. This RF energy is then taken out of the cavity by a waveguide or other coupler. A small fraction of the energy may be used to drive the first (buncher) cavity, making the klystron an oscillator.

TRAVELING-WAVE-TUBE. The TWT is a high gain device for amplifying frequencies in the microwave region. In the TWT a beam of electrons is generated by an electron gun, then transmitted through a helix coil which will slow them down, then they impinge on a collector. The helix structure propagates an electromagnetic wave at the same velocity as the electron beam. The motion of these electrons through the structure couples their kinetic energy into the EM field, building it up in intensity. It is then coupled out for use in some external circuit. This output power is the input signal, amplified. An external magnetic field is normally used to provide focusing of the beam.

RF AND MICROWAVE TRANSMISSION LINES



3. Generation of Microwaves (Continued)

c. Transmission Lines

The choice of transmission line for any specific microwave circuit depends on the amount of power to be transmitted, the frequency of the energy, and the length of line needed.

THE SHIELDED PAIR. The shielded pair is used mainly for frequencies up to 30 MHz. Above this frequency excessive losses occur in the insulating material. Open lines may be used up to about 100 MHz.

THE COAXIAL LINE. The coaxial line is used as a transmission line for frequencies up to 3,000 MHz.

WAVEGUIDES. At frequencies above 3,000 MHz the waveguide must be used as a transmission line. This type of line consists of a length of circular or rectangular metal pipe. The physical size of the waveguide depends on the frequency of the microwave energy, therefore an inconveniently large guide would be required to act as a transmission line for very low frequencies, and an inconveniently small guide would be required for very high frequencies. The width of the waveguide must be on the order of the wavelength to be transmitted through it. A microwave frequency of 3,000 MHz would require a waveguide width of 3 inches while the standard broadcast band frequency of 1.5 MHz would require a waveguide width of approximately 350 feet.

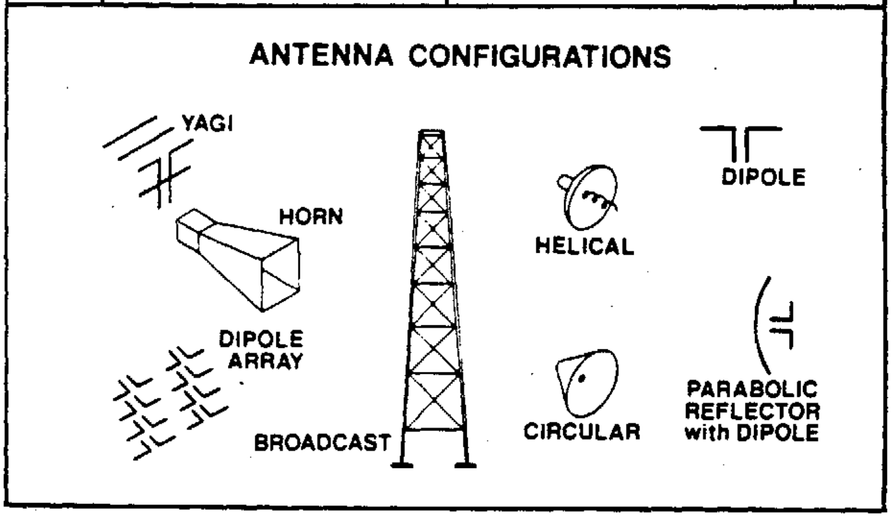
14	MICROWAVES	INTRODUCTION	14

3. Generation of Microwaves (Continued)

d. Antennas

At microwave frequencies it is possible to radiate electromagnetic energy in such a manner that the radiated energy gives increased power in a particular direction. This is accomplished by the antenna. The directivity and focusing effects of antennas in the microwave region are very similar to a spotlight producing beam of light. Antennas are produced in many configurations. In the radio-frequencies, a single vertical metallic rod is utilized as an antenna whereas the television frequencies, because of the need for directionality, require an antenna consisting of a horizontal rod with a second rod used as a reflector. At the higher microwave frequencies the antenna configuration is usually a parabolic section of metal, either circular or rectangular, and may be as small as 30 inches in diameter or as large as 150 feet in diameter.

14	MICROWAVES	INTRODUCTION	15



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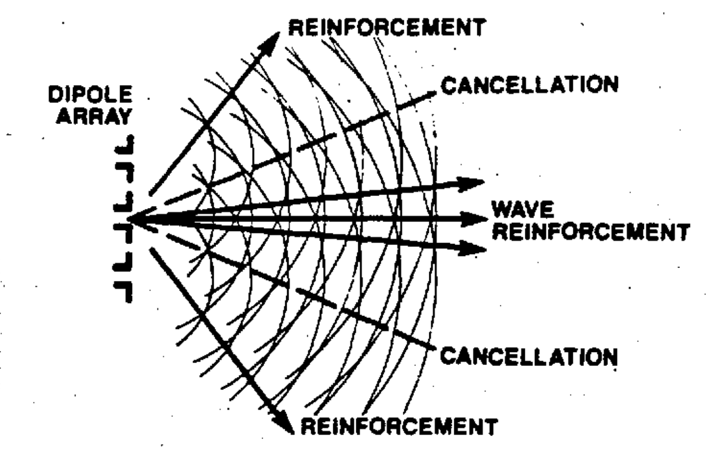
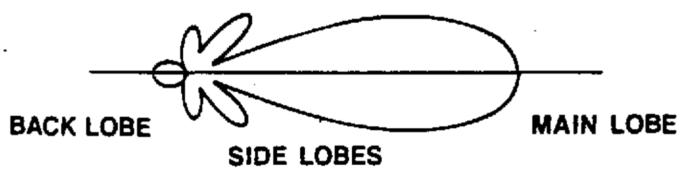


Antennas often are designed to "beam" or focus RF power in some particular direction. This may be accomplished by reflectors, by horns, or by use of interference patterns from arrays of antennas. Even a simple dipole antenna (see previous chart) radiates non-isotropically, that is, differently in different directions.

An array of dipoles, each radiating wave preferentially at right angles to its lengthwise axis, can be used to beam RF energy. The configuration and the phase of the feed energy to each antenna is designed so that waves from different dipoles will reinforce (E-fields add) in the desired direction, and cancel (E-fields subtract) in other directions.

ANTENNA RADIATION PATTERN



Typically, from any directional antenna, in addition to the "main lobe" or direction into which most of the energy is beamed, there are directions of secondary reinforcement, or "side lobes," into which some energy is also radiated. Radiation protection personnel must be aware of these side (and sometimes even backward) lobes, since significant amounts of power density may be radiated in them.

The chart shows a typical antenna pattern, with main, side and back lobes. The size of the lobe indicates the relative signal strength in any particular direction.

14	MICROWAVES	INTRODUCTION	18

ANTENNA GAIN

A = P.D. at distance R

$A = GAIN \times \frac{P}{4\pi R^2} \left(\frac{W}{Cm^2}\right)$

ISOTROPIC RADIATION PATTERN

$\frac{P}{4\pi R^2} \left(\frac{W}{Cm^2}\right)$ = P.D. at distance R

Antenna "gain" is the ratio of the power transmitted along the principal beam direction (A) to that which would be present if the power were radiated isotropically (in all directions equally), (B). Arithmetically, gain is defined as A/B). In decibel units, gain (db) = $10 \log_{10}(A/B)$ db.

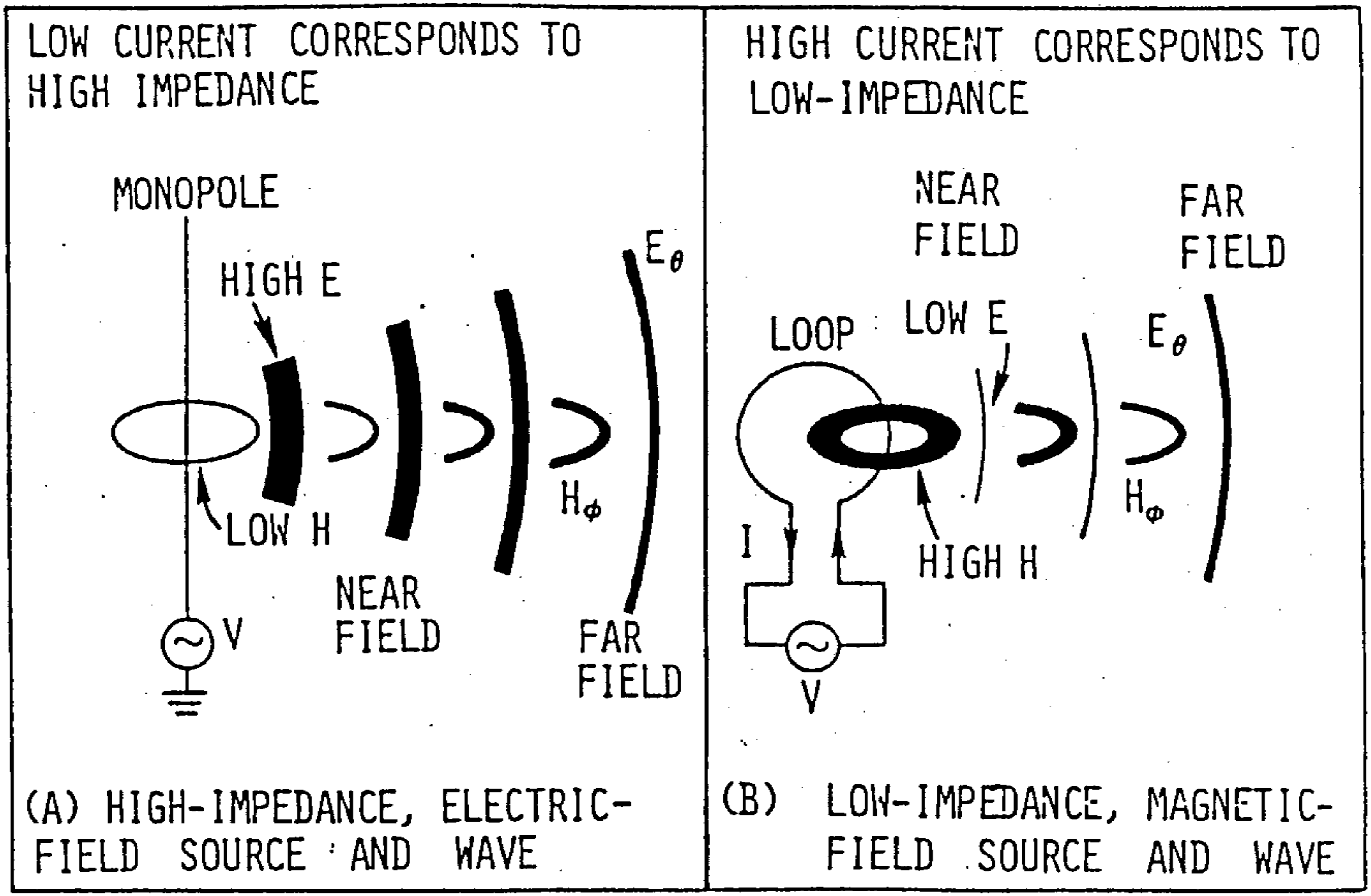
If P is the power radiated, then $P/4\pi R^2$ is the power density that would be found at distance R (in the far field) if the antenna radiated isotropically. (This is just the total power divided by the area of a sphere of radius R.) With the real antenna, if one measures a power density A (W/cm^2) at the distance R (cm) along the main lobe, then the antenna gain along that lobe is

$$\text{Gain} = (A(W/m^2))(4\pi R^2 (m^2))/P\ (W),$$

according to the definition above. (The student should verify this.) Gain usually refers to the main lobe power, but can also be used to describe the side or back lobes.

14 19A

CONCEPTUAL ILLUSTRATION OF FIELD INTENSITIES VS SOURCE TYPE AND DISTANCE



RADIO-FREQUENCY QUANTITIES

- E-FIELD (E) VOLTS/METER, V/m
- M-FIELD (H) AMPERE-TURNS/METER, AT/m
- POWER DENSITY $\propto |E \times H|$

$Pwr = \frac{E^2}{Z}$ (Z = impedance) watts/cm² $= \frac{E^2}{377}$ { FREE SPACE FAR-FIELD ($E \propto H$) }

(377 ← Z of Free Space)

- ABSORBED POWER DENSITY

SPECIFIC ABSORPTION RATE (SAR), Watts/kg

POWER DENSITY OF EM WAVE

$\propto (E^2 + H^2)$

- IN <u>FAR FIELD</u> $E \propto H$

  $\therefore$ P.D. $\sim E^2 = \frac{E^2}{377\,\Omega}$

  p.d. meter reading

  impedance of free sp

- IN <u>NEAR FIELD</u> $E \not\propto H$

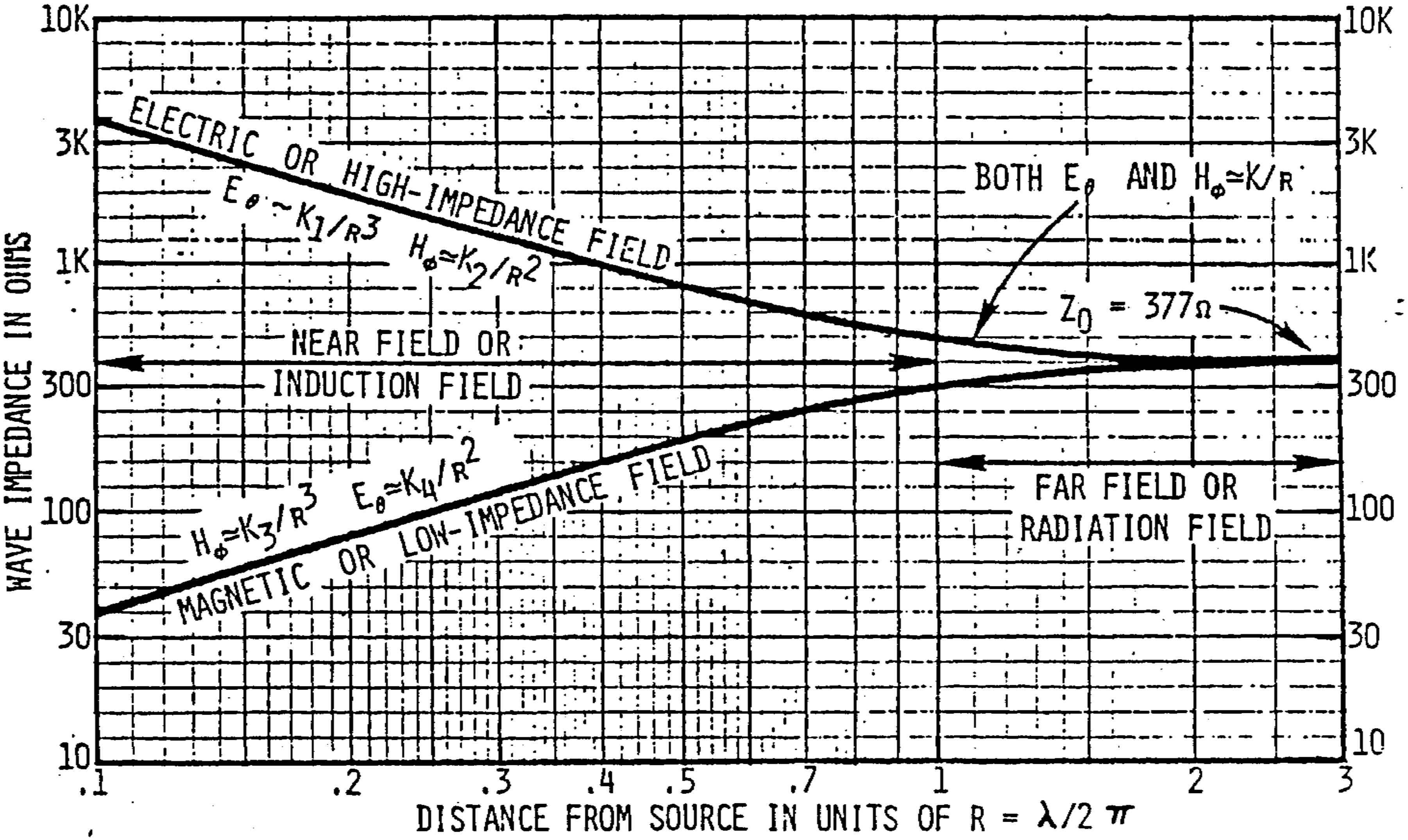
  $H^2 \times 377$ } $\frac{E^2}{377}$ ..

  $\therefore$ MUST DETERMINE E, H SEPARATELY.

  $\therefore$ ANSI STANDARD REQUIRES THIS

14 19D

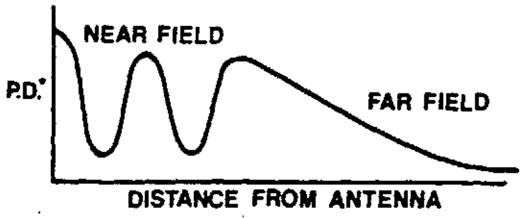
FIELD IMPEDANCE AS A FUNCTION OF SOURCE DISTANCE



14	MICROWAVES	INTRODUCTION	19

NEAR-FIELD AND FAR-FIELD

- CLOSE TO ANTENNA E AND B FIELD RELATIONSHIPS GENERALLY ARE NOT ESTABLISHED
- IN NEAR-FIELD WIDE VARIATIONS IN POWER DENSITY AND POLARIZATION



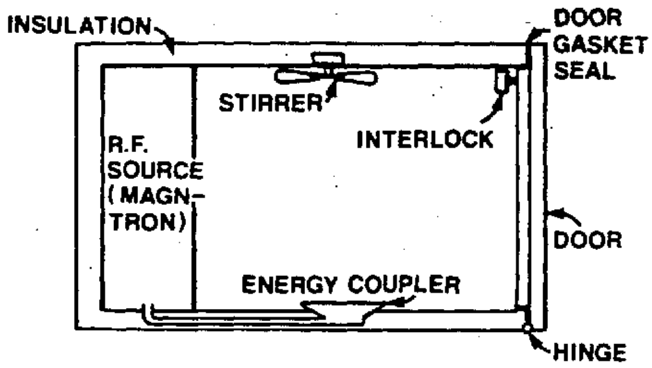
*DIFFICULT TO INTERPRET MEASUREMENT IN TERMS OF P.D.

A subject of extreme importance in the problem of microwave hazards and measurement is the distinction between "far-field" and "near-field." Close to an antenna, or any RF source, the E-field and B-fields are generally not established in their perpendicular, in-phase relationship that characterizes the transverse wave propagation shown on an earlier chart. The E- and B-fields may vary drastically over short distances, in both their magnitudes and directions, as well as in their mutual angular relations. This fact poses questions of what an RF probe (antenna) is actually measuring, and how to relate what it measures in the "near-field" to quantities such as power density or absorbed power.

As one measures the EM field at increasing distances from the antenna, these large fluctuations of the near field subside. At larger distances the E- and B-fields gradually become established as mutually perpendicular and in-phase. The power density, which is proportional to the product of E and B when they are perpendicular and in-phase, then falls off smoothly according to the inverse square law. This is the "far-field."

14	MICROWAVES	TYPES OF SOURCES	20

MICROWAVE OVEN SCHEMATIC



1. Heating Sources

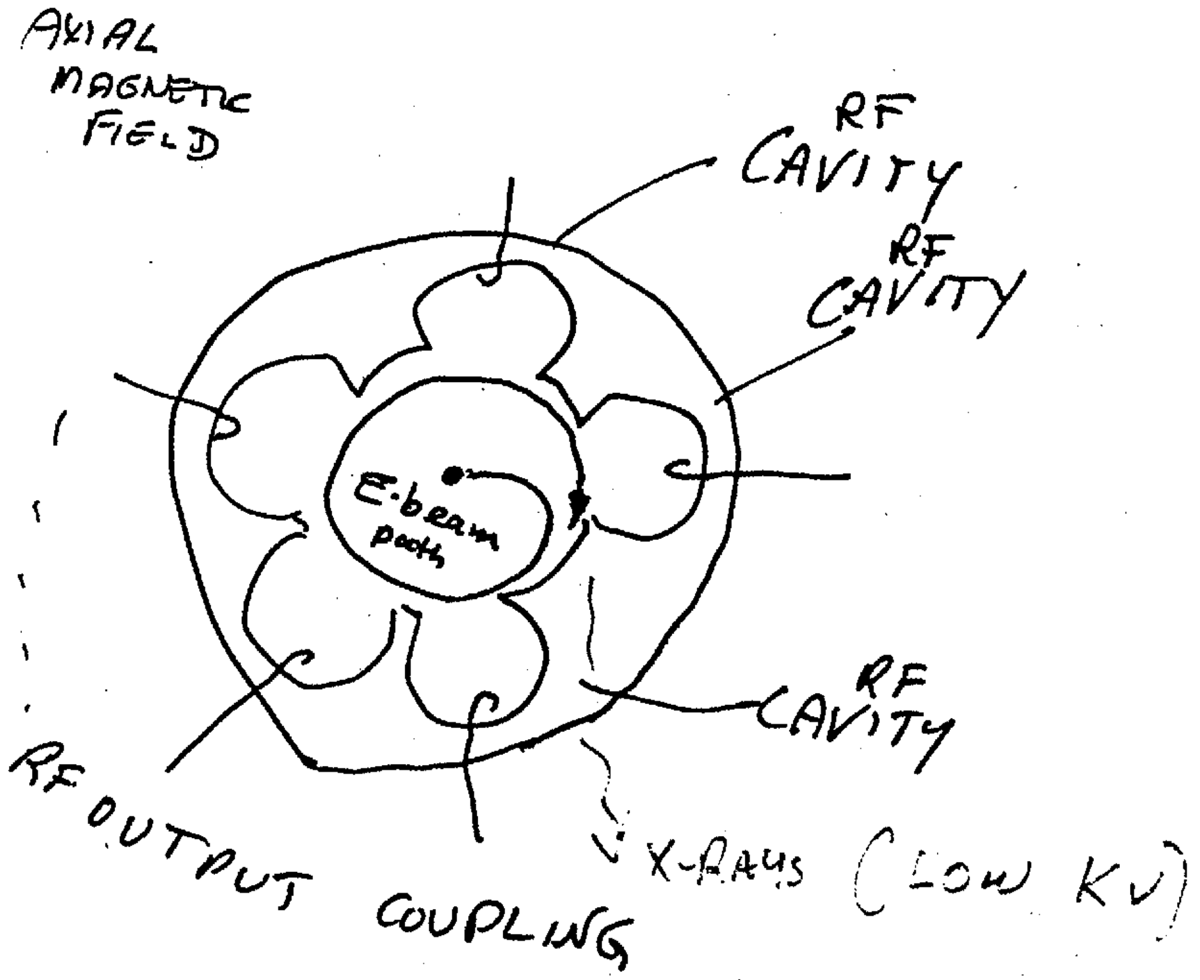
a. Microwave Oven

Probably the greatest single increase in the use of microwave radiation within the last two years is the microwave oven or range. This device has been used for several years for food preparation by commercial restaurants and the military, and now is available for home use. Some estimates put the microwave oven purchase as 25% of all ovens bought in the United States by 1976, or approximately 1.8 million ovens. The advantages of microwave cooking as compared to more conventional methods are: (1) Only the food is heated, not the oven walls, therefore cleaning is accomplished easily and cooking is more efficient. (2) The food is cooked throughout rather than only from the surface inward. (3) Cooking time is usually on the order of a few minutes rather than hours.

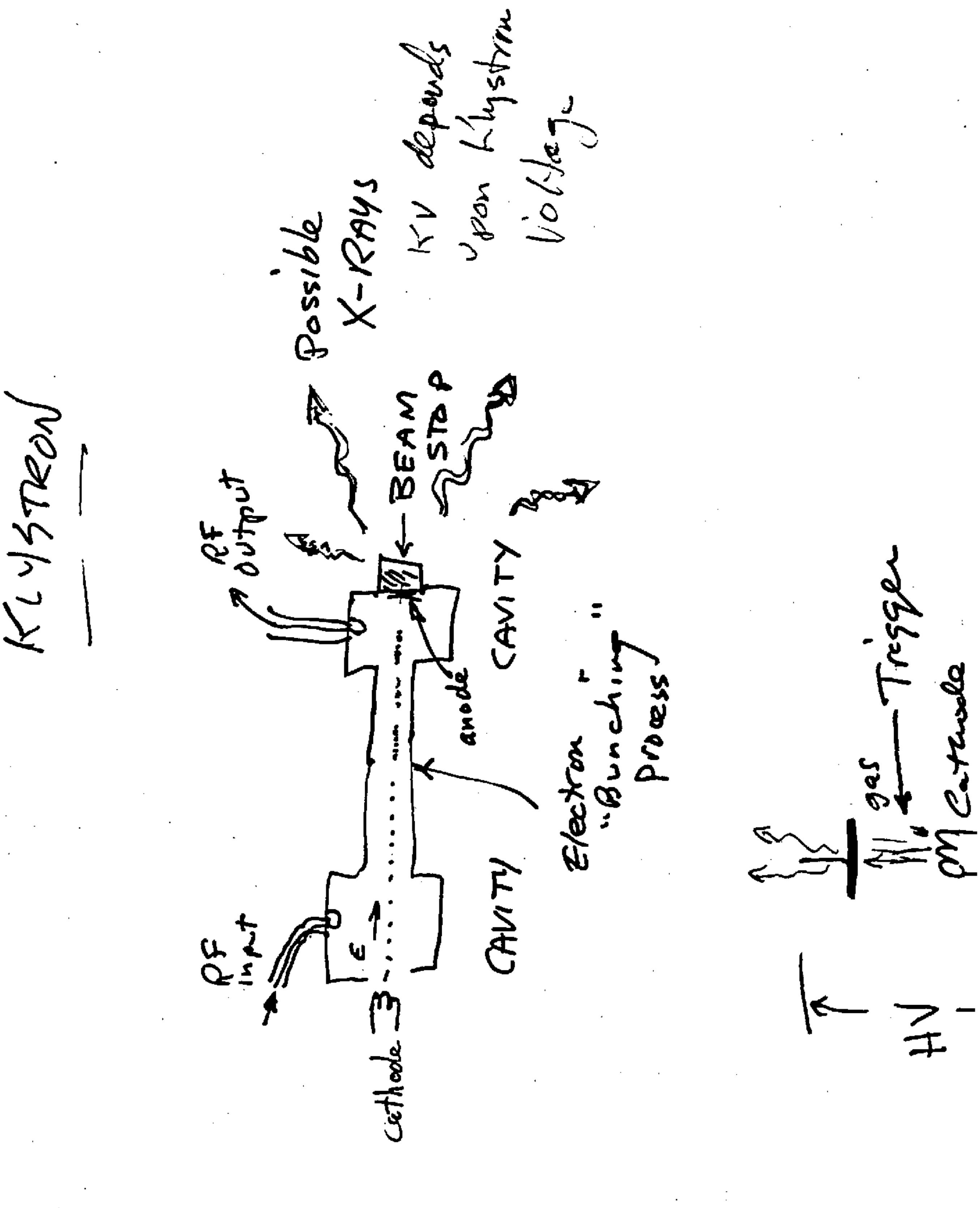
Microwave ovens operate at either 915 or 2450 MHz. Most manufacturers use the 2450 MHz band for these ovens.

The oven typically has a magnetron source, a means of coupling RF energy, controls for turning off and on at desired times, a stirrer to uniformalize the average field inside the oven, and a gasket seal to prevent RF field leakage. Also, there is an interlock switch to turn off the power automatically if the door is opened.

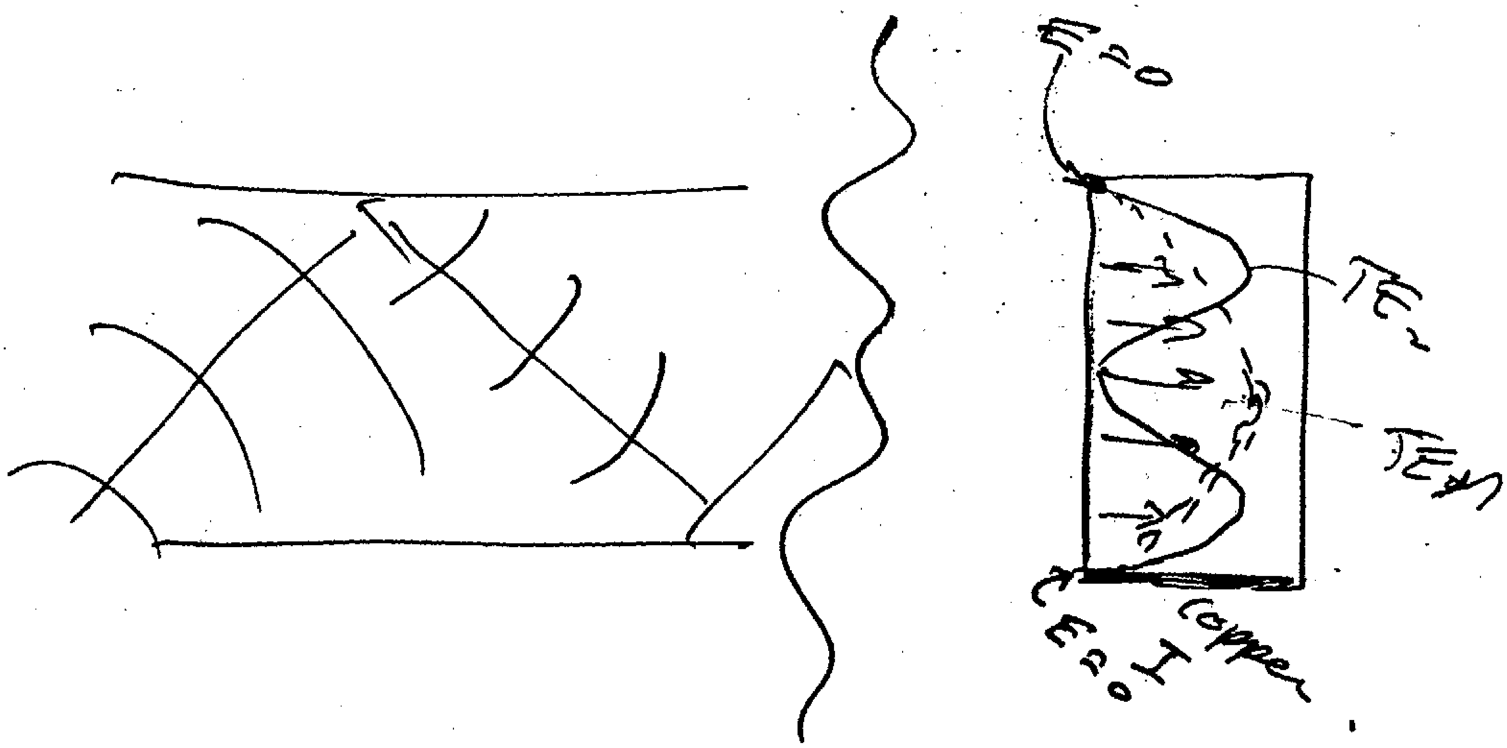
MAGNETRON


AXIAL
MAGNETIC
FIELD
RF
CAVITY
RF
CAVITY
E-beam
path
RF
CAVITY
RF OUTPUT COUPLING
X-RAYS (LOW KV)

14

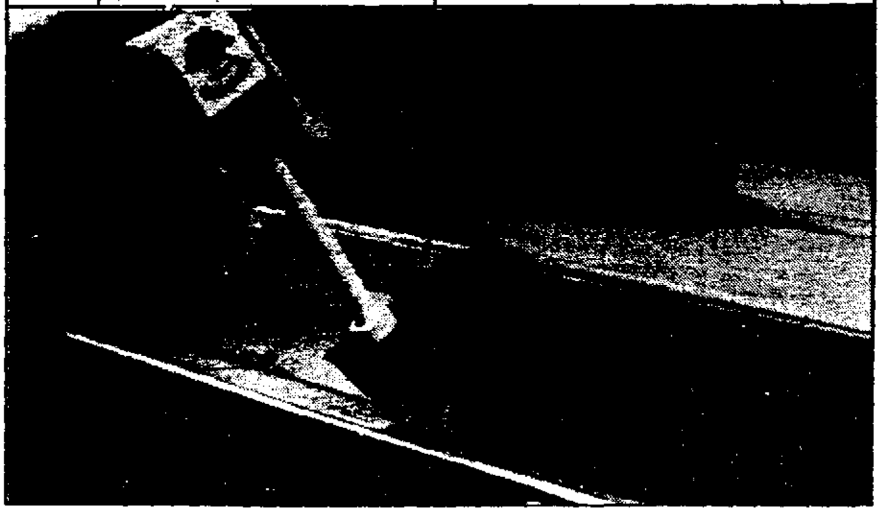

KLYSTRON
RF Input
cathode
E
CAVITY
CAVITY
RF output
anode
BEAM STOP
Possible X-RAYS
KV depends upon klystron voltage
Electron "Bunching" process
HV
gas
Trigger
Cathode

WAVE-GUIDE MODES



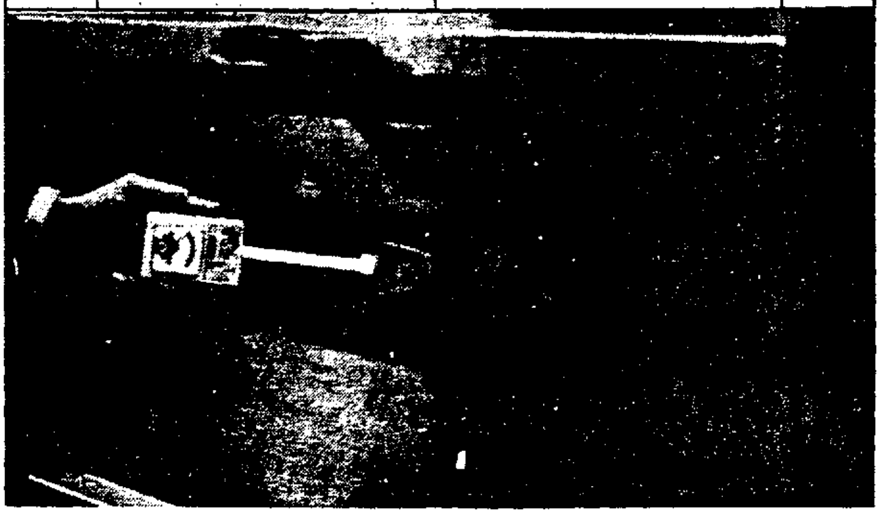
B. TYPES OF SOURCES

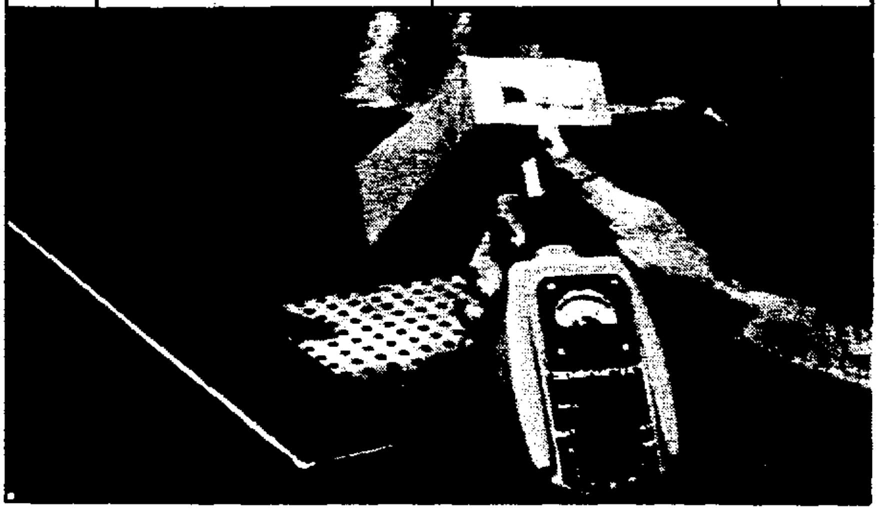
14	MICROWAVES	TYPES OF SOURCES	21



In surveying a microwave oven, one uses a standard probe (antenna), and checks the various possible apertures for leakage, for example, the door seals, vents, etc. We will discuss these probes and the measurement methods later.

14	MICROWAVES	TYPES OF SOURCES	22





1. Heating Sources (contd.)

   b. Potato Chip Drying

   The potato chip driers in use today in the U.S.A. have a microwave power output of 50 kW and an operating frequency of 916 MHz. The choice of frequencies is based on the availability of reliable high power magnetrons, on practical considerations of equipment size having proper energy densities for this application, and on the dielectric properties of potato chips at the two lower ISM microwave bands. The dielectric properties of potato chips and of the oils commonly used in the potato chip industry dictate the use of an operating frequency of 916 MHz in semi-resonant tunnel applicators.

   A 50 kW system will handle a production rate of between 1400 and 2000 lb/hr of finished chips, depending on the input moisture content of the chips. Bed depths on the finish drying tunnel conveyors range from 3-inches to 6-inches depending on moisture throughout and residence time requirements. Typically a microwave potato chip dryer is operated at a constant power level of 50 kW; the input air temperature is set at 220°F and the residence time in treatment portion of the tunnel is about 3 minutes.

RF Applications

Plastic sealers 20 – 40 MHz

Induction heating — Plasma etching 14 MHz.

Wood drying / Paper drying 915 1000 MHz

- Medical diathermy / tumor treatment 27-29 MHz → 400 MHz.
- Food production / cooking 2-4 GHz
- radar 100 MHz → 100 GHz
- communications, telephone, TV, radio 8-20 GHz — 100 MHz

PAPER DRYING

PREVENTS OVERDRYING

FREQUENCY 2450 MHz

POWER 50 KW

1. Heating Sources (contd.)

c. Paper Drying

Microwave drying results in accurate three dimensional paper moisture leveling, without overdrying. Overdrying is a common practice with conventional drying equipment in order to achieve leveling. Paper with a uniform moisture profile has better converting characteristics, printability and end product quality. Drying only to the required moisture content reduces power cost and eliminates the irreversible, undesirable effects of overdrying on paper quality.

Microwave drying has a number of advantages in the coating section of the paper machine. Since the paper does not physically touch the microwave dryer, the coating is set before a roll is contacted. The paper is dried from the inside outward and any binder migration problems are minimized. Further, microwave drying prior to the coater presents a level moisture profit at the coater which results in even and uniform coating application.

Microwave drying is self-compensating since the wettest areas automatically and instantaneously receive the greatest amount of energy. A minimum of skill is, therefore, required to operate the machine. Replaceable items that cause moisture variation will have longer life since greater variation in moisture level prior to the microwave drying sections will be allowable. A product with pre-determined thickness and moisture content would be more easily reproducible on a new start-up after a change of grade or other shut down. Microwave drying provides a diagnostic means of control. If moisture is level, variations in basic weight must be due to variations in fibre content. This indicates the need for adjustment at the forming section of the machine. Paper with more uniform basis weight should result.

Microwave drying instantly responds to moisture streaks, automatically applying more energy to the wettest portion of the paper. The result is a product with a more uniform three-dimensional moisture content with greater strength, better printability, and higher overall quality.

14	MICROWAVES	TYPES OF SOURCES	25

VENEER DRYING

BENEFITS

A. CLOSE MOISTURE CONTROL
B. MOISTURE CONDITIONS CAN BE VARIED
C. TOTAL DRYING PROCESS COST ARE DIMINISHED
D. VENEER QUALITY IS ENHANCED
E. FREQUENCY 915 MHz AND 50 KW POWER

1. Heating Sources (contd.)

d. Veneer Drying

Veneer for plywood must be dried after the initial processing. In this application, microwave heating has a natural propensity to concentrate energy where moisture is greatest. Major interest in plywood processing is bonding and drying of various coatings to the wood, allowing installation of pre-finished plywood in buildings and other applications without costly finishing.

Veneer moisture contents vary widely due to difference between heart and sap wood, knot-formation, grain growth and other characteristics. This variation causes severe problems in veneer drying. Microwave processing provides an answer to this problem.

Exposure to microwaves actually results in a lowering of moisture content in those few areas that are excessively wet without drying the areas which are initially acceptable. This has been the goal of veneer drying for many years, but it has been unattainable with conventional heat sources.

A microwave veneer redryer now in operation uses both microwave power and conventional hot air and, by varying the speed and air temperature, can produce the degree of moisture leveling required for the veneer being processed. This is important to the plywood producer since face and back veneer (the exterior sheets) may contain higher moisture contents than core veneer (the interior sheets) and, as stated before, over-drying results in reduced strength and dryer productivity.

The redryer has 50 kW of 915 MHz microwave power and employs a slotted waveguide applicator. The hot air system is gas fired and the unit is capable of processing up to 24,000 surface feet of veneer per hour.

14	MICROWAVES	TYPES OF SOURCES	26

CHICKEN PARTS

CONVEYOR SYSTEM
2450 MHz
2 KW MAGNETRONS

1. Heating Sources (Continued)

   e. Cooking of Chicken Parts

   A typical large system is a chicken cooker which has 54 independent,2 kW magnetrons,feeding the large multimode resonator through which chicken parts pass at the rate of over a ton per hour. Each chicken is cut up and carried along 100 meters of conveyor through nine operations: 5 minutes of microwave cooking at 85°C, chilling, battering, breading, deep fat frying, a second chilling, freezing at -25°C, sorting into package sets and packaging and weighing. It was previously difficult to cook chicken parts uniformly by raising the surface temperature to any particular value, simply because the parts vary in size and shape. With microwaves it is possible to obtain much more uniformity and so obtain a higher yield of usable product. The storage life is also improved for reasons that are not well understood and labor costs are drastically reduced.

PASTEURIZATION

A. EFFECTIVE
B. RAPID
C. PASTEURIZE IN CONTAINER

1. Heating Sources (Continued)

f. Pasteurization

Microwaves have been found to be very effective as a heat source for pasteurization. This is especially true in the case of fungi or molds and non-spore forming bacteria. Due to the rapid penetration and heat generation of microwaves deep within the product, the times required for pasteurization are substantially shorter. For instance, the time period required for microwave pasteurization is generally 2 to 3 minutes, in comparison to 10 to 100 minutes by conventional means. The lengthy time periods in the latter case are due to the slow rate of heat penetration throughout the product. Once the temperature is up to that of pasteurization, the micro-organism is usually killed in a matter of seconds or minutes.

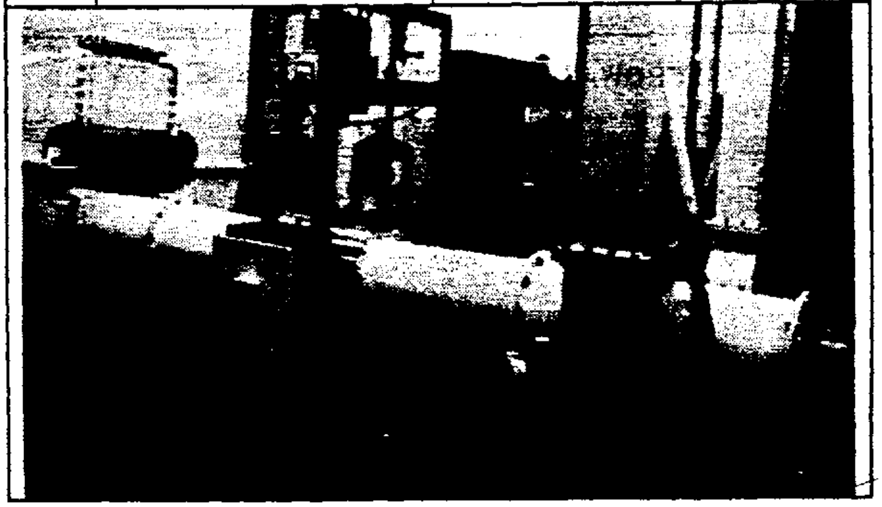
Often, a given product can be successfully pasteurized in its final glass, plastic or paper container. The package then remains free from outside contamination as long as the seal is intact.

1. Heating Sources (Continued)

   g. Ceramics

   This oven is used for curing of ceramic parts. It consists of two power supplies each with its own individual waveguide. The power supplies may be operated individuallv or together. The microwave source is a magnetron at a frequency of 2450 MHz and maximum power of 2 kW.

14	MICROWAVES	TYPES OF SOURCES	29



1. Heating Sources (Continued)

h. Pultrusion Curing

Pultrusion involves the pulling of resin-impregnated fibers through a shaped die while effecting a continuous cure of the composite material simultaneous with its compaction during passage through the die.

Conventional heating methods using conduction, convection, or radiation for heat transfer will not meet pultrusion curing requirements for a system that is very fast (200^{o}F/min rate of rise). A microwave oven, however, is compatible with composite materials, and provides uniform heating rate throughout the material cross section. A continuous process to be practical, requires cure time reductions to seconds or minutes. Microwave heating penetrates to the section interior to heat its entire area at the same rate, making it many times faster than conventional heating methods.

The curing process is accomplished by microwaves and a frequency of 915 MHz and 30 kW of power.

MEDICAL DIATHERMY

- APPLICATION OF THE HEATING PROPERTIES OF RF ABSORPTION
- DEEP TISSUE HEATING
- CONTROLLED POWER

1. Heating Sources (Continued)

   i. Diathermy

   Medical diathermy is an application of the heating properties of RF absorption, using the 27.3, 915, and 2450 MHz frequencies, in carefully controlled power levels to warm deep tissues.

   Medical diathermy heating pads use much less power than ovens, typically less than a kilowatt available in the RF source, depending upon the energy transfer efficiency of the pads.

14	MICROWAVES	TYPES OF SOURCES	31

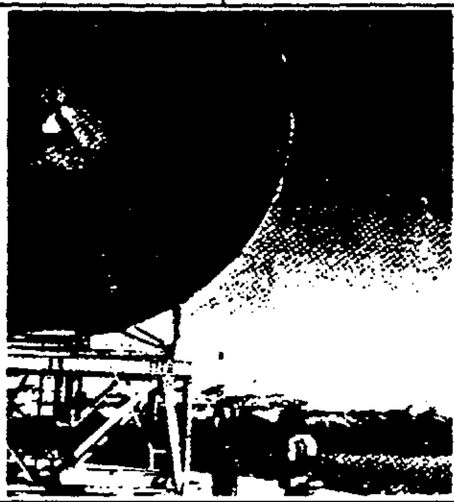
2. Information Conveying Sources

a. Communications

1) Radio

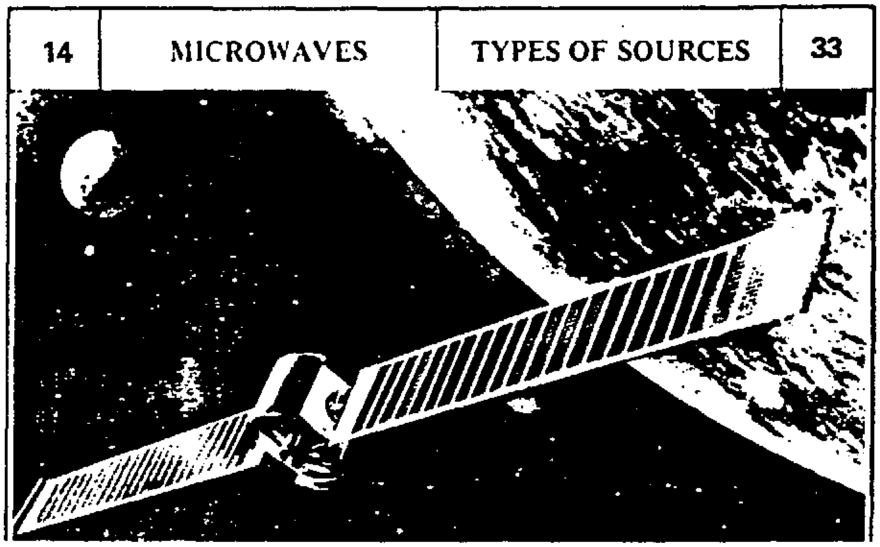
This is a relay link installation, which is a familiar sight across the continent. In this system, the total radiated power is so low, that conditions are safe anywhere in the beam of the antenna.

14	MICROWAVES	TYPES OF SOURCES	32



2) Telephone

Slide 28 shows an antenna for a tropospheric scatter propagation communication link. The power of this transmitter is high enough to warrant a field strength survey in front of and around the antenna. In this system calculations indicated that a protective fence was needed. After the fence was erected, measurements (at half power) indicated that the power density outside the fence would be less than 10 mw/cm^2 at full power, a value which is 1/10 that which is considered safe for indefinite exposure.

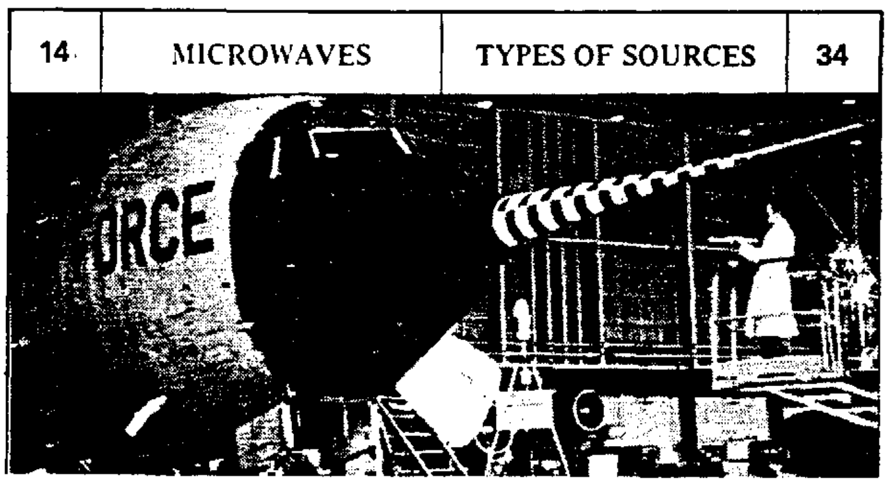


2. Information Conveying Sources

a. Communications (Continued)

3) Television

The newest advance in microwave communications to lessen the line-of-sight problem is satellite communications. Both civilian and military communications agencies have progressed to the point where both now have operating networks utilizing various satellite systems. The two types of satellites now in use are active satellites (containing receivers and transmitters so that a received signal is retransmitted by the satellite) and passive satellites (simply serves as a reflector for earth-based transmitters and receivers). Since the passive type reflects signals, systems using this type of satellite require much greater transmitter power outputs than do active satellites.

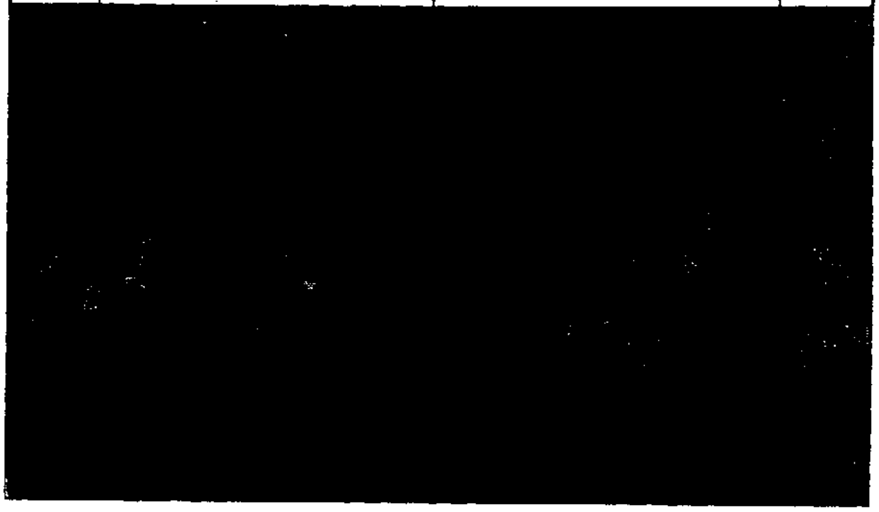


b. Detection Radar

1) Weather

This slide shows a man surveying the weather radar. The frequency will normally be in the C or X band. Hazardous distance will vary considerably due to the different types of aircraft on which the radar system is used.

14	MICROWAVES	TYPES OF SOURCES	35



2. Information Conveying Sources

   b. Detector Radar (Continued)

   2) Research and Development

   These antennas are at an R&D installation. As can be seen the fence around the antennas is located rather close to the antenna itself. This is due to the very lower power at which they operate.

14	MICROWAVES	TYPES OF SOURCES	36

This slide shows another R&D installation, this one being located some distance from the ground. If high power is used, the distance from ground to antenna should provide enough distance to keep personnel out of the hazardous area.

14	MICROWAVES	TYPES OF SOURCES	37

DETECTION RADAR

OTHER USES:

A. TRAFFIC CONTROL

B. SECURITY

2. Information Conveying Sources

   b. Detection Radar (Continued)

      3) Other Uses

         a) Police car microwave monitors can keep track of an entire city's police force and enable police controllers to respond to emergencies by sending the nearest patrol car. That public all-time favorite, the police radar speed trap, is another use of microwave detection radar.

         b) Radars are used to detect intruders into secure installations, such as military bases or nuclear energy facilities.

14	MICROWAVES	TYPES OF SOURCES	38

POWER TRANSMISSION

EQUIPMENT WOULD BE SMALL

MICROWAVE GENERATION AND ENERGY CONVERSION IS PRESENTLY INEFFICIENT

3. Power Transmission

Many estimates have been made recently about the possibility that future generations may utilize microwaves as the primary means of power distribution. This would have certain advantages over the present high voltage alternating current system. The microwave transmission equipment would be very small compared to conventional high voltage power lines. To date, relatively inefficient methods of microwave generation and conversion of the microwave energy back into electrical energy make it impossible for microwave power transmission to compete with conventional methods.

C. BIOLOGICAL EFFECTS OF MICROWAVE RADIATION

14	MICROWAVES	BIOLOGICAL EFFECTS	39

BASIC BIOLOGICAL EFFECTS OF MICROWAVES

- THERMAL
  - ABSORBED RF ENERGY PRODUCES HEAT WHICH MAY CAUSE TISSUE DAMAGE
  - GENERAL
  - LOCAL
  - PRIMARY AND SECONDARY EFFECTS
- NON-THERMAL
  - INTERACTS WITH BIOLOGICAL SYSTEMS DIRECTLY
  - MECHANISMS UNKNOWN IF ANY

C. BIOLOGICAL EFFECTS

1. Action on Biological Tissue

Although the exact nature of the biological effects of microwave radiation is not completely understood, most of the experimental data support the concept that the effects are primarily due to local or general hyperthermia, that is, heating. The heating effect of electromagnetic radiation on humans was first demonstrated in 1890 by D'Arsonval. Since that time, microwaves have been used in diathermy for heating tissues for therapeutic purposes. Some non-thermal effects are also observed.

The biological effects of microwave radiation are probably the result of the conversion of electromagnetic energy into heat energy within the tissue itself. The effects are the same as with any burn, but the heat may be generated deep in the tissue rather than on the surface.

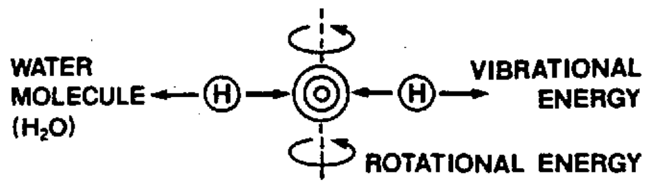
Since temperature is related directly to the rate and extent of molecular vibrations, a large part of the increase in temperature is due to increased vibration of polar molecules such as water, which is the major constituent of biological systems.

Both direct and indirect effects of heating occur. Direct heating of tissues is a primary effect, whereas an effect caused by a system reaction to that heating would be secondary, or indirect. A general heat stress due to whole body heating, or damage to some specific body tissue due to local heating are examples of primary effects. Adaptation stresses, or endocrine system or Central Nervous System (CNS) reactions to the primary heating are examples of secondary effects.

Effects have been reported also by some researchers at power density levels below which significant tissue heating could be expected. The mechanisms of such effects are not understood, if in fact they occur.

14	MICROWAVES	BIOLOGICAL EFFECTS	40

HOW EM FIELDS GENERATE HEAT



- E-FIELD EXERTS ELECTRICAL FORCES ON ATOMS IN MOLECULES
- EM FIELD IMPARTS ENERGY TO EXCITE ROTATIONAL AND VIBRATIONAL ENERGY STATES
- MOLECULAR MOTION (INCLUDING INTERNAL MOTION) IS WHAT CONSTITUTES HEAT
- WATER AND OTHER BIOMOLECULES ABSORB RF/MICROWAVES.

In an applied oscillatory electrical field, polar molecules of a material tend to line up and vibrate. They oscillate (vibrate) with greater amplitude than their normal thermal vibrations when an electric field is imposed on them. Another way to say this is that the energy in the microwaves is absorbed by causing transitions to occur that excite vibrational states of the molecules; rotational energy substates are also produced, by the longer wavelengths. Water is a particularly good absorber because of the vibrational and rotational energy states that can be excited by radio and mocrowave frequency energy.

Heat generation (and thus microwave absorption) is greatest in those tissues with a high content of water and is enhanced locally in the areas adjacent to bone or tough fascia (muscle) planes which act as reflecting surfaces. Such local reflection and possible superposition effects can produce localized heating.

THERMAL EFFECTS OF R.F./MICROWAVES

- PRINCIPAL EFFECTS OBSERVED ARE DUE TO HEATING
  - GENERAL HYPERTHERMIA
    HEAT STRESS
  - LOCAL HEATING ("HOT SPOTS")
    EYE – CATARACTS
    TESTES – INFERTILITY
    CNS
- HEATING DEPENDS UPON
  - EXPOSURE FACTORS (POWER DENSITY, DURATION)
  - ABSORPTION FACTORS (WAVELENGTH, GEOMETRY)
  - HEAT REDISTRIBUTION BY BODY

Most U.S. Researchers believe that the principal biological effects of microwaves are due to the direct heating of tissue. At high levels of power density, heat prostration sets in and experimental animals are observed to due from general hyperthermia. The human body, like that of many mammals, can adapt to mild hyperthermia, by increased blood flow and perspiration, depending upon the environment. The human body can normally redistribute and reject additional environmental heat up to the equivalent of about a 30 mW/cm^2 microwave power density level incident upon it.

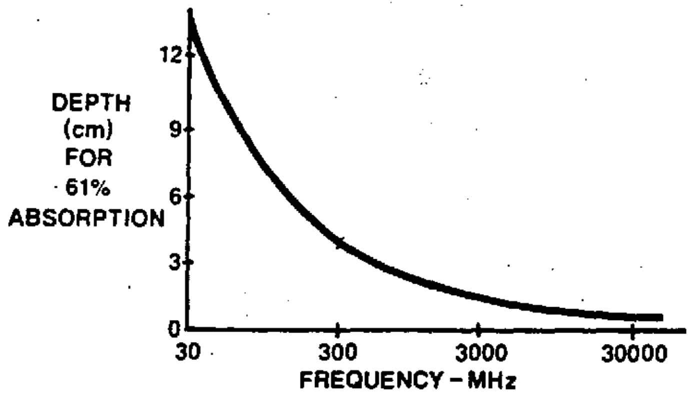
In microwave irradiation, there are likely to be reflections from internal body tissue interfaces, and wave superposition patterns within body structures such as the head, trunk or limbs. The exact pattern of EM energy present and absorbed in the body depends upon the sizes and shapes of these structures, upon the type(s) of tissue within them, and upon the wavelength of the EM waves. The result of these patterns may be "hot spots" where the waves reinforce.

For example in a tissue sphere with radius $0.4\ \lambda/2\pi$, the absorption, and thus the local heating, may be from 4 to 10 times as much as would occur in a large homogenous slab of tissue. The exact value of the enhancement in absorption depends upon the tissue dielectric constant and electric conductivity, which in turn depend upon water content of the tissue and frequency of the EM radiation. Examples of body structures that might be affected by such local heating effects are the eyes, the testes, and inter-cranial (brain) regions.

The amount of body heating, and therefore the biological effect, thus depends upon: (1) the incident power density; (2) physical absorption factors, such as wavelength, tissue type, (water content, principally), and body geometry (size, shape, locations of various tissue type interfaces), particularly as the geometry relates to wavelength; (3) the body's ability, as a whole system, to redistribute and reject the internally deposited heat.

14	MICROWAVES	BIOLOGICAL EFFECTS	42

PLANE WAVE RF ABSORPTION IN BULK TISSUE, SHOWING FREQUENCY DEPENDENCE OF PENETRATION



By way of summarizing the frequency dependence of RF wave absorption in tissue, the chart shows the penetration depth in soft tissue at which 61% of the wave energy is absorbed, for a wide spectrum from 30 to 30,000 MHz. This assumes a plane wave (far-field) incident upon a bulk plane tissue slab; it is highly non-representative of any actual exposure condition. However, it makes the point that higher frequencies are more strongly absorbed in tissue, that is, they do not penetrate as deeply as the lower frequencies. Put another way, the higher frequencies tend to be absorbed in the outer layers of tissue.

MICROWAVE ABSORPTION QUANTITIES

- { ABSORBED POWER DENSITY / SPECIFIC ABSORPTION RATE (SAR) } { WATTS/cm^3 / WATTS/kg }
- AT ANY POINT SAR DEPENDS UPON
  - POWER DENSITY (W/cm^2)
  - FREQUENCY ← MATERIAL PROPERTIES
- EXAMPLE: AT 2450 MHz, PLANE WAVE IN FATTY TISSUE, 10 mW/cm^2 PRODUCES ~ 10 W/kg.

In the literature of microwave hazards, the quantities used to describe the amount of microwave energy are "absorbed power density," and "specific absorption rate," or SAR. Units of watts per cubic centimeter (W/cm^3) or watts per kilogram (W/kg) are usually used for absorbed power density. SAR usually has the units W/kg. These are "normalized" units, describing the power being deposited at any point in a body of tissue. (Think of a tiny volume of tissue, having a mass of m kg; if the power deposited within that mass is p watts, then the SAR there is p/m.)

An absorbed powr density value of 1 mW/cm^3 is approximately the same as a SAR value of 1 W/kg. Can you show this? (Hint: the density of tissue is approximately 1 g/cm^3.)

PHYSICAL AND BIOLOGICAL FACTORS AFFECTING MICROWAVE ABSORPTION RATE

- NEAR-FIELD OR FAR-FIELD CONDITIONS
- FREQUENCY-DEPENDENT MATERIAL PROPERTIES
  - DIELECTRIC CONSTANT AND PERMITTIVITY
  - ELECTRIC CONDUCTIVITY
  - ABSORPTION COEFFICIENT
- TYPE OF TISSUE (SKIN, FAT, MUSCLE, BONE)
- WATER CONTENT OF TISSUE
- BODY STRUCTURE, SHAPE AND SIZE, RELATIVE TO WAVELENGTH

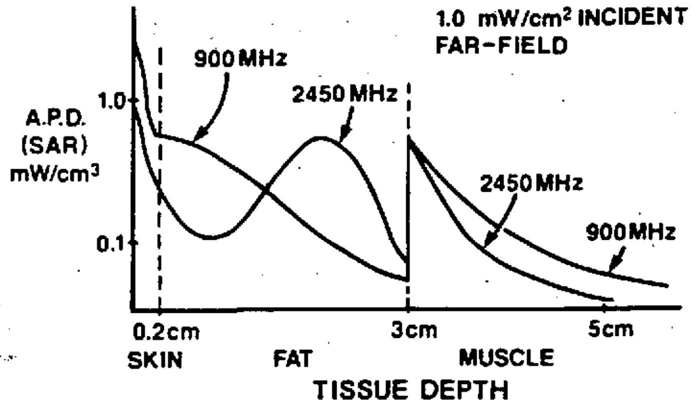
The microwave absorption rate depends upon both physical and biological factors. This fact complicates the interpretation of experiments on the effects of microwaves. Many U.S. researchers feel that these complications in both measurement of absorption rate and the biological factors involved are responsible for the lack of agreement between Eastern bloc researchers (and some U.S. groups, too) and the bulk of the U.S. research results.

Probably the most crucial problem is that although the near-field condition is difficult to characterize it is also easy to obtain. Therefore many experiments and industrial hazards involve near fields. In making generalizations about hazards, one must be careful to distinguish the experimental or field conditions.

The next physical factor is the microwave wavelength, to which tissue absorption parameters are quite sensitive. The dielectric constant, permittivity, and conductivity together determine the absorption coefficient of a material, and all of these are frequency-dependent. All of these material properties are also dependent upon water content, and so the absorption rate depends upon the type of tissue. (Other biomolecules may also be important.) Muscle and skin tend to have high water content, while bone and fat have less water. Water content especially influences the electric conductivity, but is also important because the molecular rotations and vibrations of water are the mode of primary energy deposition by microwaves.

A critical factor in the pattern of heat deposition in the body is the shape and size of body structures relative to wavelength. Microwaves are partially reflected at air-skin, muscle-fat and bone-muscle interfaces. They may establish standing wave patterns in the cranium, trunk, arm, leg or neck. Thus the EM field intensity and the associated absorbed power density may be considerably enhanced within these body structures. For example, it is calculated (and measured using tissue-equivalent dummies or phantoms), that at 918 MHz there are resonances due to plane wave incident (far-field) irradiation in the human cranium, producing "hot spots" about one centimeter from the brain center, with about twice the energy absorption as is observed on the edge of the brain. Similarly, arms, legs and neck tend to have enhanced absorption due to superposition and reinforcement of internally reflected microwaves.

APPROXIMATE DISTRIBUTION OF ABSORBED POWER DENSITY IN TYPICAL TISSUE LAYERS



As an example of how local variations in absorption occur within the body, consider the three layers of tissue shown: 0.2 cm skin, over 3.0 cm of fat, over 5 cm of muscle. Two different microwave frequencies are shown incident upon this (slab) geometry, and the absorption patterns of each are plotted. Notice the effect of reflections from the fat-muscle interface, especially at 2450 MHz. Note also the magnitudes of SAR for a 1.0 mW/cm^2 incident field.

14	MICROWAVES BIOLOGICAL EFFECTS	46

FACTORS AFFECTING LOCAL AND GENERAL HEATING OF TISSUES

- INCIDENT POWER DENSITY (FAR-FIELD)
- FREQUENCY- AND LOCATION-DEPENDENT SAR FACTORS*
- BLOOD FLOW TO REDISTRIBUTE HEAT
- AMBIENT ENVIRONMENT (TEMPERATURE, HUMIDITY)

*SEE CHART NO. 44.

In a previous chart we discussed the factors affecting microwave power absorption. Now consider the factors that determine how hot the tissues will become, that is, what temperature rises may occur locally or generally.

The most obvious factor is the incident power density, most clearly defined and measureable in the far-field. The more the power density the larger the absorbed power will be.

The body handles a general increase in temperature, as in a fever, or local heating, by various physiological mechanisms, including: (1) increased blood flow, by faster heart rate and dilation of blood vessels; (2) perspiration on the skin; and (3) faster breathing rate. These have the effect of redistributing local heat and rejecting it to the environment by evaporation and convection. Thus the ambient environment will play a part in the body's ability to handle microwave thermal effects. On a hot humid day, a person will generally be able to handle less added heat load than on a cool dry day.

14	MICROWAVES	BIOLOGICAL EFFECTS	47

POWER DENSITY EFFECTS

- HEATING DIRECTLY PROPORTIONAL TO POWER DENSITY x EXPOSURE TIME
  $W/cm^2 \times SEC = JOULES/cm^2$
- HIGH HEATING RATES DON'T ALLOW BODY TIME TO DISTRIBUTE AND DISSIPATE HEAT

2. Physical Factors Influencing Tissue Damage (contd.)

   c. Power Density

      The hazard potential of microwave radiation is dependent upon the power density of the radiation and the length of exposure. The thermal response to microwave radiation is a function of the energy input or flux density. The fact that the amount of heating in tissues can be controlled by regulating the intensity and length of exposure forms the basis for the clinical use of microwave diathermy and the development of microwave ovens.

      The importance of the length of time between exposures to pulsed microwaves has been demonstrated indicating that a longer interval of time between exposures, or a reduced heating rate, allowed for some adjustment by the heat regulatory mechanisms of the body.

14	MICROWAVES	BIOLOGICAL EFFECTS	48

PHYSIOLOGICAL EFFECT OF TEMPERATURE RISE

- INCREASE IN BASAL METABOLISM RATE
- INCREASE IN BLOOD CIRCULATION
- INCREASE IN RESPIRATION
- INCREASE IN OXYGEN DEMAND
- INCREASE IN OXYGEN CARRYING ABILITY OF BLOOD
- DAMAGE SAME AS FEVER INDUCED

3. Whole Body Exposure (contd.)

b. Physiological Effects of Temperature Rise

The problem of heat dissipation is complicated by the fact that for each degree of temperature rise above normal the basal metabolic rate increases by as much as 14%. This increase in basal metabolic rate demands an increase in the blood circulation and respiration, as well as a 50 to 100 percent increase in the supply of oxygen to the tissues to maintain cellular activity. The condition is aggravated by the reduced capability of hemoglobin to combine with oxygen and by the increased blood circulation rate, which reduces the time available for oxygen transfer in the lungs.

Since the whole body will tolerate only a limited increase above normal temperature, an excessive rise in temperature due to microwave irradiation will produce tissue damage indistinguishable from that due to fever of any origin.

14	MICROWAVES	BIOLOGICAL EFFECTS	49

NON-THERMAL EFFECTS

- FUNCTIONAL CHANGES
- PEARL CHAIN EFFECT
- CELL MUTATIONS
- AUDIO EFFECT
- SYSTEM DISRUPTION
- UNCERTAIN RESULTS

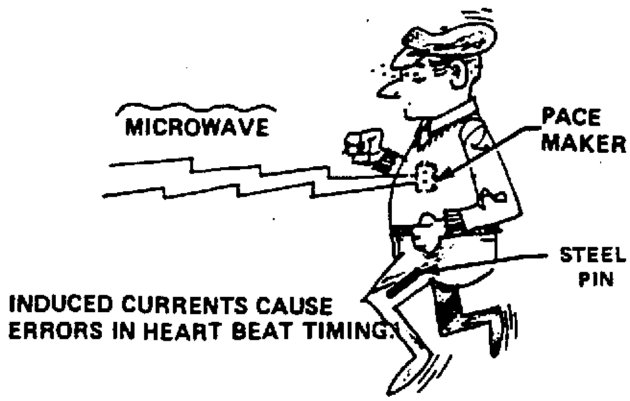
1. Action on Biological Tissue (contd.)

b. Non-Thermal Effects

While certainly the most readily observed effects of absorption of microwaves in biological systems are thermal, there is also some evidence for non-thermal effects. Several investigators have pointed out that microwaves may also interact with biological material without the production of a significant amount of heat. According to Russian workers, exposure of animals to microwaves of low intensity, which do not produce any appreciable thermal effect, lead to functional changes mainly in the nervous and cardiovascular systems. Other reported non-thermal biological interactions include "pearl chain" formations of blood cells, mutations in exposed garlic root tips, changes in proteins in human gamma globulin, sounds "heard" by several people which correspond to the frequency of modulation of an incident microwave beam and occasionally epigastric (stomach) distress in humans. Generally these data are uncertain in nature, quality, and repeatability. Some of these effects may be explained by localized heating, or secondary effects such as adaptation stresses. Many people are studying the problem in laboratories around the world.

14	MICROWAVES	BIOLOGICAL EFFECTS	50

PACEMAKERS/ARTIFICAL ORGANS



1. Action on Biological Tissues

   b. Non-Thermal Effects - Pacemakers (contd.)

   EM energy is readily absorbed by conductive materials. Thus an electrical conductor which is part of an artificial organ or pacemaker implanted in the body will absorb this energy which induces electrical currents in the conductor.

   Pacemakers are sometimes implanted in people with heart trouble to assist their hearts in keeping pumping rhythm. Pulsed microwave energy at even low power levels can be hazardous to people with pacemakers, since the spurious currents induced may cause the heart to get out of synchronization. Early (pre-1974) pacemakers generally present the greatest problem. More recent designs are less susceptible. However, no levels of microwave power can be considered safe for people with pacemakers. They should be excluded from areas around microwave ovens, and other pulsed microwave sources.

   Similarly pins or other orthopedic implants may heat up in high EM fields and cause pain or injury.

14	MICROWAVES	BIOLOGICAL EFFECTS	51

CRITICAL ORGANS

- RELATED TO BLOOD FLOW RATE (COOLING CAPABILITY)
- EYES
- TESTES
- ARTIFICIAL PACEMAKERS AND METALLIC IMPLANTS

4. Critical Organs

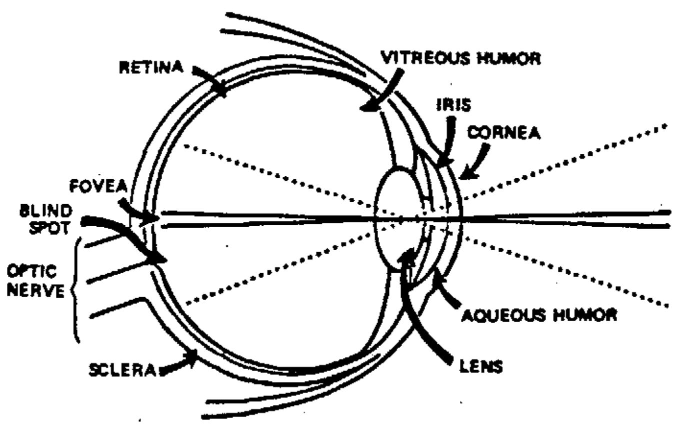
a. General

Experimental evidence has established that certain organs (eyes, testicles, gall bladder, urinary bladder, and portions of the gastrointestinal tract) of the body are more susceptible than others to microwave radiation. This increased susceptibility is due to difference in the blood flow rate which affects the rate of heat removal from these tissues during exposure. Experimental evidence indicates that the eyes and testicles are the most vulnerable to microwave radiation.

Any implanted conductor, such as a pacemaker or bone pin, will absorb microwaves and cause localized heating which may result in damage if the local blood flow is not sufficient to dissipate the heat.

14	MICROWAVES	BIOLOGICAL EFFECTS	52

SCHEMATIC OF HUMAN EYE



4. Critical Organs (contd.)

   b. Eye

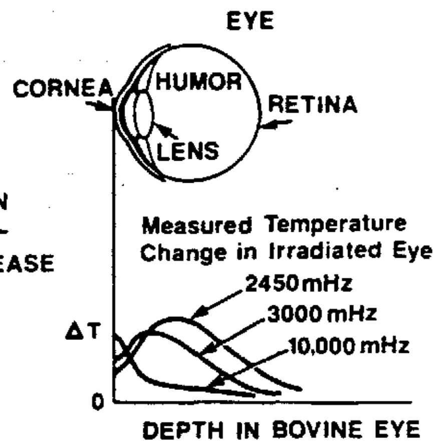
      1) Thermal Damage Mechanism

      Within the critical wavelengths, the potential hazard to the eye is one of the most serious aspects of microwave exposure. In addition to the relatively poor blood supply, there are cavities near the eye and intraocular fluids in these cavities have high electrical conductivity. Therefore there is short penetration, or high absorption, of electromagnetic radiation in the eyeball. The eye is unable to conduct excessive heat to other parts of the body. The lens, being avascular and enclosed in a capsule, is at a disadvantage by not having a cooling system (blood flow) as do other tissues. Not having mechanisms to remove dead cells or to replace cells, it cannot repair itself as do other tissues in the body. Thus, damage to the lens is generally irreversible. Depending upon the dose, the damaged cells slowly lose their transparency and the opacity may not occur until sometime after exposure. Microwave irradiation may also produce damage to other ocular structures such as the conjunctiva, cornea, and iris.

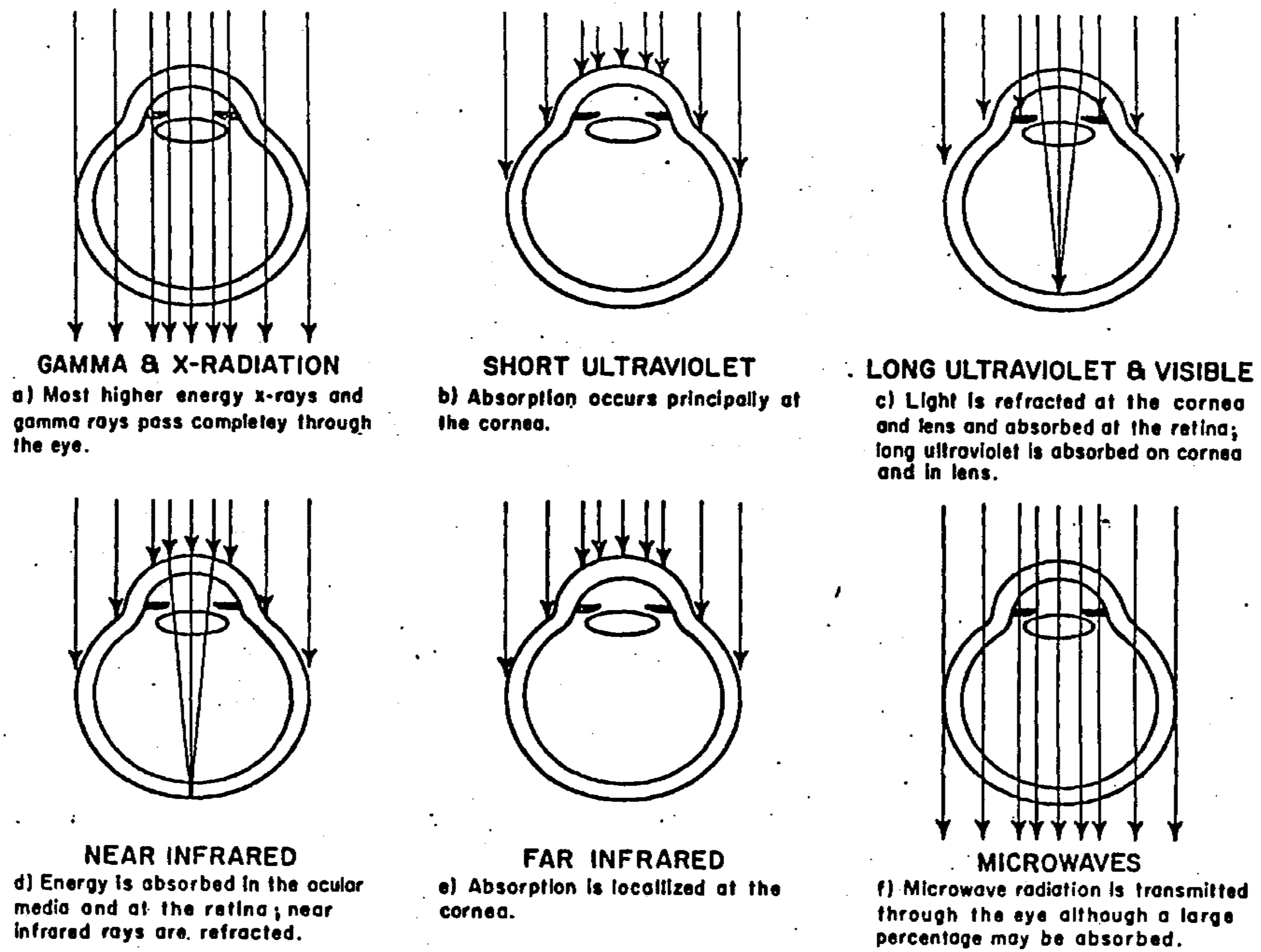
14	MICROWAVES	BIOLOGICAL EFFECTS	53

CATARACTS - I

LENS OPACITIES (Cataracts) ARE PRODUCED BY AN EXCESSIVE TEMPERATURE INCREASE IN THE LENS.



One of the well-established effects of microwave irradiation is the production of cataracts, or opacities in the lens of the eye. These are known to be caused by heating of the lens, which has poor circulation and so is not cooled efficiently. The temperature changes measured in bovine eye during irradiation as a function of position and for different frequencies are shown in the chart. The bovine eye is similar in size to the human eye. At 3000 MHz, the peaking of the temperature in the lens is noticeable.



~~Figure 2-1.~~ **Absorption Properties of the Eye for Electromagnetic Radiation.**

14	MICROWAVES	BIOLOGICAL EFFECTS	54

CATARACTS – II

- EFFECTS DEPEND UPON POWER DENSITY
  - DEGREE OF OPACITY
  - TIME DELAY BETWEEN EXPOSURE AND EFFECT
  - CRITICAL TEMPERATURE REQUIRED IN LENS
- THRESHOLD FOR SINGLE EXPOSURE ~ 80 mW/cm^2
- EVIDENCE FOR CUMULATIVE EFFECTS CONTROVERSIAL (LONG-TERM, CHRONIC LOW-LEVEL EXPOSURE, AND NON THERMAL EFFECTS)
- DAMAGE (IN HUMAN) PRONOUNCED AT 10–12 cm WAVELENGTH

The degree of opacity, or severity of the cataract, depends directly upon the power density of the microwave field. There is a time delay typically between exposure and onset of opacities, whose duration is inversely related to the power density. There is experimental biochemical evidence that a critical temperature must be reached during irradiation in order for cataracts to be formed. If this is so, then we would expect some threshold power density below which cataracts would not be produced, and that there would be no cumulative effects leading to cataracts.

Various researchers have investigated the question of a threshold power density for cataractogenesis, with various results. U.S. workers generally would agree that for single exposures of durations up to about an hour, with 48 hours pause before another such exposure, the threshold is about 80 mW/cm^2. Other workers, especially Russians and Polish, but also including some Americans, believe that there are cumulative effects of lower power density exposures over long times. Many questions of interpretation of test data and dosimetry exist, and are not yet settled to everyone's satisfaction.

As shown on the previous chart, one expects, and finds, more cataract effects of 10—12 cm waves, 2500—3000 MHz, or S-band, than of much lower or much higher wavelengths.

14	MICROWAVES	BIOLOGICAL EFFECTS	55

PULSED VS C.W. EFFECTS IN EYES

WHETHER PULSED MICROWAVES, WITH HIGHER INSTANTANEOUS POWERS ARE MORE EFFECTIVE IN PRODUCING CATARACTS THAN SAME AVERAGE CONTINUOUS WAVE POWER IS STILL UNKNOWN.

4. Critical Organs

   b. Eye (cont'd.)

      3) Pulsed Power vs. Continuous Wave Effects

         As with other research in this field, there is some controversy whether or not pulsed microwave power is more effective in producing cataracts than continuous wave (cw) of the same average power. It seems to be so in rabbits' eyes, but there are questions about how the experiments are done, relating to near-field power measurement interpretation. Many researchers have found no difference in cataract formation caused by repetitively pulsed or cw microwaves of the same average far field power density.

CUMULATIVE EYE DAMAGE

- PROBABLY NO CUMULATIVE EYE DAMAGE FROM SUBTHRESHOLD (< 80 mW/cm^2) POWER DENSITY IF COOLING TIMES ALLOWED BETWEEN EXPOSURE

4. Critical Organs

   b. Eye (contd.)

      4) Cumulative Damage

      Unless there is some non-thermal damage effect involved, which is still a point of controversy, there is probably no cumulative cataractogenic damage of subthreshold power density exposures in the far field. The threshold is thought to be 80 mW/cm^2.

14	MICROWAVES	BIOLOGICAL EFFECTS	57

REPRODUCTIVE ORGANS - TESTICLES

- EXTREMELY SENSITIVE TO HEAT
- REDUCTION IN FERTILE SPERM FOR MICROWAVE POWER DENSITY>10 mW/cm^2
- DAMAGE APPARENTLY REVERSIBLE

4. Critical Organs (contd.)

c. Reproductive Organs

The testicles are extremely sensitive to elevations in temperature. It has been found in cases of undescended testes (as in young boys) that the spermatogenesis can take place only at temperatures below that of the body core. Normal human testicular temperatures (95°F) are below that of the body core. Of the various organs studied, the testes appear to be the most sensitive in terms of minimum exposure required to produce a detectable change.

A study utilizing dogs, rabbits, and rats tried to determine the threshold value of the lowest power density required to produce a minimal change in the most sensitive animal in the group. For this criteria, a continuous exposure rate of 0.01 W/cm^2 was found to be the threshold for testicular damage. The damage observed at such low levels of power is slight, almost certainly fully recoverable, and in no way different from that due to other common forms of heat that might be applied to the testes. The reduction in testicular function due to heating appears to be temporary and probably reversible except in severe cases. Because of the paucity of information, any statement concerning the genetic implications of microwave radiation would be premature.

14	MICROWAVES	BIOLOGICAL EFFECTS	58

MICROWAVE EFFECTS EXPERIMENTS

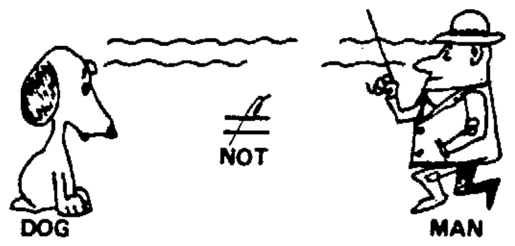
EXPERIMENTAL ANIMAL	FREQUENCY	EFFECT STUDIED
RAT CAT RABBIT DOG COW MONKEY ETC.	918 2450 MHz 10000	GENERAL HEAT STRESS LESIONS – BURNS CATARACTS INFERTILITY GENETIC TERATOGENESIS CARCINOGENESIS BLOOD CELLS C.N.S. BASIC BIOCHEMISTRY BASIC DOSIMETRY

- MANY EXPERIMENTS IN NEAR-FIELD
- ABSORBED DOSE DIFFICULT TO MEASURE *IN-SITU*
- SMALL ANIMAL EFFECTS MAY NOT EXTRAPOLATE TO MAN.

Experiments to determine the effects and thresholds for effects of microwaves have been performed by many researchers on many different animal species, at a variety of frequencies. They have been looking for thermal effects such as general heat stress, lesions such as burns or cataracts, and infertility; and also for non-thermal effects such as genetic mutations, teratogenesis (birth defects), carcinogenesis (cancer production), blood cell effects, and central nervous system effects such as behavioural changes. There is also considerable basic research into the biochemical effects of microwaves in tissue, and on the dosimetry, or means of measuring actual power absorption in complex tissue geometries. In general, the non-thermal effects are not reproducibly found by all researchers, but there may be such effects. Many of the experiments are done in near-field conditions where measurements are hard to interpret in terms of SAR. Further, the probes used often affect the field or the biological response. A big difficulty comes when one tries to extrapolate to humans the effects data from small animal studies, not only because of the size and shape effects, but also because of differences in physiology.

14	MICROWAVES	BIOLOGICAL EFFECTS	59

DATA FROM ANIMALS



NOT EQUIVALENT, BUT CAN PROVIDE GUIDELINES

Accumulated experimental data show that each species differs in terms of relative sensitivity to whole body radiation. Thus it would be inaccurate to extrapolate to man from data obtained from animals; however, this information does provide guidelines. The great variability is due to many factors such as thickness and texture of the animals' hair and skin, the ratio of surface area to body mass, body size in relation to wavelength employed, etc. Also the mechanisms of thermo-regulation and their efficiency vary in different species and in this respect man is perhaps the best protected of all animals. Human beings, for example, exposed to a flux of 0.22 W/cm^2 for 48 minutes showed a slight fall in rectal temperature due to the efficiency of the sweating mechanism in the dissipation of heat. In contrast, rabbits showed a 1°C rise with a flux of only 0.02 W/cm^2 and some deaths from hyperthermia occur in two hours at a power density of 0.03 W/cm^2.

It has been estimated that a continuous exposure to 100 mW/cm^2 would be required to maintain a human body temperature rise of 2°C.

14	MICROWAVES	BIOLOGICAL EFFECTS	60

CONTROVERSY: ARE THERE NON-THERMAL EFFECTS OF MICROWAVES?

- AT LOW P.D. (< 10 mW/cm²) BODY SHOULD BE ABLE TO DISSIPATE THE ADDED HEAT LOAD.
- RUSSIAN, POLISH, SOME U.S. WORKERS HAVE FOUND EFFECTS AT LOWER P.D.'s (1–3 mW/cm²).
- GENERAL OPINION OF U.S. SCIENTISTS: "NON-THERMAL" EFFECTS RESULT FROM
  - LOCAL HEATING DUE TO REFLECTIONS' ETC.
  - POOR EXPERIMENTAL CONTROLS, AND ESTHETICS, ETC.
  - IMPROPER EXTRAPOLATION FROM ANIMAL DATA.
- RUSSIANS BELIEVE IN DIRECT FIELD EFFECTS ON C.N.S.

We have mentioned that there is some scientific controversy over the existence of non-thermal, or direct field effects of microwaves, and of radio fraquency EM in general. People agree that at low power density levels, say below 10 mW/cm², the body should be able to dissipate the added heat load, and no thermal effects should be found. However, the Russians and Poles, as well as some U.S. workers, have found effects in both humans and experimental animals at lower power density levels, in the range 1 to 3 mW/cm². They therefore feel that there must be some non-thermal, sometimes cumulative, damage produced.

The general opinion of the U.S. research community is that the observed "non-thermal" effects result from local heating within the animals due to reflections, etc., so that even with low incident power density there may sometimes be enough absorbed power to reach the threshold for local damage. Also, there are many questions about experimental design and controls; for example, anaesthetics used in some animal studies produce chemical effects that could alter the results. As mentioned earlier, many of these studies were done in near-field conditions that are quite unreproducible and in which probe measurements are seldom interpretable in terms of power density. Then, too, there is the problem of deciding how to scale up a result from rabbit to man, or monkey to man.

In spite of these reservations in the U.S., the eastern bloc researchers feel that there are direct field effects of microwaves. In other words, they believe that the E fields even at low field strengths interact with the biological molecules directly to produce effects, especially effects in the central nervous system. Radiation protection officers should continue to read the literature in this field to follow the controversy and to help decide how to provide a safe work-place for the employees for whom they are responsible.

CUMULATIVE WHOLE BODY EFFECTS

- CONTROVERSIAL DATA – SOVIETS/POLES REPORT EFFECTS, BUT MOST U.S./WESTERN STUDIES NEGATIVE
  - STRESS ADAPTATION FATIGUE SYNDROME
  - GENERAL BEHAVIOURAL EFFECTS
  - LYMPHATIC AND OTHER SYSTEMS
  - GENETIC, TERATOGENETIC, NOT ESTABLISHED
- CATARACTS (AT P.D. $< 10\ mW/cm^2$)
  - SOME U.S. RESEARCHERS CLAIM CUMULATIVE EFFECTS OF LOW P.D. (RADAR WORKERS)
  - QUESTIONABLE STATISTICS AND DOSIMETRY

Cumulative damage is related to the non-thermal effects controversy. Even if there is no lasting obvious effect of irradiation, whenever the body reacts to a stress such as added heat load, there is some fatigue associated. This is called "stress adaptation fatigue syndrome" and has been extensively studied. Some people feel that subthreshold microwave exposure causes at least some adaptation fatigue, and so there is some cumulative effect. The Russians also report general behavioural effects in people after long term low-level exposures, but these reports are hard to evaluate. Further, they report slight changes in various body systems, such as the lymphatic (a white cell system), and genetic changes, but western scientists have generally been unable to reproduce these results.

The question of cumulative damage leading to cataracts due to low level exposure is similarly controversial. Some opthalmologists have claimed to have seen significant numbers of opacities in radar workers and others who have had low level exposures. However, the dosimetry is uncontrolled, and the types of cataracts seen do not conform to the type and location in the eye of "normal" microwave-induced opacities.

Animal studies of chronic (long term) whole body exposures up to 20 mW/cm^2 indicate no cumulative or long term pathological effects in mice, rabbits or dogs.

An old report concerning genetic mutations or birth defects resulting from microwaves needs to be mentioned to set the record straight. It was reported that two military radarmen had Mongoloid children, and the inferrence was drawn that microwaves had caused this. A much larger and longer study of military people, using occupationally exposed persons and unexposed controls living on the same bases, demonstrated no cumulative, genetic, or teratogenetic effects of microwaves under 10 mW/cm^2.

In general the conclusion is that if there are cumulative effects of microwaves they are small and not readily observable, hence more of concern to researchers than to occupational health personnel.

RUSSIAN AND AMERICAN STANDARDS PHILOSOPHY

- U.S.

  10 mW/cm^2 IS ABSOLUTE LIMIT FOR 8 HRS.

- U.S.S.R.

  MUCH LOWER VALUES (MICROWATT/cm^2 RANGE) GUIDELINES FOR ROUTINE EXPOSURE

It is instructive to understand the difference between the Russian and American approaches to microwave standards. In the U.S. the limits are set by law and enforced as absolute upper limits for occupational exposure. Typically any given worker is rarely exposed to such levels, and much effort is expended to keep the power density in the work place as low as reasonably achievable.

In the eastern bloc countries, the much lower limiting values (10's of microwatts per square centimeter), are considered as guidelines for operational work. That is, these are the values to which radar workers are routinely exposed, rather than absolute upper limits.

14	MICROWAVES	BIOLOGICAL EFFECTS	66

SUMMARY – I

FREQUENCY MHz	SITE OF MAJOR TISSUE EFFECTS	MAJOR BIOLOGICAL EFFECTS
LESS THAN 150	WHOLE BODY	GENERAL WHOLE BODY HEATING
150 - 1000	INTERNAL BODY ORGANS	DAMAGE TO INTERNAL ORGANS FROM OVER-HEATING
1,000 - 3,000	LENS OF THE EYE, TESTES	LENS OF THE EYE PARTICULARLY SUSCEP-TIBLE TISSUE HEATING
ABOVE 3,000	TOP LAYERS OF THE SKIN, LENS OF THE EYE	SKIN HEATING WITH THE SENSATION OF WARMTH REFLECTION

7. Summary

Although the biological effects of microwaves have been studied, certain areas, such as the possibility of cumulative effects form subthreshold exposure, functional changes from low intensity irradiation as reported by the Russians and possible nonthermal changes need further clarification. Large gaps also exist in the current knowledge of possible genetic implications and the actual long-term effects, if any, of microwave radiation on humans.

The table summarizes microwave effects on humans, insofar as these effects are understood.

14	MICROWAVES BIOLOGICAL EFFECTS	67

MICROWAVES BIOEFFECTS SUMMARY – II

- LONGER WAVELENGTHS PENETRATE TISSUE MORE, ABSORB LESS STRONGLY
- EFFECTS AT $\gg$ 10 mW/cm^2 DUE TO GENERALIZED OR LOCALIZED HEATING OF TISSUES
  - EYE – CATARACTS
  - TESTES – (TEMPORARY) INFERTILITY
  - HEAT STRESS
- EFFECTS AT $\ll$ 10 mW/cm^2 CONTROVERSIAL
  - NON-THERMAL OR HOT SPOTS?
  - FIELD EFFECTS
- ← IMPLANTS/PACEMAKERS

Several pertinent facts are listed on the chart. Longer wavelengths penetrate more deeply, that is, they are absorbed less strongly. At high power density levels, much above 10 mW/cm^2 (the MPE limit), the biological effects are due to general or local heating of tissue, and result in cataracts, temporary infertility, and heat stress. At power density levels below 10 mW/cm^2 there may be non-thermal effects due to field interactions, but most U.S. researchers believe that effects seen are due to reflections and superposition of the EM energy that produces local heating in the body.

D. MICROWAVE MONITORING EQUIPMENT

14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	69

BASIC MEASUREMENT EQUIPMENT

- BASIC EQUIPMENT REQUIREMENTS FOR MICROWAVE HAZARD MONITORING
- NOT ALL REQUIREMENTS ARE MET BY ANY PARTICULAR AVAILABLE INSTRUMENT

1. Basic Equipment Requirements

In this section will be discussed several specific equipment systems used commonly in microwave power measurements. The equipment list is not exhaustive but rather representative. In the first slides a list is given of basic requirements for any field-survey instrument to be used in microwave hazard work. The equipment types discussed in later slides should be compared against these requirements. Unfortunately very few commercially available instruments have all these features. Before purchasing any of these, or any other survey equipment, study manufacturers' literature thoroughly.

14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	70

BASIC EQUIPMENT REQUIREMENTS - I

SMALL ANTENNA PROBE, WELL MATCHED
(TO AVOID REFLECTIONS AND FIELD DISTORTION)

ISOTROPIC RESPONSE
(INSENSITIVE TO INCIDENCE ANGLE, ± 1 dB)

POLARIZATION INSENSITIVITY ± 1 dB

The antenna probe must be sufficiently small (or the impedance matched well enough) to produce insignificant back-scatter and/or interference of the probe to the source.

The receiver system should have both isotropic response and polarization-insensitivity at the ± 1 dB level.

BASIC EQUIPMENT REQUIREMENTS - II

RESPONSE TIME: 3 SEC TO CHANGE FROM 0 - 90% OF STEP INPUT VALUE

WIDE FREQUENCY RANGE (INCLUDING 915 AND 2450 MHz)

DIRECT READING AT 915 AND 2450 MHz

1. Basic Equipment Requirements (contd.)

The response time should meet the 0-90% (3-second) criteria required by the Bureau of Radiological Health for oven hazard measurements, (ref: Federal Register 6 Oct. 1970, "Oven Leakage Standards 890-6000 MHz").

It is important that the frequency response cover as wide a range as practical. In particular, direct reading at 915 and 2450 MHz is essential, since these are the two most common frequencies in oven and industrial applications.

BASIC EQUIPMENT REQUIREMENTS – III

ACCURACY ± 2 dB

TWO OR MORE SENSITIVITY RANGES,

MINIMUM SENSITIVITY OF 0.1 mW/cm^2

BURN-OUT PROOF, OR ABLE TO SURVIVE 3x to 10x MAX.

SCALE POWER

1. Basic Equipment Requirements (contd.)

Instrument accuracy should be less than ± 2 db over the quoted range for calibration by using a plane wave.

Several ranges of sensitivity should be available, (for example, 0-2, 0-20, 0-200 mW/cm^2).

The instrument should be able to withstand a continuous exposure of at least 300% of full scale, using an unmodulated signal, and a one-second exposure to 1000% of full scale. A burn-out proof probe is desirable.

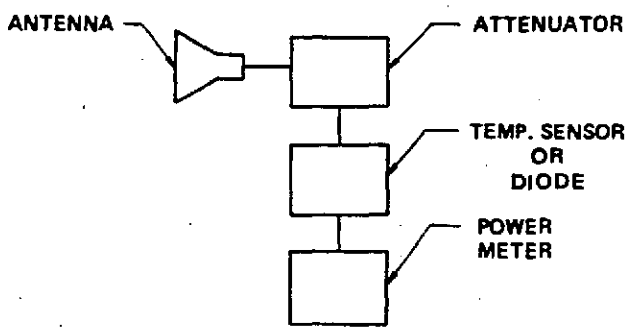
A 2-inch (5 cm) spacer should be provided to enable positioning of the probe at the correct distance from an oven to meet federal measurement standards.

The power source should be by an internal rechargeable or easily replaceable battery. The instrument should indicate when an error of ± 5% of full scale occurs due to low power.

Some reliable calibration must be available, and it must be simple to operate.

The instrument should have sufficiently high sensitivity to measure accurately a flux of 0.1 mW/cm^2.

POWER DENSITY MEASURING SYSTEM



2. Power Density Measuring Systems

The necessity for measuring relatively higher power densities and also measuring them accurately (to conform with the exposure criteria) imposes stringent requirements for power density measurement equipment.

The slide shows a block diagram of a typical test equipment to measure power density.

This equipment may consist of the following components:

a. Test Antenna or Probe - A calibrated antenna which is used as a pickup device to sample the radiated field.

b. Attenuator - a device with either a fixed or variable known attenuation factor, used to reduce the received microwave energy to a level that can be handled by the rest of the system.

c. Bolometer or Thermister - a heat sensitive device.

   1) Absorber and Temperature Sensor. A material that absorbs the energy, converting it to heat, and a device that measures the temperature change, providing an electrical output, such as a resistance change or a voltage.

   2) Alternatively, the current from the antenna/attenuator may be detected electrically by, say, a diode.

d. Power Meter - an electronic circuit and readout device which converts this electrical output to a visually indicated power or power density reading.

   All of the above items should be individually calibrated and of known accuracy. In certain systems any or all of the above may be combined into one or two integrated units. When combined into an integrated system, this is usually calibrated to be a direct reading system, i.e., output reads directly in power density (mW/cm^2). When made up of individual components, it is usually an indirect reading system.

ANTENNAS AND PROBES

R.F. FIELD SENSORS SHOULD (BUT MAY NOT)

BE INSENSITIVE TO POLARIZATION
USE SEVERAL DIPOLES

NOT DISTORT EM FIELD
REFLECT/SCATTER

3. Antennas and Probes

The antenna is a critical component in the system. It must have two important properties: polarization-insensitivity and small distortion of the source field. In the near field region, local variations in polarization can be important, although the biological hazard is not polarization-sensitive. Since dipoles, loops, and ellipses are polarization sensitive (either to linearly or circularly polarized fields), a common technique to obtain uniform sensitivity is to employ several differently-oriented dipole antennas with the components added electrically.

The antenna should not distort the source field. In general, a receiving antenna not only absorbs energy, but also transmits, reflects and re-radiates. A probe should extract field energy in a manner similar to the behavior of tissue.Tissue-equivalent conductive materials have been developed for research probes.

When one attempts to make a meaningful measurement, one must consider the reflections from the person, walls, and any metallic sheets (e.g., metal tables) which affect the reading. Surrounding objects do not "interfere" but rather act to determine the value of the field at every point in space.

An antenna which is small compared to the wavelength will absorb and reflect very little of the energy. Hence, it will not distort the field much, but the signal strength will be low. Conversely, a large antenna in the near field can set up coherent standing-wave phenomen and disturb both the transverse and reactive components of the source field. Another important property of the antenna is its resonance. A length comparable with a half-wavelength would be highly tuned to that frequency, but at lengths much shorter than half-wave, frequency response can be relatively uniform depending on the load.

14'	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	75

TEMPERATURE SENSORS

- ABSORBED RF ENERGY PRODUCES TEMPERATURE RISE
  - THERMISTOR OR BARETTER (BOLOMETER SYSTEM) VARIES RESISTANCE
  - THERMOCOUPLE PRODUCES VOLTAGE
- SLOW RESPONSE TIME

3. Antennas and Probes (contd.)

   a. Temperature Sensors

      A thermal detector is one in which the current from the antenna produces heating and the resulting rise in temperature produces an electrical effect which is measured. There are two types of thermal detectors, a bolometer system in which the change of resistance of a baretter or thermistor is used to sense the temperature change, and the second where the temperature change is measured by the electrical output of a thermocouple. All of these thermal detectors are sensitive to ambient-temperature changes. A common solution to this problem is the use of a matched pair of thermal detectors, only one of which is heated by the microwave-induced current. Another problem with thermal devices is a relatively slow response time, which can be limiting in some applications.

14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	76

OTHER SENSOR SYSTEMS

- **AIR HEATING**

  MEASURE PRESSURE RISE

- **GLOW TUBES**

  NEON BULBS THAT GLOW IN AN EM FIELD
  SIMPLE BUT UNRELIABLE

3. Antennas and Probes (Continued)

   b. Other Sensing Techniques

   Absorption Probes. Another probe method utilizes a material which directly absorbs a known fraction of the microwave energy impinging upon it. This does not measure E-field directly, but rather the temperature change is related to the power density in the field.

   Glow Tubes are neon bulb devices that emit light in an EM field. They are simple but somewhat unreliable.

OSHA STANDARD

29 CFR 1910.

10 mW/cm^2 > 0.1 hr

1 $mW\text{-}hr/cm^2$ < 0.1 hr

energy

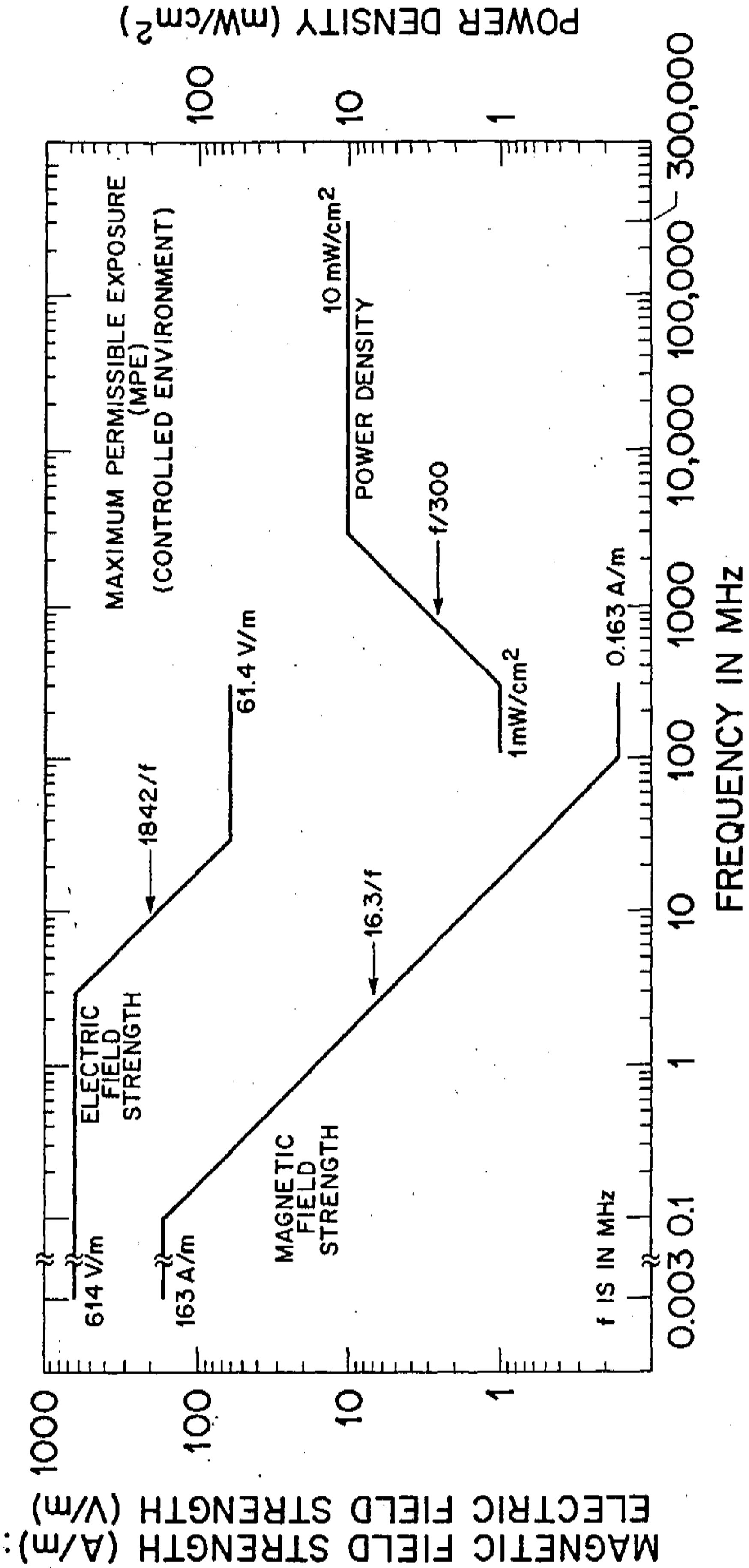


Fig A2
Graphic Representation of Maximum Permissible Exposure in Terms of Fields and Power Density for a Controlled Environment.

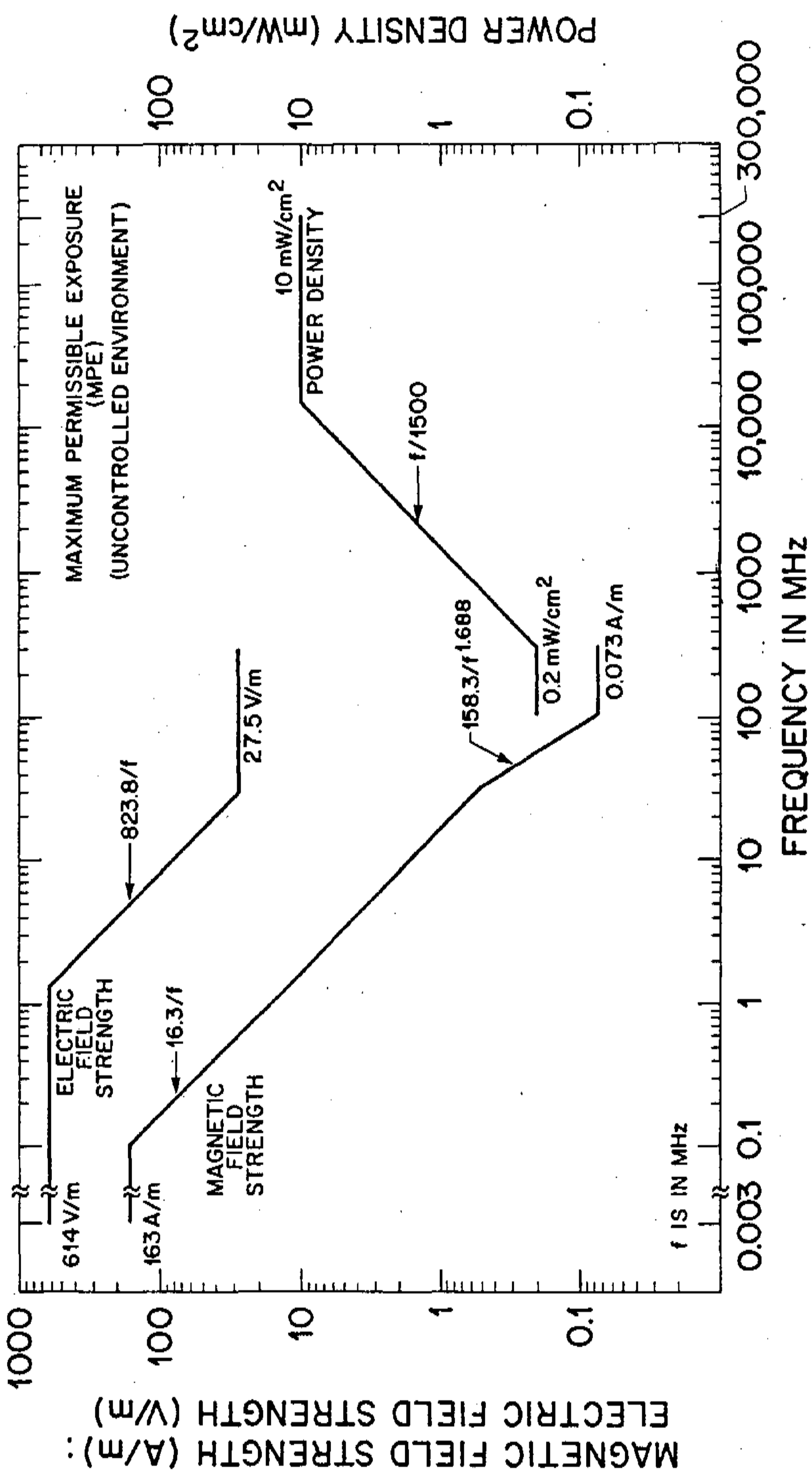


Fig A3
Graphic Representation of Maximum Permissible Exposure in Terms of Fields and Power Density for an Uncontrolled Environment.

14 68D

yspace power densities (S) and the induced currents (I) in the body that can be associated with exposure to such fields or contact with objects exposed to such fields, is given in Table 1 as a function of frequency. Exposure associated with a controlled environment includes: exposure that may be incurred by persons who are aware of the potential for exposure as a concomitant of employment, exposure of other cognizant individuals, or exposure that is the incidental result of passage through areas where analysis shows the exposure levels may be above those shown in Table 2, but do not exceed those in Table 1, and where the induced currents may exceed the values in Table 2, Part B, but do not exceed the values in Table 1, Part B.[3]

Table 1
Maximum Permissible Exposure for Controlled Environments

Part A
Electromagnetic Fields*

1 Frequency Range (MHz)	2 Electric Field Strength (E) (V/m)	3 Magnetic Field Strength (H) (A/m)	4 Power Density (S) E-Field, H-Field (mW/cm^2)	5 Averaging Time $\lvert E\rvert^2$, $\lvert H\rvert^2$ or S (minutes)
0.003 - 0.1	614	163	(100, 1 000 000)†	6
0.1 - 3.0	614	$16.3/f$	(100, $10\,000/f^2$)†	6
3 - 30	$1842/f$	$16.3/f$	($900/f^2$, $10\,000/f^2$)†	6
30 - 100	61.4	$16.3/f$	(1.0, $10\,000/f^2$)†	6
100 - 300	61.4	0.163	1.0	6
300 - 3 000			$f/300$	6
3 000 - 15 000			10	6
15 000 - 300 000			10	$616\,000/f^{1.2}$

Part B
Induced and Contact Radiofrequency Currents‡

Frequency Range	Maximum Current (mA) Through both feet	Through each foot	Contact
0.003 - 0.1 MHz	$2000f$	$1000f$	$1000f$
0.1 - 100 MHz	200	100	100

f=frequency in MHz

*The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).

†These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

‡It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object. See text for additional comment.

(a) In a controlled environment, access should be restricted to limit the rms RF body current (averaged over any 1 second) and potential for RF shock or burn as follows:
  (i) For freestanding individuals (no contact with metallic objects), RF current induced in the human body, as measured through each foot, should not exceed the following values:

[3] The means for the identification of these areas is at the discretion of the operator of a source.

$$\Sigma \; Peak\ MPE \times Pulsewidth\ (seconds) = \frac{MPE \times Avg.\ Time\ (seconds)}{5}$$

4.1.2 MPE in Uncontrolled Environment. For human exposure in uncontrolled environments to electromagnetic energy at radio frequencies from 3 kHz to 300 GHz, the MPE, in terms of rms electric (E) and magnetic (H) field strengths, the equivalent plane-wave free-space power densities (S) and the induced currents (I) in the body that can be associated with exposure to such fields or contact with objects exposed to such fields are given in Table 2 as a function of frequency.

Exposure associated with an uncontrolled environment is the exposure of individuals who have no knowledge or control of their exposure. The exposures may occur in living quarters or workplaces where there are no expectations that the exposure levels may exceed those shown in Table 2, and where the induced currents do not exceed those in Table 2, Part B. Transitory exposures are treated in 4.1.1.

Table 2
Maximum Permissible Exposure for Uncontrolled Environments

Part A
Electromagnetic Fields*

1 Frequency Range (MHz)	2 Electric field Strength (E) (V/m)	3 Magnetic Field Strength (H) (A/m)	4 Power Density (S) E-Field, H-Field (mW/cm^2)	5 Averaging Time (minutes) $\|E\|^2$, S	or $\|H\|^2$
0.003 - 0.1	614	163	(100, 1 000 000)†	6	6
0.1 - 1.34	614	16.3/f	(100, 10 000/f^2)†	6	6
1.34 - 3.0	823.8/f	16.3/f	(180/f^2, 10 000/f^2)†	f^2/0.3	6
3.0 - 30	823.8/f	16.3/f	(180/f^2, 10 000/f^2)†	30	6
30 - 100	27.5	158.3/$f^{1.668}$	(0.2, 940 000/$f^{3.336}$)†	30	0.0636 $f^{1.337}$
100 - 300	27.5	0.0729	0.2	30	30
300 - 3 000			f/1 500	30	
3 000 - 15 000			f/1 500	90 000/f	
15 000 - 300 000			10	616 000/$f^{1.2}$	

Part B
Induced and Contact Radiofrequency Currents‡

Frequency Range	Maximum Current (mA) Through both feet	Through each Foot	Contact
0.003 - 0.1 MHz	900f	450f	450f
0.1 - 100 MHz	90	45	45

f=frequency in MHz

*The exposure values in terms of electric and magnetic field strengths are the values obtained by spatially averaging values over an area equivalent to the vertical cross-section of the human body (projected area).

†These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequency and are displayed on some instruments in use.

‡It should be noted that the current limits given above may not adequately protect against startle reactions caused by transient discharges when contacting an energized object. See text for additional comment.

(a) In uncontrolled environments, where individuals unfamiliar with the phenomenon of induced RF currents may have access, it is recommended that precautions be taken to limit induced currents to values not normally perceptible to individuals, as well as prevent the possibility of RF burns.

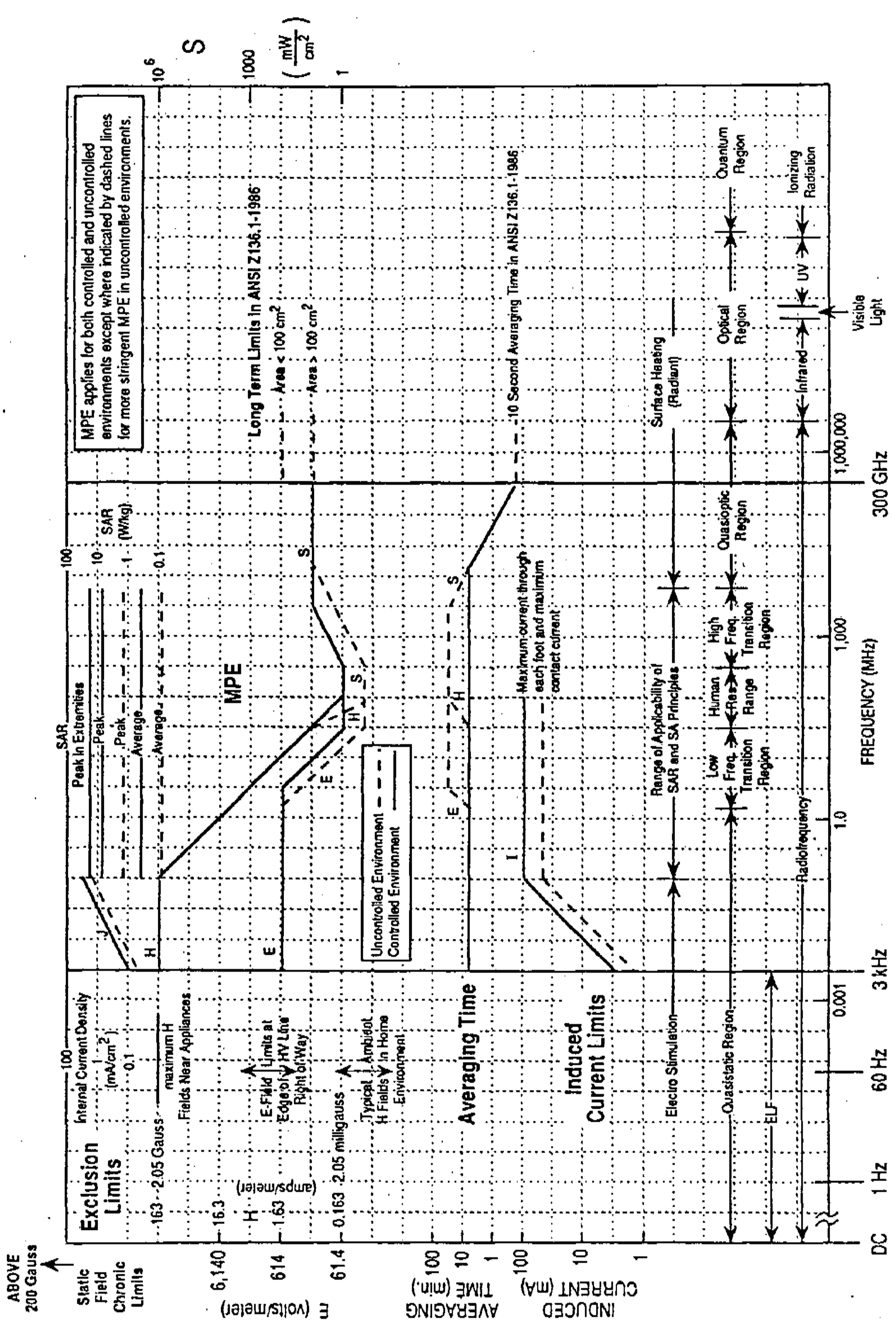
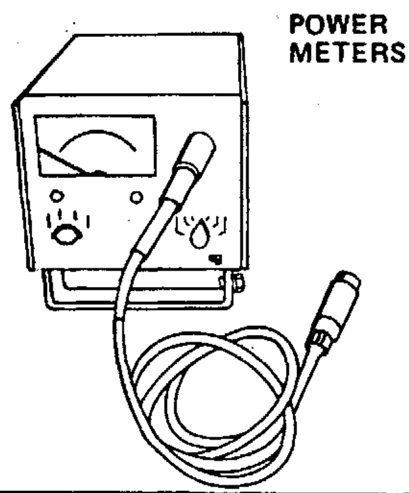


**Fig A1
Capsule Guide to the Standard**



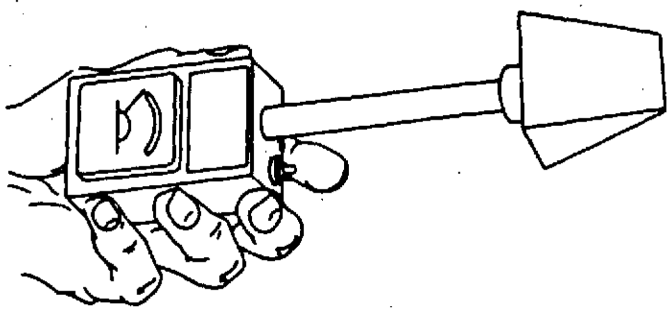
4. Power Meters

Power meters are read out devices that convert an input current to the movement of a pointer on a meter. The meter has a power scale graduated in watts or dB units. Typically they contain electrical amplifiers and gain controls.

A power meter may be used to read out the signals from a thermocouple, bolometer bridge, diode detector, or other sensor that produces a voltage or current proportional to field strength or power density.

14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	78

MICRODEK 310



5. Survey Equipment

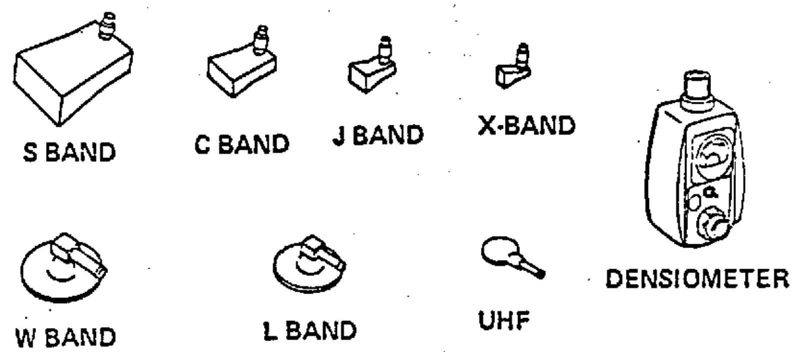
In the following charts and paragraphs are given various vendor information on several types of survey equipment.

a. Microdek 310

Microdek 310, International Crystal, Microwave Oven Leakage Meter. This portable, hand-held, meter has a shaped dipole antenna and hot-carrier diodes, driving the meter directly by means of detected power rather than by batteries. It is calibrated to operate at 2450 MHz, on two ranges 0.4 to 6.0 mW/cm^2, and 1.0 to 23 mW/cm^2. It will not burn out below 500 mW/cm^2. Its claimed accuracy is 1 dB over a ±20 MHz range at 2450 MHz. Because of its dipole antenna, it is sensitive to E-fields in only one direction, and must be rotated 90° to obtain the other direction of field; then the two power readings are summed to obtain a total.

14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	79

DENSIOMETER AND ANTENNA ASSORTMENT

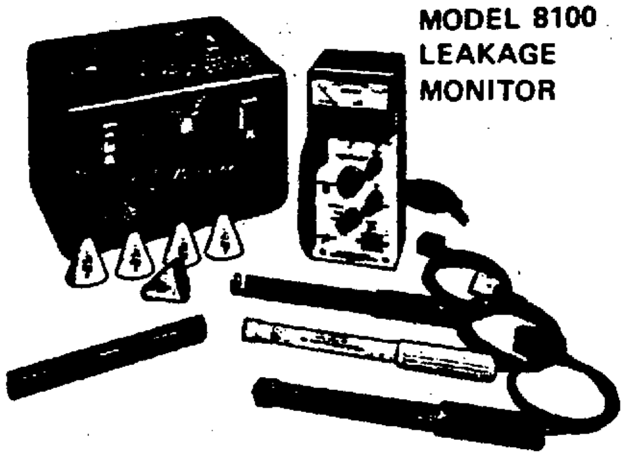


5. Survey Equipment (contd.)

b. The Waveline (Ramcor) 1200B.

This is a portable, battery operated power density meter.

With its seven antennas it covers a frequency range of 200 MHz to 11 GHz and directly indicates power densities from 0 - 20 mW/cm2. This power input may be extended by the use of suitable attenuators. It is a rugged, accurate, and light weight instrument and ideally suited for portable field use as the instrument, plus the heaviest antenna, weighs only a little more than two pounds and may be held in one hand. Its main limitations are: (1) its frequency coverage, for it cannot accurately be used for frequencies below 200 MHz or above 11 GHz; (2) its polarization sensitivity, for it detects only one E-Field direction and the antenna must therefore be turned 90^{o} to determine power density in the near field. An accuracy of ± 1 db is claimed at 10 mW/cm2.



5. Survey Equipment

c. Narda (contd.)

(1) 8100 Leakage Monitor

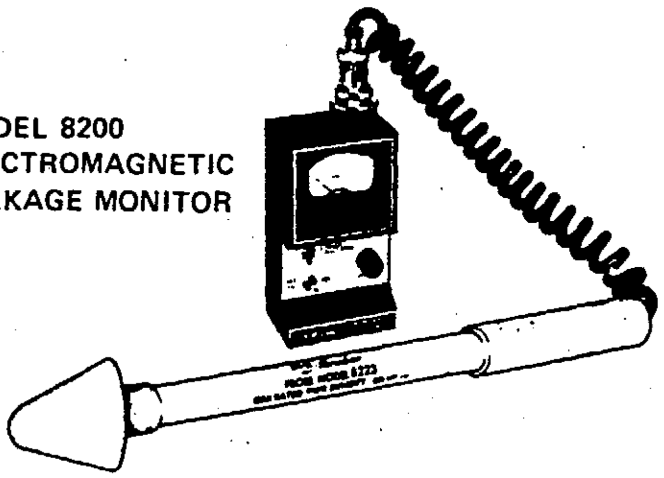
The Narda Electromagnetic Leakage Monitor Model 8100, complies fully with the requirements specified for test equipment in the performance standards published by the Department of Health, Education, and Welfare in the Federal Register, Volume 35, dated October 1970.

Design

A completely portable detector, the Model 8100 Electromagnetic Leakage Monitor has been developed specifically to fill the need for a reliable device to make microwave oven measurements at close range with good accuracy. It detects and measures hazardous microwave radiation leakage from microwave ovens, heaters, dryers, and medical equipment, which operates at 915 MHz and at 2450 MHz the two frequencies in most common use. Calibrations of other frequencies available upon special request.

Three different hand-held probes, each having a dynamic range of 23 dB, can be used with the Leakage Monitor. Advanced state-of-the-art design of the probes minimizes the perturbations in the electromagnetic field pattern during test. This feature enables the probe to measure radiation emanating through cracks and joints, and to determine the power density at varying distances from the radiation source.

MODEL 8200
ELECTROMAGNETIC
LEAKAGE MONITOR



5. Survey Equipment

c. Narda (contd.)

(2) 8200 Leakage Monitor

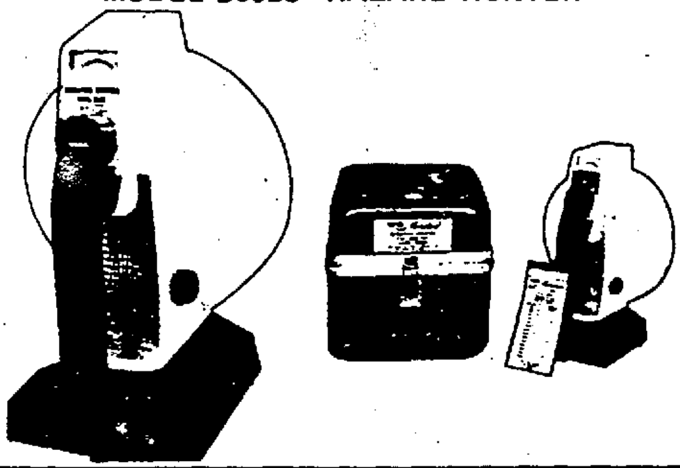
The Narda Electromagnetic Leakage Monitor Model 8200 , fully complies with the requirements specified for test equipment in the proposed performance standards published by the Department of Health, Education, and Welfare in the Federal Register, Volume 35, dated October 1970.

The Narda "Mini-Surveyor", Model 8200 Electromagnetic Leakage Monitor, has been specifically developed to provide maintenance and repair personnel with a small, completely portable, lightweight, battery operated device to make accurate, microwave measurements close to the radiation source on site. It detects and measures microwave radiation leakage from the microwave ovens, heaters, dryers, and medical equipment. The "Mini-Surveyor" supplements the well-known Narda Model 8100 Electromagnetic Leakage Monitor, to provide a small simple inexpensive unit for use by field repairmen. The probes provided with the "Mini-Surveyor" employ identical characteristics as those provided in the 8100 Surveyor

The probe and monitoring device is separated by a coiled cable, to provide maximum safety. The operator, by extending the coiled cable its full length, can monitor the unit under test without placing his eyes in the potentially hazardous radiation field.

To maintain its high degree of accuracy, the monitor is shielded to make it insensitive to extraneous radiation. The hand-held probe provided has a dynamic range of 23 dB.

MODEL B86B3 "HAZARD HUNTER"



5. Survey Equipment

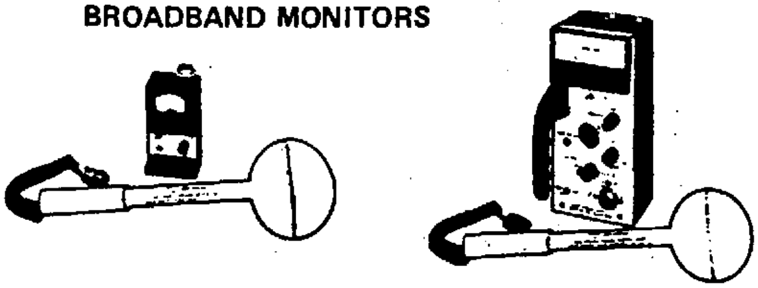
c. Narda (contd.)

All incident energy is integrated and the total field strength is read on the meter. The total field is measured in a single operation, obviating the need for summing a series of measurements at a number of frequencies and polarization. The broadband antenna covers the full operating bandwidth.

The Model B86B3 is provided with a calibration chart, to be used for quantitative measurements of continuous wave or pulsed power density. A plug-in-jack is provided at the base, for remote monitoring. The radiation monitor may be installed at a fixed location to monitor varying power densities with a meter readout or alarm circuit located some distance away. The remote meter should have 1 milliaampere, 50 millivolt full-scale movement. When the remote meter is used, the meter on the radiation monitor is inoperative.

The completely portable unit is contained within a high-impact strength housing with integral handle. The only control is a combined on-off, zero-adjust knob which is used to zero the meter before exposing the instrument to an RF field.

BROADBAND MONITORS



5. Survey Equipment

c. Narda (contd.)

The Model 8300 Series Broadband Isotropic Radiation Monitors provide flat accurate near and far field power density measurements over the broad frequency range of 300 MHz to 18 GHz. The isotropic property of the probe provides equal response when energy is received from any and all directions. The square law elements, arrayed in three mutual perpendicular planes, permit the addition of all energy (incident) sensed from all directions.

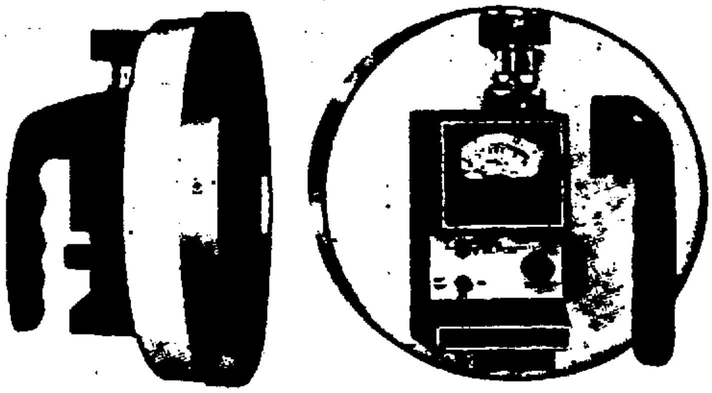
The Models 8300 and 8305 fully comply with the requirements specified for test equipment in the performance standards published by the Department of Health, Education, and Welfare in the Federal Register, Volume 35, dated October 1970.

Description

The Model 8200 Series Monitors and the hand-held Broadband Isotropic Probe, Model 8321, provide measurement capability over a 23 dB dynamic range with full scale power density range of 1 mW/cm^2. and 20 mW/cm^2. The minimum measurable power density is 0.1 mW/cm^2.

The Model 8200 series provides monitoring capability of electromagnetic radiation emanating from a variety of systems: such as, communications links; satellite communications and military electronic countermeasure systems. The square law response and isotropic properties of these monitors provide accurate power density measurements of arrayed antenna and multiple transmitter systems.

MODEL 8521 WITH MODEL 8210 METER MOUNTED



5. Survey Equipment

c. Narda (contd.)

(5) 8500 Broadband Monitors

The Model 8500 Broadband Radiation Monitor provides accurate far field power density measurements over the frequency range of 0.915 to 13.8 GHz. Measurements are independent of the polarization of the incident wave. Pulse or CW power densities are integrated to provide an average power density measurement.

The Model 8500 set consists of the Antenna Detector Model 8521, the Model 8210 meter, and Model 8440-01 interconnecting cable and carrying case.

The Model 8521 antenna detector provides measurement capability over a 20 dB dynamic range with full scale power density ranges of 2 mW/cm^2 and 20 mW/cm^2. Antenna detectors with full scale power density ranges of 0.2 mW/cm^2 and 2 mW/cm^2 or 20 mW/cm^2 and 200 mW/cm^2 are available on special request.

In applications requiring recorded data and an audible alarm, the Model 8521 Antenna Detector may be used with the Model 8110 meter.

The model 8110 meter operates on a rechargeable nickel-cadmium battery. A recorder output is provided which allows permanent data to be obtained of microwave radiation as a function of time. The Model 8110 also is equipped with an audible alarm whose threshold level is continuously adjustable from 0 to 100% of the full scale range selected.

14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	85

OVEN LEAKAGE METER

HOLADAY MODEL HI 1500
PORTABLE
2450 MHz
0 - 2 TO 0 -100 mW/cm^2
POLARIZATION INSENSITIVE
BATTERY OPERATED

5. Survey Equipment (contd.)

d. Holaday Model HI1500 Microwave Oven Leakage Meter

This portable meter, with an attached cable and probe, operates at 2450 MHz, with 3 ranges 0-2, 0 - 10, 0 - 100 mW/cm^2, using a double dipole antenna array of 8 hot-carrier diodes. It is thus not very polarization-sensitive for plane waves. The probe cable can produce some field distortion and should be moved around to determine the magnitude of this effect. An accuracy of ±1dB is claimed, and the user can select either fast (1 Sec.) or slow (3 Sec.) response times for 90% of a step input. It uses two 9-volt batteries.

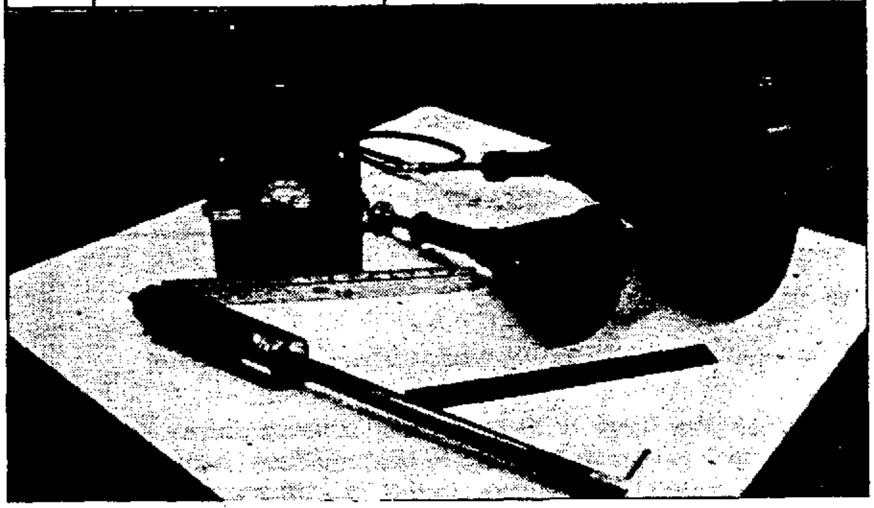
14	MICROWAVES	MICROWAVE MONITORING EQUIPMENT	86

G. E. OMNIDIRECTIONAL DETECTOR

- LOW POLARIZATION SENSITIVITY
- 915 - 2450 MHz
- RANGES 0 - 1, 0 - 20 mW/cm^2
- NO BATTERIES

e. General Electric Omni-directional Detector of Microwave Leakage

This hand-held device is one of the few with small polarization sensitivity. It uses an antenna consisting of a tetrahedral structure with six diodes on the edges. It has ±20% sensitivity over all orientations. It operates in the frequency range of 915-2450 MHz, and reads from 1 mW/cm^2 to 20 mW/cm^2. It needs no batteries but operates on the power being detected.



5. Survey Equipment (contd.)

   f. The NF-157 Power Density Meter is a portable, battery operated density meter. The frequency range of 200 MHz to 10 GHz is covered with three antennas. The meter reads power density directly and covers the range from 0 - 2000 mW/cm^2, 0 - 2 mW/cm^2 by means of built-in switchable attenuators. This wide range is an excellent feature. Although battery powered and portable, its weight is greater than ten pounds and the antenna being separate makes it somewhat cumbersome, especially when it is necessary to climb towers. Each of the three antennas has a calibrated probe which must be adjusted according to the frequency of the radiation to be measured. These probes must be set very accurately or erroneous readings may result. This is a disadvantage when the exact frequency of the radar system under test is unknown. Also since these antennas are dipoles they are sensitive to polarization.

14 68A3

IEEE C95.1-199X (July 1990 DRAFT)

MPE's FOR CONTROLLED ENVIRONMENT

part A: ELECTROMAGNETIC FIELDS

FREQ RANGE MHz	E (V/m)	H (A/m)	P.D.(S)** (mW/cm²) [**plane wave equivalent]
0.003 - 0.1	614	163	100
0.1 — 3	614	16.3/f	$10000/f^2$
3 — 30	1842/f	16.3/f	$900/f^2$
30 — 100	61.4	16.3/f	1.0
100 — 300	61.4	0.163	1.0
300 — 3000			f/300
300 — 15,000			10
15000 - 300,000			10

Part B: Induced and Contact RF Currents (mA)

	both feet	each foot	Contact
0.003 - 0.1 MHz	2000f	1000f	1000f
0.1 — 100 MHz	200	100	100

PBN-89-1328

A Capsule Guide to the Final Draft Revision; ANSI C95.1-1990

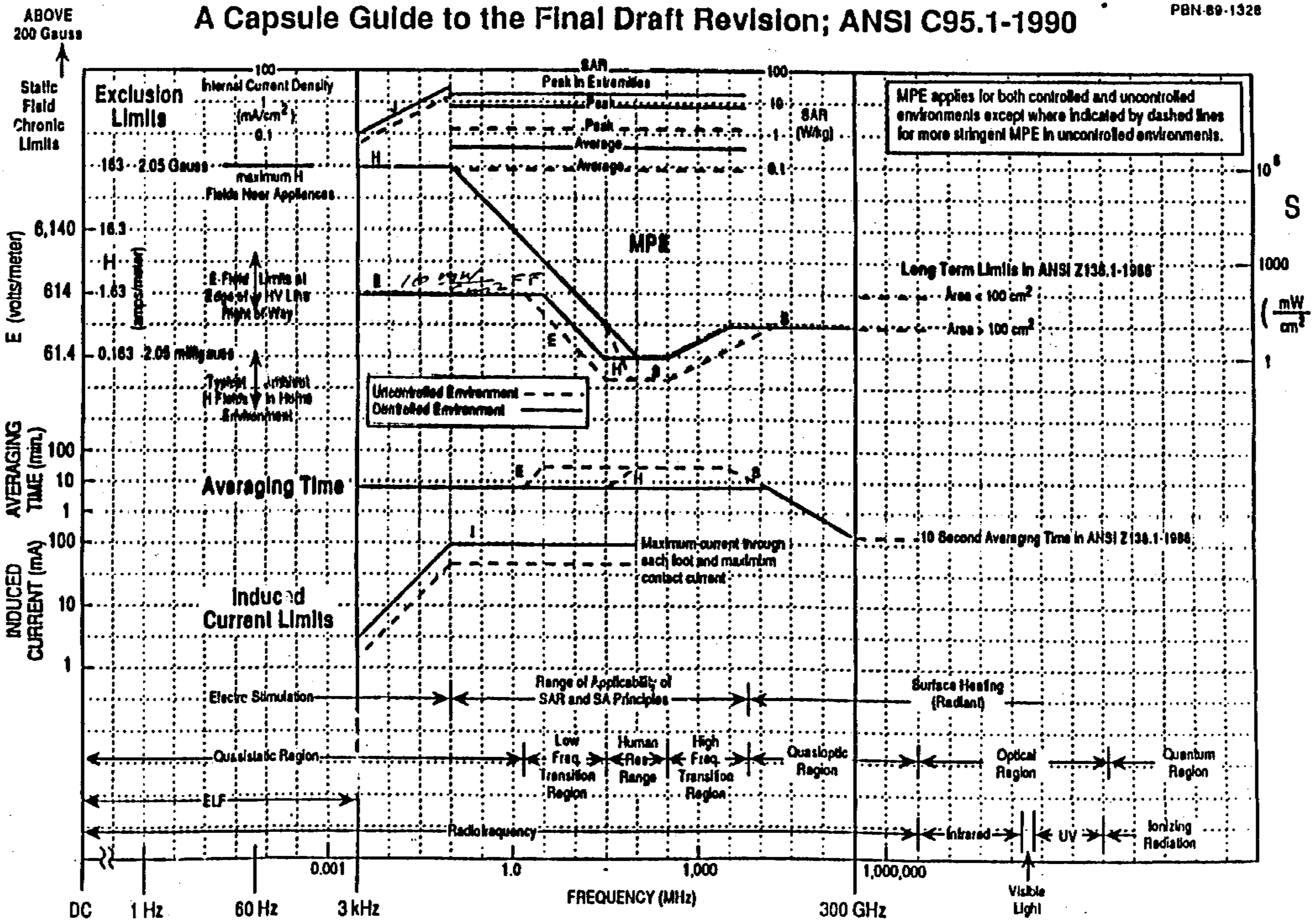


Figure A1 Capsule Guide to the Standard

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	89

WHAT CONSTITUTES A POTENTIAL MICROWAVE HAZARD

- EQUIPMENT CAPABLE OF $\geq$ 10 mW/cm^2 P.D.
  - HIGH OR MEDIUM POWER CW SYSTEMS
  - PULSED SYSTEMS
- NEAR-FIELD CONDITIONS

1. Maximum Permissible Exposure (contd.)

   We will now consider controls for microwave hazards. Whenever there is equipment that can radiate directly or indirectly (e.g., via leakage or side lobes) power density levels of 10 mW/cm^2 or greater, there is a potential hazard. This is generally true of high or medium power cw and pulsed systems. Also one should always be alert to the near field conditions where power density fluctuates.

14'	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	90

EVALUATION OF THE HAZARD

a) KNOWLEDGE OF THE TYPE OF INSTALLATION

b) KNOWLEDGE OF THE CALCULATED SAFE DISTANCES

c) IS RADIATED AREA OCCUPIED OR POTENTIALLY OCCUPIED ?

d) ARE THERE REFLECTIVE OR SCATTERING SURFACES ?

e) DO YOU HAVE ADEQUATE SURVEY EQUIPMENT ?

2. Evaluation of Hazard

Of prime importance in radiation control is an assessment or evaluation of the hazard in occupied and potentially occupied areas. Some basic information needed for this evaluation would be:

a. Knowledge of the type of microwave installation involved, such as: frequency of wave, power level, gain, duty cycle, and angle of rotation.

b. Knowledge of the calculated safe distances from the antenna to the boundary of potentially hazardous zones.

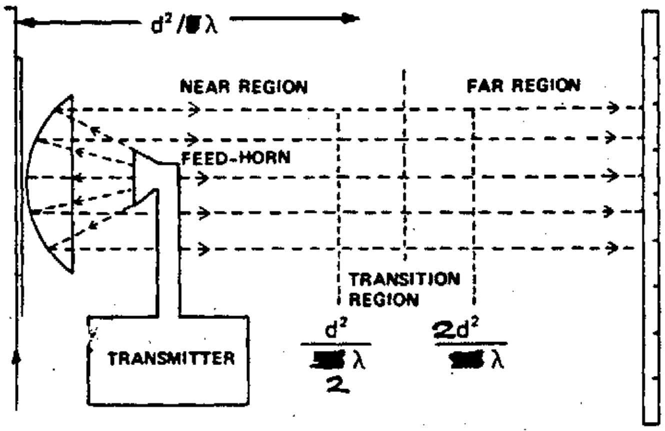
c. A listing of normal and possible locations of working personnel and the general population with respect to the radiating antennas.

d. An awareness of the presence of highly reflective surfaces (walls, windows, vehicles, etc.) that may intensify beams in specific locations.

e. Accurate measurement of existing radiation intensity levels by reliable instruments in the hands of personnel well trained in the use of such equipment.

14'	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	91

MICROWAVE TRANSMISSION



2. Evaluation of Hazard (contd.)

At varying distances from the transmitting antenna, many complex factors of reflection and refraction determine the power density level. Generally, two specific regions are defined: (1) the "Near Field" (or Fresnel region) and (2) the "Far Field" (or Fraunhaüfer region). Between these two regions there is a transition region in which it is difficult to predict definite field power densities. The range of the Near and Far Fields of the projected microwave field is a function of the cross-sectional area (effective) of the antenna and the length of the wave.

The effective area (A_{eff}) of an antenna depends upon its size (e.g., diameter if it is circular) and the transmitted wavelength. The center of the near-far field transition is thus located at about $A_{eff}/2$, or at $d^2/2\lambda$ for a circular antenna.

At distances closer than $d^2/2\lambda$, one definitely is in the near field. At distances greater than $2d^2/\lambda$, one is in the far field, unless there are nearby reflecting surfaces that might act as secondary radiators.

Recall that in the near field, (1) the E and B fields are not established in their mutually perpendicular and in-phase relationship; (2) that power density measurements made with simple probes may be meaningless; and (3) that the absorbed power density in a material may fluctuate widely over short distances. In the far field, the E and B fields are established in proper spatial and temporal relationships, the power density is proportional to E^2 and thus can be measured with a simple dipole probe, and the power density falls off with distance according to the inverse square law.

D = antenna diameter

Chart 14-9/A

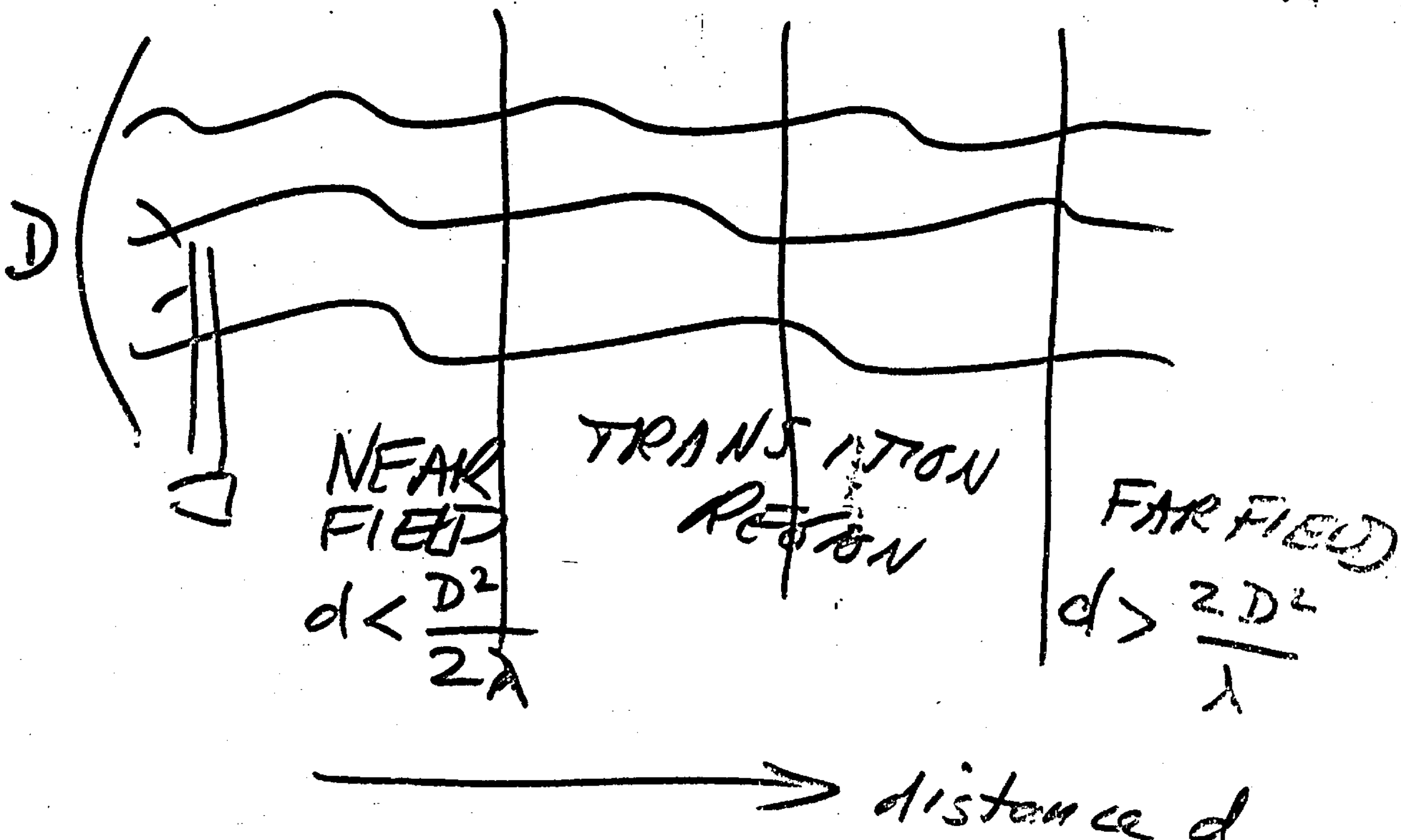
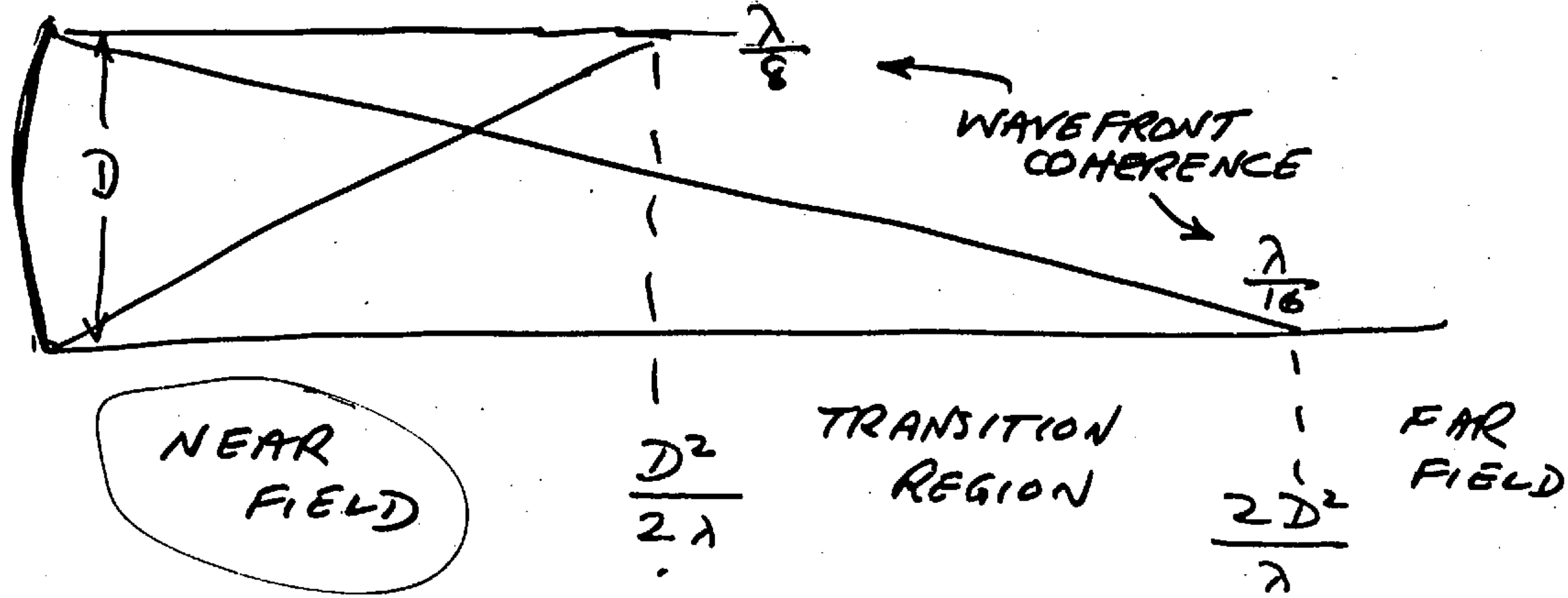


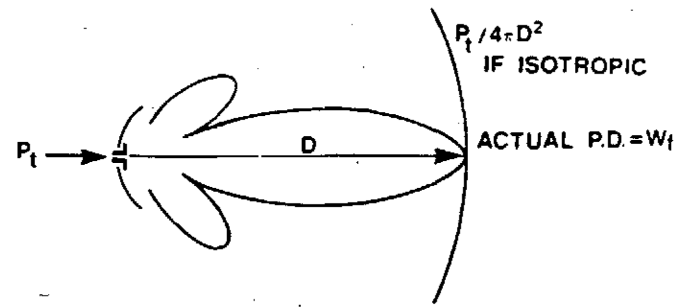
Chart 14-91B

NEAR-FIELD / FAR-FIELD



Q14-82

ANTENNA GAIN



$$\text{ANTENNA GAIN} = \frac{\text{MAIN LOBE POWER DENSITY (Far Field)}}{\text{ISOTROPICALLY RADIATED P.D.}}$$

Recall that a microwave antenna is designed to radiate power preferentially in one direction. If all the power input, P_t, were radiated equally in all directions (isotropically), then the power density at distance D would be $P_t/4\pi D^2$. The power density along the principal lobe of a directional antenna, W_f, is equal to the antenna gain, G, times the isotropic value. This is simply the definition of antenna gain:

$$G = W_f/(P_t/4\pi D^2) = 4\pi W_f D^2/P_t.$$

Gain, being a power ratio, is often expressed in decibel units (db). We will use this definition of antenna gain in the next few charts to show how to calculate safe distances from antennas, that is, distances such that the power density, W_f, is less than 10 mW/cm^2.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	93

FAR FIELD CALCULATION

$$W_f = \frac{P_t G_t}{4 \pi D^2} \qquad D = \sqrt{\frac{P_t G_t}{4 \pi W_f}}$$

W_f = FAR-FIELD POWER DENSITY, IN WATTS/cm^2

P_t = AVERAGE TRANSMITTER POWER IN WATTS

G_t = POWER GAIN OF ANTENNA

D = DISTANCE FROM ANTENNA, IN CENTIMETERS

2. Evaluation of Hazard (contd.)

a. Calculations

(l) Far Field

The field intensity in the far-field region (W_f) may be calculated by use of the equation shown. The point at which $W_f = 0.01$ W/cm^2 may be caluclated by using the equation solved for D. These calculated distances can be verified by the use of a power density survey meter.

Example:

Given: Frequency = 1300 MHz
Average power = 1080 watts
Antenna gain = 30.56 db (a power gain of 1140)

$$D = \sqrt{\frac{1080 \text{ watts} \times 1140}{4\pi \times 0.01 \text{ (W/cm}^2\text{)}}}$$

$$D = \sqrt{\frac{1.23 \times 10^6}{0.1256}}$$

$$D = 3110 \text{ cm (102 ft.)}$$

14'	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	94

SAFE DISTANCE CALCULATION

$$D = \sqrt{\frac{0.08\ P_t G_t}{P\,(w/m^2)}}$$

WHERE D = DISTANCE IN METERS

P_t = POWER INPUT TO ANTENNA, IN WATTS (AVG)

G_t = RATIO OF POWER GAIN OF THE TRANSMITTING ANTENNA OVER AN ISOTROPIC RADIATOR

P = POWER DENSITY, IN WATTS PER SQUARE METER

2. Evaluation of Hazard

a. Calculations (contd.)

(2) Safe Distance

The equation from the previous chart, defining antenna gain, may be arranged by substituting the numerical value of pi and converting units to meters, to obtain the form shown:

$$d = \sqrt{\frac{0.08\ P_t G_t}{P(w/m^2)}}$$

where: d = distance in meters

P_t = power input to antenna, in watts (average)

G_t = ratio of power gain of the transmitting antenna

$P(w/m^2)$ = power density, in watts per square meter

Similarly, as shown in the next two charts, the equation may be converted by unit substitutions to give safe distances in yards with power input in watts.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	95

SAFE DISTANCE EVALUATION

(1) $$d = \sqrt{\frac{0.08\, P_t G_t}{P(W/m^2)}} \quad \text{(DISTANCE IN METERS)}$$

(2) $$D = \sqrt{\frac{0.096 G_t P_t}{P(W/m^2)}} \quad \text{(DISTANCE IN YARDS)}$$

2. Evaluation of Hazard

a. Calculations

(2) Safe Distance (Continued)

The safe distance equation (1) shown above gives the distance in meters and the power density in watts/m^2. This equation will now be modified to give the distance in yards using a power density in watts/cm^2. The first step converts the distance in meters to distance in yards yielding equation (2).

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	96

SAFE DISTANCE EQUATION

(2) $$D_Y = \sqrt{\frac{0.096\, G_t P_t}{P(W/m^2)}} \longrightarrow$$

(3) $$D_Y = \sqrt{\frac{0.0000096\, G_t P_t}{P(W/cm^2)}}$$

(4) $$D = \sqrt{\frac{0.0000096\, G_t P_t}{0.01}}$$

(5) $$D = \sqrt{0.00096 G_t P_t}$$

Next the equation is altered so that W/cm^2 can be used instead of W/m^2. This form is shown by equation (3). The safe power density of .01 watts/cm^2 is now used in the equation as shown in (4). This is simplified to equation (5) which gives the safe 10 mW/cm^2 distance in yards.

ANTENNA GAIN

$$G = \frac{4\pi \, A\,eff.}{\lambda^2} = \text{POWER RATIO}$$

A_{eff} = EFFECTIVE CROSS-SECTIONAL AREA OF ANTENNA IN cm^2 = πD^2 (CIRCULAR ANT.)

λ = MICROWAVE WAVELENGTH IN cm

GAIN (db) = $10 \log_{10}$ (POWER RATIO)

2. Evaluation of Hazard

a. Calculations (contd.)

(3) Antenna Gain

The antenna focusing characteristic is defined as a ratio or in terms of decibels. Since the decibel is a logarithmic function (to the base 10), 10 decibels is a multiplication factor or gain of 10 times; 20 decibels is a gain of 100 times, etc. Manufactured antennas will have a known gain, so this type of calculation will not always be needed.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	99

WHY MONITOR?

(1) TO ESTABLISH FORMAL RECORDS

(2) FOR COMPLIANCE INSPECTIONS AND LAWSUITS

(3) TO GET DATA FOR EQUIPMENT DESIGN

2. Evaluation of Hazard (contd.)

   b. Monitoring

      (1) Why Monitor?

      There are several reasons for surveying microwave setups: (1) If you are a company inspector you are creating the official records for the company. (2) These records support the company during inspections by the State and Federal government inspections and also support the company in case claims or lawsuits against the company arise. (3) These surveys can provide helpful information for equipment and facilities design.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	100

PREPARING FOR SURVEY

1. BACKGROUND INFORMATION

2. TYPE OF INSTRUMENTATION

3. SPECIAL EQUIPMENT

(2) Preparing for a Survey

When preparing for a survey one must first get all the information possible about the setup to be surveyed. This may be from previous survey records or from other people who may have made this survey before. Information needed would be frequency, average power, antenna gain, and type of environment. From this, one can determine the proper instrumentation needed and whether or not any type of shielding or absorber may be needed.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	101

PERFORMING A SURVEY
OF A MICROWAVE OVEN

(1) PLACE ABSORBER IN OVEN

(2) SURVEY DOOR

(3) CHECK ALL CRACKS AND OPENINGS

(4) CHECK DOOR INTERLOCKS

2. Evaluation of Hazard

b. Monitoring (contd.)

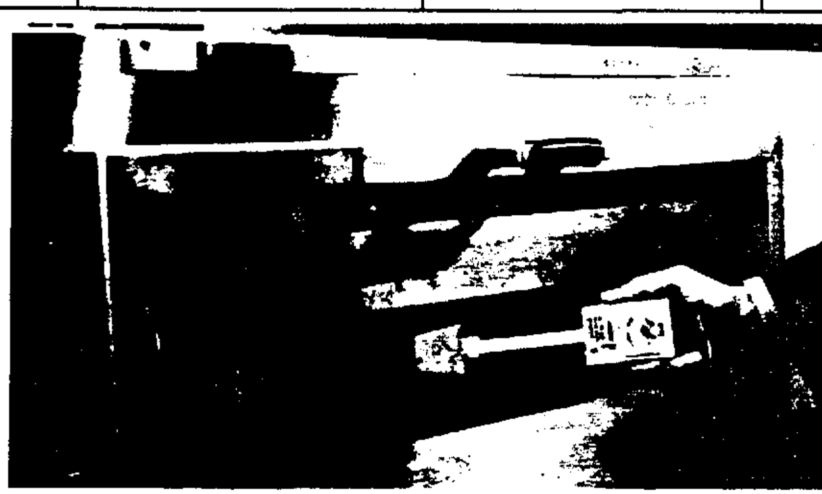
(3) Performing a Survey

To start an oven survey you must first place a cup of water in the open cavity. Moving your survey meter along the edge of the door, rotate the detector to be certain you have the right polarization. Survey the grill area, covering the entire area. To check the door interlocks, place the detector next to the edge of the door and slowly open the door. It is advisable to do this several times holding the detector at different locations.

Note: Should the water in the oven begin to boil during the measurement, stop and replace it with cold water.

This slide illustrates the method of surveying along the door seam of a microwave curing oven. This survey operation should be made in two passes rotating the meter to check for maximum reading. This operation could be done in the same manner for standard cooking ovens.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	102



This slide shows the proper way to survey the grill area of a microwave curing or standard cooking oven. Remember to rotate the meter 45° and repeat the scan for maximum reading.

2. Evaluation of Hazard

b. Monitoring

(3) Performing a Survey (continued)

On microwave units which have a conveyor belt system, a survey should be made at the areas where the belt enters and exits the unit. These are the areas where personnel will be standing for the longest periods of time. Check the area very thoroughly from very close in to several feet around the opening. Because of the reflection through this type of opening, the readings could be high at some areas back from the openings.

PERFORMING A LARGE ANTENNA SURVEY

1. MAIN BEAM
2. SIDE LOBES
3. BACK LOBES
4. REFLECTION
5. POLARIZATION
6. ASSOCIATED HAZARDS

2. Evaluation of Hazard

b. Monitoring

(3) Performing a Survey (contd.)

When doing the actual survey you have to be at a distance which is far enough from the antenna so the radiation field is less than 10 mW/cm^2. (Note: If the antenna is a scanning antenna, it is much better to have the antenna stationary during the survey because of slow instrument response.) From this distance you can verify the hazardous distance in the main beam. While surveying, one must be certain that the detector is in the proper plane for polarization. When the hazardous condition is known, then the side and back lobes should be surveyed. Other things that should be surveyed are reflections of metal buildings or vehicles nearby. An X-Ray survey of the high-voltage supply should also be made.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	105

ASSOCIATED HAZARDS

X-RAY

HIGH-VOLTAGE

2. Evaluation of Hazard

c. Associated Hazards

(1) X-Ray and High Voltage

X-ray production in microwave transmitting systems occurs because certain electronic tubes, such as klystrons, magnetrons, traveling wave tubes and high voltage thyratrons, posess the basic physical parameters which allow them to act as x-ray generators. The most important parameter is the extremely high voltages required to operate the tubes utilized in the generation of microwave energy.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	106

X-RAY SURVEY INSTRUMENTATION

(1) DESIGN TO MEASURE X-RADIATION

(2) RF INSENSITIVE

(2) X-Ray Survey

Instrumentation used for detection and measurement of this unwanted x-radiation is essentially the same as standard x-ray survey meters with a few important exceptions. The microwave or radio frequency energy present does affect the circuitry of most standard x-ray survey meters and, therefore, this instrumentation must be shielded to protect it from this susceptibility which may cause erroneous readings. Also, this protective shielding should not unduly affect the meter's ability to accurately measure x-rays at low energy levels (20 kV) such as are found around thyratrons. An example of a survey meter which has been designed specifically to measure x-radiation in the presence of radio frequency radiation is the Victoreen Model 440RF.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	107

PROTECTIVE ENGINEERING

OPERATING PROCEDURES

1. HAZARDOUS PROPERTIES
2. PRECAUTIONS
3. RESPONSBILITIES

2. Evaluation of Hazard (contd.)
   d. Protective Engineering

      (1) Operating Procedure

      It is important when working with microwave radiation that effective controls are established. An operating procedure should outline the hazardous properties, precautions, and responsibilities when working with microwave. The following slides illustrate a usable operating procedure.

PROTECTIVE ENGINEERING OPERATING PROCEDURE

RESPONSIBILITIES

GENERAL

SPECIFIC

2. Evaluation of Hazard

d. Protective Engineering (contd.)

(1) Operating Procedure

RESPONSIBILITIES

General

Each Supervisor will take action to establish effective control of microwave radiation hazards in his area. He will post (as hazardous) all areas in his jurisdiction in which an individual may be exposed to radiofrequency energy having a power density of 0.01 Watt/cm^2. He will ensure that his employees are instructed on the hazards of microwave radiation.

Using Organizations will be responsible for making arrangements and sending exposed employees for physical examinations as required by the Medical Department.

Using Organizations should review any proposed deviation from acceptable practices and established regulations which may be hazardous to health.

Specific

The Medical Department will:

Specify minimum microwave radiation health requirements.

Give periodic physical examinations as required.

Quality Control Department:

The Inspection Planning Unit will plan and sequence test procedures to minimize radiation hazards.

The Engineering Department will:

Coordinate any proposed new equipment or contemplated deviation in operating equipment or facility which may be hazardous to health.

Evaluate the existing microwave radiation hazard.

OPERATING PROCEDURE PRECAUTIONS

1. PERSONAL PROTECTION
2. PROTECTIVE FACILITIES
3. FIRE PROTECTION

2. Evaluation of Hazard

d. Protective Engineering

1) Operating Procedure (contd.)

Personal Protection

Avoid any exposure to radiofrequency energy having a power density of 0.01 Watts/cm² or greater. No exposure to power density greater than 25 mW/cm² is allowed.

NOTE: **Short exposure (less than 10 minutes in any one hour) may exceed the 0.01 Watts/cm² if prior approval is obtained. The average 8-hour power density must not exceed 10 mW/cm².**

Do not make detailed visual examination of any microwave radiator, reflector, waveguide opening, waveguide horn, or magnetron during periods of transmission.

Limit the number of personnel having access to areas immediately adjacent to test stands or benches containing equipment radiating energy of hazardous power. Only those required to perform specific tests should be present.

Protective Facilities

Use dummy loads, water loads, or other absorbent materials whenever possible to absorb the energy output of the transmitter while being operated or tested.

When the above cannot be complied with, provide absorbent screening to isolate test stands from each other or from adjacent administrative areas which may be affected by the microwave radiation.

Areas accessible to personnel and having a power density equal to, or greater than 0.01 Watt/cm² will be posted with "WARNING-MICROWAVE RADIATION HAZARD" signs and flashing lights.

Provide absorbing shielding for ordnance device.

Fire Protection

Comply with Operating Procedures for Fuel/Defuel operations on all types of aircraft and missiles.

OPERATING PROCDURE
HAZARDOUS PROPERTIES

1. HEALTH
2. FIRE
3. SAFETY

2. Evaluation of Hazard

d. Protective Engineering

1) Operating Procedure (contd.)

HAZARDOUS PROPERTIES:

Health Hazards

When Microwave energy is absorbed in matter, it produces localized heating. This heating effect can cause damage to certain human organs where normal heat control is poor and blood circulation is low. The organs most likely affected are the eyes and testes.

Biological damage is related to wavelength and power intensity. In general, the longer wavelengths (10 cms, or more) are more deeply penetrating than the short wavelengths (less than 10 cms). The longer wavelengths produce a greater temperature rise in a significant volume of tissue than the shorter wavelengths, but with less subjective awareness to the heat for a given power intensity.

Power intensities sufficiently high to cause damage to the eyes may occur in the fields of radiating radar antennas. An intolerable temperature rise in body tissues can result from exposure of a significant portion of the body (100 cm^2, or more) to microwaves in the frequency range from 30 cms wavelength (1.0 giga-Hertz) to 10 cms wavelength (3.0 giga-Hertz).

Fire Hazards

Dry steel wool can be ignited by a radar beam under certain circumstances. Photo flash bulbs have been ignited at distances up to 350 feet. Fuel vapors may be ignited where metals and fuel are in close proximity in the radar beam. (These effects are primarily due to power intensity, although frequency is also important.)

Safety Hazards

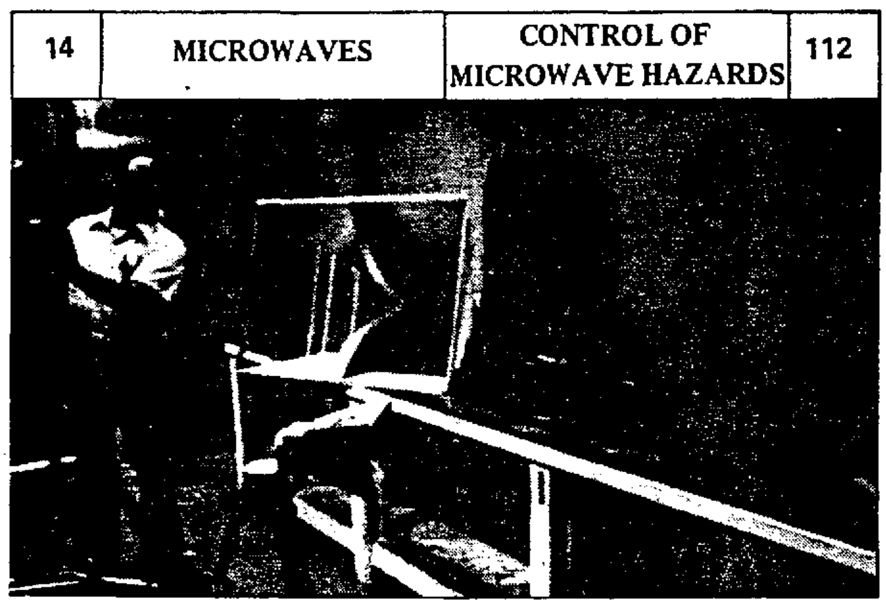
Ordnance items, such as "squibs" may be detonated by microwave energy.

2. Evaluation of Hazard

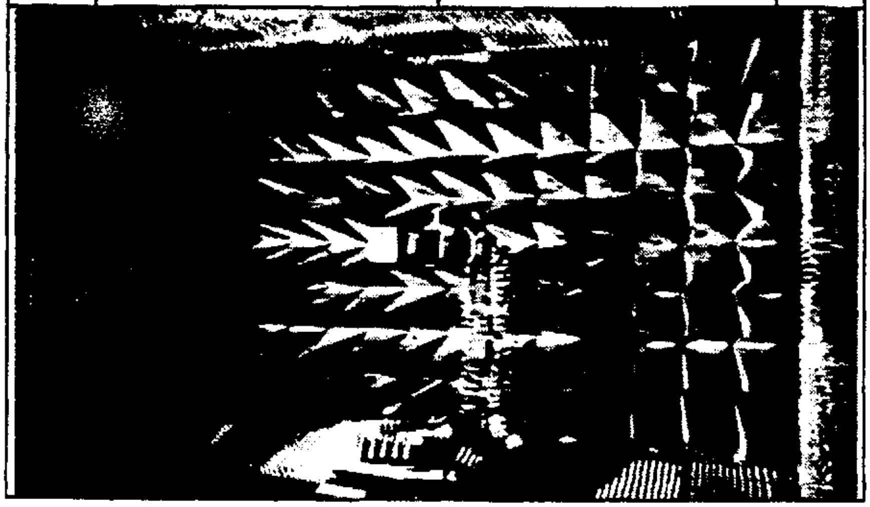
d. Protective Engineering (contd.)

2) Facility Design

Shield rooms such as the one shown are now used for tests which may be hazardous to the personnel or equipment in the test area. These rooms are constructed of 2 sheets of plywood sandwiched between metal. All vents are shielded with honeycomb to absorb any reflected RF. This particular room is capable of handling frequencies from 14 Hz to 10 GHz and radiated power up to 200 W/m.



A closed circuit TV monitoring system is used to scan the equipment to watch for possible malfunctions and also monitor detection equipment that may be used.



2. Evaluation of Hazard

   d. Protective Engineering

      2) Facility Design (contd.)

Absorber rooms or even small boxes may be constructed to handle short term RF tests in a safe manner. The amount of absorber used will depend on the frequency and power being irradiated. In this type of shield one must be careful not to use more power than the particular absorber can handle. Too much power can cause internal combustion in the absorber which is practically impossible to extinguish.

MICROWAVE SHIELDING PROPERTIES @ 2450 MH_Z

MATERIAL	ATTENUATION FACTOR
60 x 60 MESH SCREENING	0.997
32 x 32 MESH SCREENING (WINDOW TYPE)	0.994
8" SOLID CONCRETE BLOCK	0.994
WINDOW GLASS	0.37
¾" PLYWOOD	< 0.37

2. Evaluation of Hazard

d. Protective Engineering

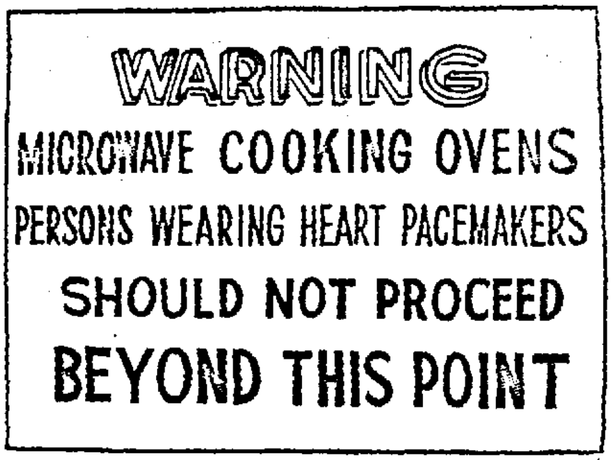
2) Facility Design (contd.)

In situations where operations would be unduly restricted by implementation of the above methods, suitable attenuation of power density levels may be accomplished by shielding. An attenuation chart for various materials at different frequencies is as follows:

ATTENUATION FACTORS (SHIELDING)

Material	Freq. 1-3 GHz	3-5 GHz	5-7 GHz	7-10 GHz
60x60 mesh screening	20 db	35db	22 db	20 db
32x32 mesh screening	18 db	22 db	22 db	18 db
16x16 window screen	18 db	20 db	20 db	22 db
¼" mesh (hardware cloth)	18 db	15 db	12 db	10 db
Window Glass	2 db	2 db	3 db	3.5 db
¾" Pine Sheathing	2 db	2 db	2 db	3.5 db
8" Concrete block	20 db	22 db	26 db	30 db

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	115



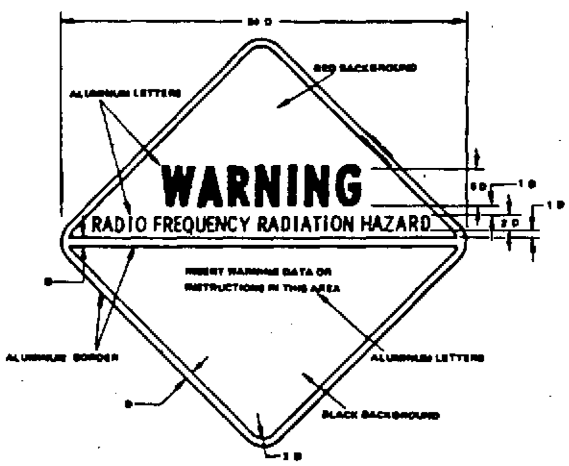
2. Evaluation of Hazard

   d. Protective Engineering

      2) Facility Design (contd.)

         A sign similar to this should be placed in such a location as to give ample warnign to a person wearing a pacemaker about the operation of microwave ovens.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	116



This sign should be located in any area where a person may be exposed to 10 mW/cm^2 or greater. Any warning information should be noted in the lower section.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	117

PROTECTIVE EQUIPMENT

EYE PROTECTION

- MESH IMBEDDED IN THE GLASS LENSES
- ABSORBENT MATERIALS IN THE SIDE
- BULKY AND UNCOMFORTABLE

2. Evaluation of Hazard (contd.)

e. Protective Equipment

1) Eye Protection

It is surprising that safety eyewear to protect personnel from the ocular hazards of lasers is readily available commercially from many manufacturers. Yet lasers are relatively new devices. However, protective eyewear for microwave radiation is practically nonexistent although this hazard has been with us for many years.

These glasses utilize a very fine mesh imbedded in the glass lenses and microwave absorbent material in the sides. Vision is relatively unaffected and the glasses have an attenuation of better than 20 db (100 times) from 1 GHz to 20 GHz and more than 15 db (40 times) from 20 GHz to 40GHz. The glasses are somewhat bulky and uncomfortable, but future refinements should reduce the size and weight.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	118

PROTECTIVE EQUIPMENT

ABSORPTION SUITS

1. REDUCTION OF HIGH-LEVEL FIELDS
2. PROTECTION AGAINST HIGH VOLTAGE
3. MINI RESTRICTION OF VISIBILITY, MOBILITY AND DEXTERITY

2. Evaluation of Hazard

 e. Protective Equipment (contd.)

  2) Absorption Suits

A suit has been designed and used that withstands severe mechanical and environmental tests; it allows complete freedom of movement without obstructing the wearer's visibility. It can be worn with safety in an electromagnetic field whose power density is 10,000 times more intensive than the present safe limit (attenuation of more than 40 decibels).

FUEL IGNITION HAZARD

≈ 5 WATTS/CM^2

IN REFUELING AREAS

3. Radio Frequency Ignition of Fuels

A fuel hazard exists whenever a peak power density of 5 watts/cm^2 or higher occurs in an area where refueling operations are conducted. The first step in the solution of a fuel hazard problem is the determination of power levels in the area. This is accomplished by calculation or by actual measurement of the energy fields. Power density measurements of fields in the vicinity of aircraft or refueling areas caused by radiation from communications transmitting antennas can be indirectly made using a field intensity meter which tunes the frequency range in question.

All radars in proximity to refueling operations which have been determined capable of generating sufficient power to cause a fuel hazard shall be required to observe strict safety control measures during refueling operations. Each operational facility will require individual study to determine the operational procedures that should be used and the safety devices that should be installed to permit operation of fueling facilities in complete safety. Typical measures that may be employed to prevent hazards during refueling operations are as follows:

a) Reduction of radar power output to decrease the maximum fuel distance. This measure, of course, results in a sacrifice of radar performance and range. Note that tower-mounted equipment, by virtue of the antenna height above ground and the beam configuration, may not create hazards at ground level.

b) Installation of sector blanking kits, or restricting the antenna rotation to a particular sector. Either measure has obvious disadvantages.

c) Installation of limiting devices on the antenna to prevent its use at low tilt angles or operationally restricting the use of elevation angles below a predetermined limit during refueling operations.

d) The use of shielding offered by natural terrain, by buildings or similar obstructions, or by properly located reflecting screens to divert the energy, thus permitting refueling operations to take place in the "shadow" of such obstructions or screens.

e) Requiring the offending radar to cease operation during refueling operations if all other measures do not provide a reasonable margin of safety. Such action, of course, reduces the effectiveness of the defense network of which the radar is a part. Consequently, consideration should be given to relocating the fueling facility, radar facility, or both.

14	MICROWAVES	CONTROL OF MICROWAVE HAZARDS	120

ELECTRO-EXPLOSIVE DEVICES

SMALL CHARGES WHICH IGNITE WHEN EXPOSED TO ELECTRICAL CHARGE

WHEN SHIPPED AND STORED IN METAL CONTAINERS, ARE SAFE

CONTAINER PROVIDES AN RF SHIELD

4. Electro-Explosive Devices

Electro-explosive devices are small-size pyrotechnic or explosive devices designed to function by the passage of an electric current through them which detonates an explosive charge. Among such devices are primers, detonators or destructors, squibs, gun and cannon primers, blasting caps, igniters, initiators, rocket igniters, jettisoning initiators, dimple motors, etc. All of these are ordnance devices which initiate a chain of actions resulting in the ignition of a main high-explosive charge. The technical name or designation given an electro-explosive device depends on the circumstances requiring its use; therefore, the term "squib" is used throughout this section as a general term to include all types of electro-explosive devices without regard to its technical application to ordnance items.

Squibs, as supplied by the manufacturer, are normally shipped and stored in metal containers. These metal storage containers provide an almost perfect RF shield, and protect the squibs from ignition by RF fields. Furthermore, the squibs as supplied are generally packaged with the short-length leg wires, folded or coiled so that induced RF currents tend to neutralize or cancel each other. Also, the squibs may be wrapped in metal foil, the ends of the bare leg wires may be twisted together, and a shunt may be installed on the leg wires. Therefore, as long as squibs are stored or transported in the original packaged form, there should be no explosion hazard from RF radiation under any circumstances.

TOXICITY

HIGH-POWER MICROWAVE WAVEGUIDE CONTAINS:

- **FREON**
- **SULFUR HEXAFLUORIDE**

WHICH CAN PROVIDE TOXIC GASES WHEN ARCOVER OCCURS

5. Gaseous Dielectric Waveguide

The development of high-power microwave transmitting equipment has reached the point where the power levels available for radiation exceed the power-handling capabilities of ordinary waveguide transmission lines. Therefore, it has been necessary to devise means by which the power-handling capability of waveguides can be increased.

The use of either Freon or sulfur hexafluoride as a dielectric medium to pressurize waveguide systems does permit increasing the wave–handling capability of the sub guide system. However, in the event of arcover or breakdown, both gases are subject to decomposition. Freon is not likely to be used in low-temperature applications because of its comparatively high condensation temperature (a Freon-filled system operated under low temperature conditions requires special treatment to keep the temperature of the gas above the condensation temperature). However, it is important to note that after breakdown, one of the decomposition products of Freon is phosgene, which is a highly toxic gas and extremely dangerous to personnel.

Sulfur Hexafluoride in its pure state is essentially inert and nontoxic, and has found use in medical applications as a therapeutic measure to rehabilitate damaged lungs. In tests on humans, the gas in its pure state has been found to be nontoxic when inhaled in gas-oxygen mixtures containing as much as 80 percent sulfur hexafluoride. However, when arcover occurs in a waveguide filled with this gas, the decomposition products that are produced constitute a dangerous personnel hazard in the form of several toxic gases, including fluorine. These toxic gases may not irritate the skin, are colorless, and cannot be detected by odor, but will cause extreme lung irritation and hemorrhaging. In animal experiments, samples of sulfur hexafluoride and its decomposition products produced by arcing proved fatal to mice and rats when small percentages of the gaseous compounds were introduced into the air chamber containing the experimental animals. Autopsy revealed extensive hemorrhaging in the lungs of the animals.

Pressurized waveguides using either Freon or sulfur hexafluoride as a dielectric can create a toxic problem. When arcing occurs in the waveguide, these gases can become very hazardous to breathe. Care should be taken when opening one of these systems.

F. CODE OF FEDERAL REGULATIONS

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	122

CODE OF FEDERAL REQULATIONS
TITLE 29, CHAPTER XVII, PART 1910

APPLIES TO:

- RADIO STATIONS
- RADAR EQUIPMENT
- RADIO NAVIGATION
- COMMUNICATION
- INDUSTRY AND SCIENCE

1. Scope

This section applies to all radiations originating from radio stations, radar equipment, and other possible sources of electromagnetic radiation such as used for communication, radio nagivation, and industrial and scientific purposes. This section does not apply to the deliberate exposure of patients by, or under the direction of, practitioners of the healing arts.

§ 1910.97 Nonionizing radiation.

(a) *Electromagnetic radiation*—(1) *Definitions applicable to this paragraph.* (i) The term "electromagnetic radiation" is restricted to that portion of the spectrum commonly defined as the radio frequency region, which for the purpose of this specification shall include the microwave frequency region.

(ii) *Partial body irradiation.* Pertains to the case in which part of the body is exposed to the incident electromagnetic energy.

(iii) *Radiation protection guide.* Radiation level which should not be exceeded without careful consideration of the reasons for doing so.

(iv) The word "symbol" as used in this specification refers to the overall design, shape, and coloring of the rf radiation sign shown in figure G-11.

(v) *Whole body irradiation.* Pertains to the case in which the entire body is exposed to the incident electromagnetic energy or in which the cross section of the body is smaller than the cross section of the incident radiation beam.

(2) *Radiation protection guide.* (i) For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100 GHz, the radiation protection guide is 10 mW/cm.^{2} (milliwatt per square centimeter) as averaged over any possible 0.1-hour period. This means the following:

Power density: 10 mW./cm.^{2} for periods of 0.1-hour or more.

Energy density: 1 mW.-hr./cm.^{2} (milliwatt hour per square centimeter) during any 0.1-hour period.

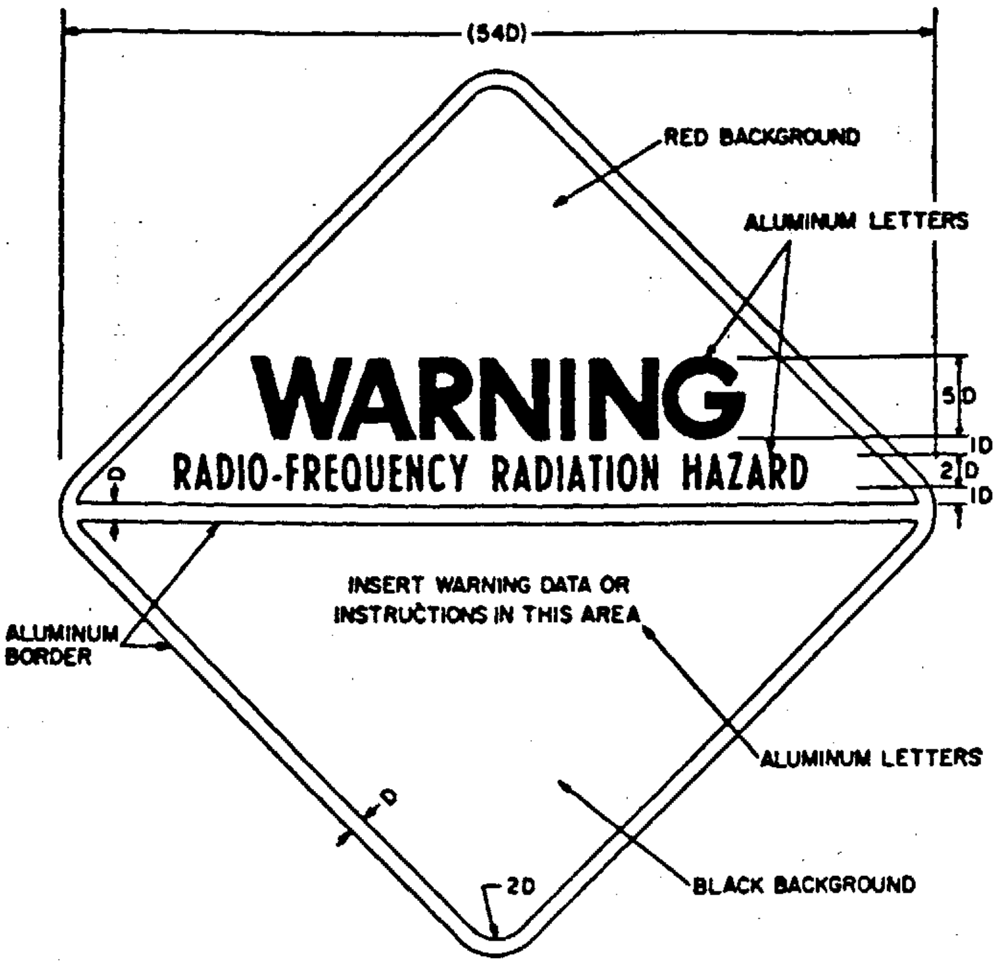
This guide applies whether the radiation is continuous or intermittent.

(ii) These formulated recommendations pertain to both whole body irradiation and partial body irradiation. Partial body irradiation must be included since it has been shown that some parts of the human body (e.g., eyes, testicles) may be harmed if exposed to incident radiation levels significantly in excess of the recommended levels.

(3) *Warning symbol.* (i) The warning symbol for radio frequency radiation hazards shall consist of a red isosceles triangle above an inverted black isosceles triangle, separated and outlined by an aluminum color border. The words "Warning—Radio-Frequency Radiation Hazard" shall appear in the upper triangle. See figure G-11.

(ii) American National Standard Safety Color Code for Marking Physical Hazards and the Identification of Certain Equipment, Z53.1-1953, shall be used for color specification. All lettering and the border shall be of aluminum color.

(iii) The inclusion and choice of warning information or precautionary instructions is at the discretion of the user. If such information is included it shall appear in the lower triangle of the warning symbol.



1. Place handling and mounting instructions on reverse side.
2. D = Scaling unit.
3. Lettering: Ratio of letter height to thickness of letter lines.

Upper triangle:	5 to 1	Large
	6 to 1	Medium
Lower triangle	4 to 1	Small
	6 to 1	Medium

4. Symbol is square, triangles are right-angle isosceles.

Fig. G-11
Radio-Frequency Radiation Hazard Warning Symbol

S 1910.97

- **ELECTROMAGNETIC RADIATION DEFINED**
- **RADIATION PROTECTION GUIDE**
- **POWER DENSITY**
  10 mW/cm^2 FOR PERIODS OF 10 MINUTES OR MORE
  25 mW/cm^2 LIMIT, UP TO 10 MIN/HR
- **AVERAGE 10 mW/cm^2 OVER DAY**

2. Definitions and Guide

1910.97 Nonionizing radiation

(a) Electromagnetic radiation

(1) Definitions applicable to this paragraph.

(i) The term "electromagnetic radiation" is restricted to that portion of the spectrum commonly defined as the radio frequency region, which for the purpose of this specification shall include the microwave frequency region.

(ii) Partial body irradiation pertains to the case in which part of the body is exposed to the incident electromagnetic energy.

(iii) Radiation protection guide is the level which should not be exceeded without careful consideration of the reasons for doing so.

(iv) The word "symbol" as used in this specification refers to the overall design, shape, and coloring of the RF radiation sign shown in Figure G-11

(v) Whole body irradiation pertains to the case in which the entire body is exposed to the incident electromagnetic energy or in which the cross section of the body is smaller than the cross section of the incident radiation beam.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	123

S 1910.97

- ELECTROMAGNETIC RADIATION DEFINED
- RADIATION PROTECTION GUIDE
- POWER DENSITY
  10 mW/cm^2 FOR PERIODS OF 10 MINUTES OR MORE
  25 mW/cm^2 LIMIT, UP TO 10 MIN/HR
- AVERAGE 10 mW/cm^2 OVER DAY

2. Definitions and Guide (contd.)

   (i) For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100GHz, the radiation protection guide is 10 mW/cm^2 (milliwatt per square centimeter) as averaged over the 8-hour work day. Up to 25 mW/cm^2 exposure is allowed for up to 10 minutes per hour, and no exposures are allowed at power density levels above 25 mW/cm^2.

*Note that these values are recommended for rulemaking of preparation of this chart.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	123

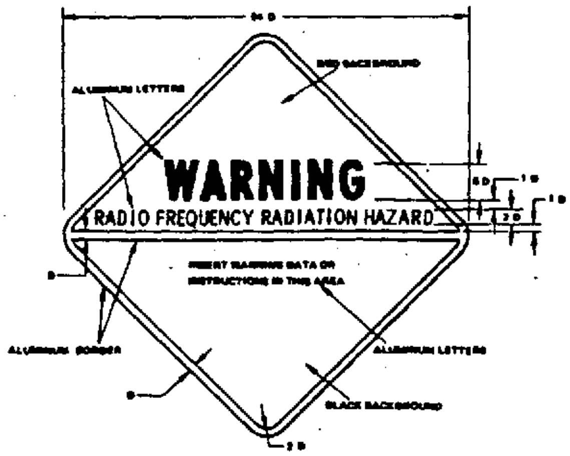
S 1910.97

- ELECTROMAGNETIC RADIATION DEFINED
- RADIATION PROTECTION GUIDE
- POWER DENSITY
  $10\ mW/cm^2$ FOR PERIODS OF 10 MINUTES OR MORE
  $25\ mW/cm^2$ LIMIT, UP TO 10 MIN/HR
- AVERAGE $10\ mW/cm^2$ OVER DAY

2. Definitions and Guide (contd.)

   (i) This guide applies whether the radiation is continuous or intermittent.

   (ii) These formulated recommendations pertain to both whole body irradiation and partial body irradiation. Partial body irradiation must be included since it has been shown that some parts of the human body (e.g., eyes, testicles) may be harmed if exposed to incident radiation levels significantly in excess of the recommended levels.



3. Warning Symbol

The warning symbol for radio frequency radiation hazards shall con- consist of a red isosceles triangle above an inverted black isosceles triangle, separated and outlined by an aluminum color border. The words "Warning - - Radio Frequency Radiation Hazard" shall appear in the upper triangle.

American National Standard Safety Color Code for Marking Physical Hazards and the Identification of Certain Equipment Z53.1-1953, shall be used for color specification. All lettering and the border shall be of aluminum color.

The inclusion and choice of warning information or precautionary instructions is at the discretion of the user. If such information is included it shall appear in the lower triangle of the warning symbol.

This sign should be displayed if there is a potential for exposure to 10 mW/cm^2 or greater power density.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	125

S 1915.55

- NO ONE SHALL WORK ON MASTS OR ALOFT AREAS UNTIL TRANSMITTERS ARE MADE INCAPABLE OF RADIATION
- THE DANGER AREA MUST BE CLEARED OF PEOPLE BEFORE ANY TESTING IS DONE

4. Work on or in the Vicinity of Radar and Radio

Code of Federal Regulations, Title 29, Chapter XVII, Part 1915.55

No employees other than radar or radio repairmen shall be permitted to work on masts, king posts or other aloft areas unless the radar and radio are secured or otherwise made incapable of radiation. In either event, the radio and radar shall be appropriately tagged.

Testing of radar or radio shall not be done until the employer can schedule such tests at a time when no work is in progress aloft or personnel can be cleared from the danger area according to minimum safe distances established for, and based on, the type, model, and power of equipment.

§ 1915.55 Work on or in the vicinity of radar and radio.

(a) No employees other than radar or radio repairmen shall be permitted to work on masts, king posts or other aloft areas unless the radar and radio are secured or otherwise made incapable of radiation. In either event, the radio and radar shall be appropriately tagged.

(b) Testing of radar or radio shall not be done until the employer can schedule such tests at a time when no work is in progress aloft or personnel can be cleared from the danger area according to minimum safe distances established for and based on the type, model, and power of the equipment.

CODE FEDERAL REQULATIONS
VOL. 38, PART 1030.10

- APPLICABILITY – MICROWAVE OVENS
- DEFINITIONS – MICROWAVE OVENS
  - – CAVITY
  - – DOOR
  - – SAFETY INTERLOCK
  - – STIRRER
  - – EXTERNAL SURFACE

5. Microwave Ovens

a. Definitions

Federal Register, Vol. 38, Part 1030. Performance Standards for Microwave and Radio Frequency Emitting Products

(1) "Microwave oven" means a device designed to heat, cook, or dry food through the application of electromagnetic energy at frequencies assigned by the Federal Communications Commission in the normal ISM heating bands ranging from 890 megaHertz to 6,000 megaHertz As defined in this standard, "Microwave ovens" are limited to those manufactured for use in homes, restaurants, food vending, or serve establishments, on interstate carriers, and in similar facilities.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	126

CODE FEDERAL REQULATIONS
VOL. 38, PART 1030.10

- APPLICABILITY – MICROWAVE OVENS
- DEFINITIONS – MICROWAVE OVENS
  - – CAVITY
  - – DOOR
  - – SAFETY INTERLOCK
  - – STIRRER
  - – EXTERNAL SURFACE

5. Microwave Ovens

a. Definitions (contd.)

(2) "Cavity" means that portion of the microwave oven in which food may be heated, cooked, or dried.

(3) "Door" means the movable barrier which prevents access to the cavity during operation and whose function is to prevent emission of microwave energy from the passage or opening which provides access to the cavity.

(4) "Safety interlock" means a device or system of devices which is intended to prevent generation of microwave energy when access to the cavity is possible.

(5) "Service adjustments or service procedures" means those servicing methods prescribed by the manufacturer for a specific product model.

(6) "Stirrer" means that feature of a microwave oven which is intended to provide uniform heating of the load by constantly changing the standing wave pattern within the cavity or moving the load.

(7) "External surface" means the outside surface of the cabinet or enclosure provided by the manufacturer as part of the microwave oven, including doors, door handles, latches, and control knobs.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	127

PART 1030.10

REQUIREMENTS:

- **POWER DENSITY LIMITS**
  - **< 1 mW/cm^2 at 5 cm (new)**
  - **< 5 mW/cm^2 at 5 cm (in use)**
- **DOOR AND SAFETY INTERLOCKS**

5. Microware Ovens (contd.)

   b. Power Density Limit

   The power density of the microwave radiation emitted by a microwave oven shall not exceed one (1) milliwatt per square centimeter at any point 5 centimeters or more from the external surface of the oven, measured prior to the acquisition by a purchaser, and thereafter, 5 milliwatts per square centimeter at any point 5 centimeters or more from the external surface of the oven.

   c. Door and Safety Interlocks

   Microwave ovens shall have a minimum of two operative safety interlocks one of which must be concealed. A concealed safety interlock on a fully assembled microwave oven must not be operable by (a) any part of the body, or (b) a rod 3 millimeters or greater in diameter and with a useful length of 10 centimeters. A magnetically operated interlock is considered to be concealed only if a test magnet, held in place on the oven by gravity or its own attraction, cannot operate the safety interlock. The test magnet shall have a pull at zero air gap of at least 4.5 kilograms and a pull at 1 centimeter air gap of at least 450 grams when the face of the magnet (which is toward the interlock switch when the magnet is in the test position) is pulling against one of the large faces of a mild steel armature having dimensions of 80 millimeters by 50 millimeters by 8 millimeters.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	127

PART 1030.10

REQUIREMENTS:

- POWER DENSITY LIMITS
  - < 1 mW/cm^2 at 5 cm (new)
  - < 5 mW/cm^2 at 5 cm (in use)
- DOOR AND SAFETY INTERLOCKS

5. Microwave Ovens

   c. Door and Safety Interlocks (contd.)

   Failure of any single mechanical or electrical component of the microwave oven shall not cause all safety interlocks to be inoperative.

   Service adjustments or service procedures on the microwave oven shall not cause the safety interlocks to become inoperative or the microwave radiation emission to exceed the power density limits of this section as a result of such service adjustments or procedures.

   Insertion of an object into the oven cavity through any opening while the coor is closed shall not cause microwave radiation emission from the oven to exceed the applicable power density limits specified in this section.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	127

PART 1030.10

REQUIREMENTS:

- **POWER DENSITY LIMITS**
  - **< 1 mW/cm^2 at 5 cm (new)**
  - **< 5 mW/cm^2 at 5 cm (in use)**
- **DOOR AND SAFETY INTERLOCKS**

5. Microwave Ovens

c. Door and Safety Interlocks (contd.)

One (the primary) required safety interlock shall prevent microwave radiation emission in excess of the requirement of paragraph b., of this section; the other (secondary) required safety interlock shall prevent microwave radiation emission in excess of 5 milliwatts per square centimeter at any point 5 centimeters or more from the external surface of the oven. The two required safety interlocks shall be designated as primary or secondary in the service instructions of the oven.

A means of monitoring one or both of the required safety interlocks shall be provided which shall cause the oven to become inoperable and remain so until repaired if the required safety interlock(s) should fail to perform required functions as specified in this section. Interlock failures shall not disrupt the monitoring function.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	128

PART 1030.10

MEASUREMENT AND TEST CONDITIONS
INSTRUMENT REQUIREMENTS:

- TIME FOR 90% READING $\leqslant$ 3 SEC
- EFFECTIVE APERTURE $\leqslant$ 25 CM^2
- NO DIMENSION $\geqslant$ 10 CM
- ACCURACY $\pm$ 1dB.

5. Microwave Ovens (contd.)

d. Measurement and Test Conditions

Compliance with the power density limits in this paragraph shall be determined by measurements of microwave power density made with an instrument system which (a) reaches 90 percent of its steady-state reading within 3 seconds when the system is subjected to a stepped input signal and which (b) has a radiation detector with an effective aperture of 25 square centimeters or less as measured in a plane wave, said aperture having no dimension exceeding 10 centimeters. This aperture shall be determined at the fundamental frequency of the oven being tested for compliance. The instrument system shall be capable of measuring the power density limits of this section with an accuracy of plus 25 percent and minus 20 percent (plus or minus 1 decibel).

Microwave ovens shall be in compliance with the power density limits if the maximum reading obtained at the location of greatest microwave radiation emission does not exceed the limits specified in this paragraph when the emission is measured through at least one stirrer cycle. Pursuant to 1010.13 of this chapter, manufacturers may request alternative test procedures if, as a result the stirrer characteristics of a microwave oven, such oven is not susceptible to testing by the procedures described in this sub-division.

14	MICROWAVES	CODE OF FEDERAL REGULATIONS	129

PART 1030.10

MEASUREMENT AND TEST CONDITIONS

- WATER BLOCK IN CAVITY
- DOOR FULLY CLOSED
- INTERLOCK CHECK

5. Microwave Ovens

d. Measurement and Test Conditions (contd.)

Measurements shall be made with the door fully closed as well as with the door fixed in any other position which allows the oven to operate.

Measurements shall be made with the microwave oven operating at its maximum output and containing a load of 275 ± 15 milliliters of tap water initially at $20^{o} \pm 5^{o}$ centigrade placed within the cavity at the center of the load-carrying surface provided by the manufacturer. The water container shall be a low form 600 milliliter beaker having an inside diameter of approximately 8.5 centimeters and made of an electrically nonconductive material such as glass or plastic.

REFERENCES - A PARTIAL LIST

"The Microwave Problem", K. Foster and A.W. Guy, Scientific American, Sept. 1986

"Microwave News" , a bi-monthly newsletter-type "Report on Non-Ionizing Radiation", generally critical of the "establishment"; see especially July/August 1985 issue (Vol V, No 6) for a discussion of standards setting by NIOSH, ANSI, IEEE.

"Biological Effects and Medical Applications of RF Electromagnetic Fields", Om Ghandi, IEEE Transactions on Microwave Theory and Techniques, Nov 1982.

"Biological effects of electromagnetic fields", in IEEE Spectrum, May 1984. A good review article.

Code of Federal Regulations (CFR), Title 29, Part 1910.97; the OSHA regulation on RF exposures of workers.

Federal Register, Vol 38, Part 1030, "Performance Standards for Microwave and RF Emitting Products"

IEEE (Institute of Electrical and Electronic Engineers) Standard C95.1 1991, for Safety Levels with Respect to Human Exposure to RF fields, 3kHz to 300 Ghz; the basis for this standard is discussed by Om Ghandi in IEEE Engineering in Medicine and Biology Magazine, March 1987.

The journals "Bioelectromagnetics" and "Health Physics" have pertinent research and comment articles and should be scanned / read regularly to keep current on developments in RF health effects and safety information.

LESSON PLAN NO. 15
ULTRAVIOLET, VISIBLE, AND INFRARED

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	OBJECTIVES	1

- SOURCE OF UV, VISIBLE AND IR RADIATION
- BIOLOGICAL EFFECTS AND HAZARDS
- STANDARDS, LAWS AND REGULATIONS
- EVALUATION OF HAZARDS
- PROTECTION AND CONTROL

15. ULTRAVIOLET. VISIBLE AND INFRARED RADIATION OBJECTIVES

At the end of this four hour presentation you will be able to demonstrate, in a problem session, your grasp of the following subjects:

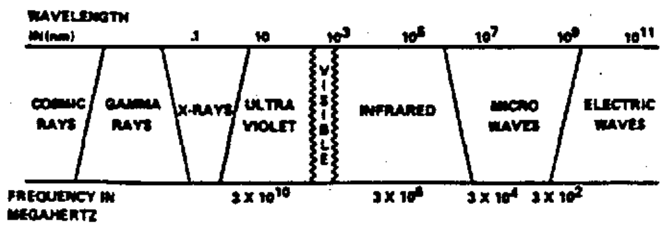
1. Sources of UV, visible and IR radiation
2. Biological effects and hazards
3. Standards, laws, and regulations
4. Evaluation of hazards
5. Protection and control

This presentation begins with a brief review of radiation fundamentals. This is material which was covered in greater detail in previous sessions. The review selects those topics of special relevance to the ultraviolet through infrared portion of the electromagnetic spectrum.

A. FUNDAMENTALS

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	2

ELECTROMAGNETIC SPECTRUM



1. Review of EM Fundamentals

The electromagnetic spectrum:

a. Is divided into regions.

b. The velocity of propagation is the same for all regions.

c. The names which have been given to the regions refer primarily to the methods of generation.

d. The various emissions differ in wavelength, frequency and energy.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	3

FREQUENCY AND WAVELENGTH

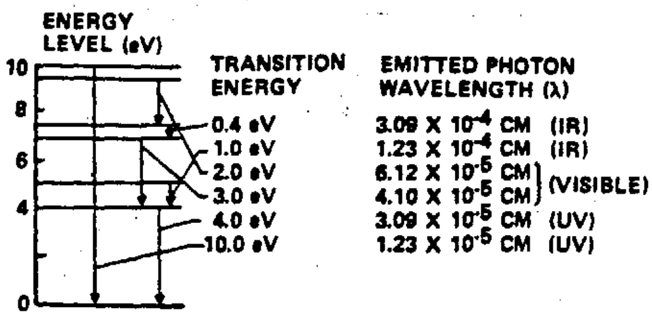
$$f = c/\lambda$$

f = FREQUENCY
c = SPEED OF LIGHT = 3×10^{10} CM/SEC
λ = WAVELENGTH

Lecture XIII established the relationship between wavelength and frequency by use of the formula $f = c/\lambda$. Where, c = speed of light (cm/sec), f = frequency (Hertz), λ = wavelength (cm).

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	4

ENERGY LEVEL AND EMITTED PHOTON WAVELENGTH



1. Review of EM Fundamentals (Contd)

Electromagnetic radiation is produced as a result of an excited state in an atom or molecule returning to its ground state by emitting a photon. The type of EM radiation emitted depends upon the energy of the photon and is related to the frequency by the formula $E = hC/\lambda = hf$, where

E = photon energy
h = Planck's constant
f = frequency
C = $3X10^{10}$ cm/sec
λ = wavelength (cm)

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	5

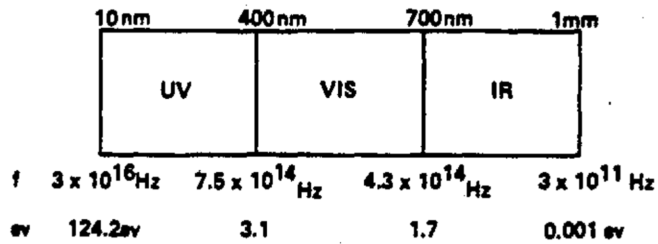
ULTRAVIOLET – VISIBLE – INFRARED

NON IONIZING RADIATION
(EXCLUDING LASERS)

This lesson covers the Ultraviolet-Visible-Infrared regions of the Electromagnetic Spectrum, considering sources other than lasers, which will be covered in the next lesson.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	6

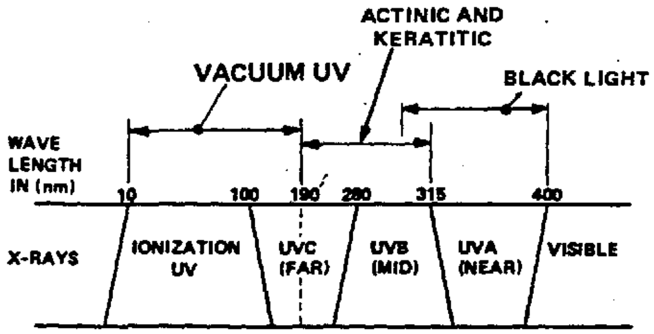
WAVELENGTH AND PHOTON ENERGIES



1. Review of EM Fundamentals (Contd)

The Ultraviolet, Visible and Infrared regions encompass the wavelengths from 10 nanometers (nm = 10^{-7} cm) to 1 mm (millimeter = 10^{-1} cm), frequencies from 3×10^{16} Hertz to 3×10^{11} Hertz, and photon energies from 124.2 electron volts to 0.001 electron volts.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	7



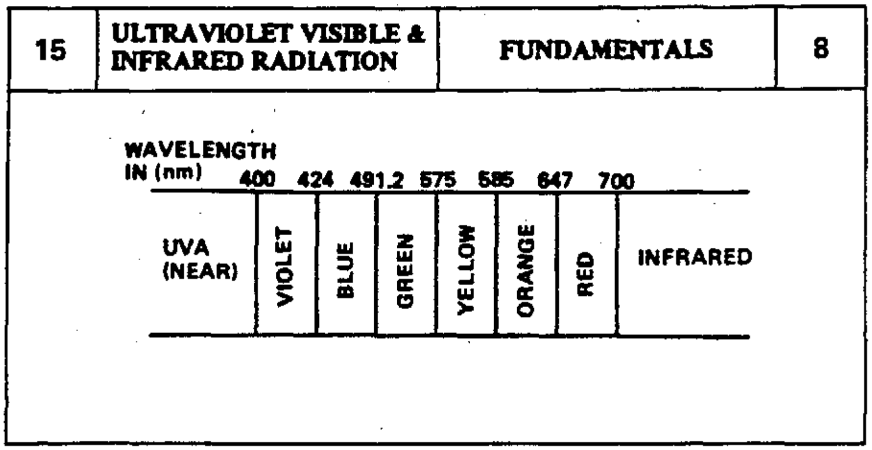
1. Review of EM Fundamentals (Contd)

The UV, visual and infrared regions have been further divided for convenience of discussion.

Ultraviolet region (10 nm–400 nm)

	Subregion	Approximate λ–range (nm)
(Near)	UVA	315–400 nm
(Mid)	UVB	280–315 nm
(Far)	UVC	100–280 nm
	Ionization	10–100 nm

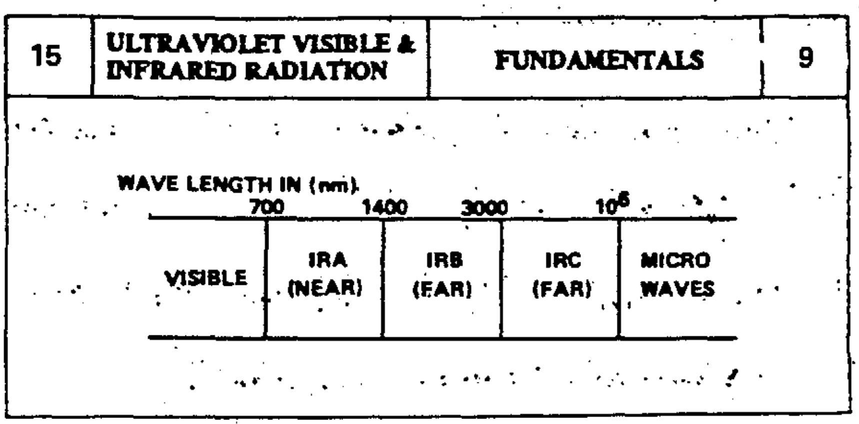
Since the wavelengths below 190 nm are strongly absorbed by air (in molecular excitation transitions) they are not easily observed except in vacuum, so this range is called the vacuum ultraviolet. Ozone, O_3, is formed from molecular oxygen, O_2, by excitation and collision combination at wavelengths from 170 to 230 nm. The actinic and keratitic regions are so-called because they produce biological effects on the skin. The skin erythemal effects are produced mainly by mid-UV photons 250–315 nm. (See also chart 4 in the Laboratory Notebook, Lesson L-7).



1. Review of EM Fundamentals (Contd)

Visible region 400 nm–700 nm

Subregion	Approximate λ–range (nm)		
Violet	400–424 nm	Yellow	575–585 nm
Blue	424–491.2 nm	Orange	585–647 nm
Green	491.2–575 nm	Red	647–700 nm

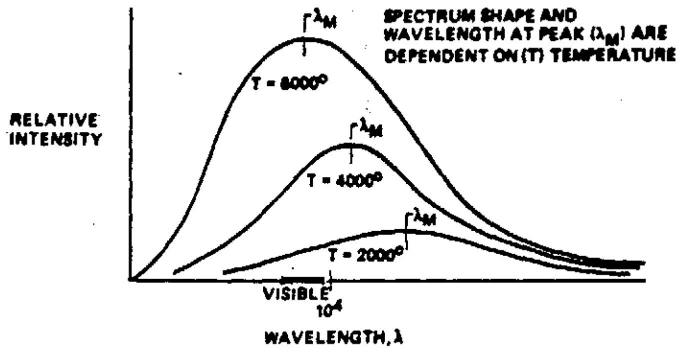


Infrared region 700 nm–10^6 nm

	Subregion	Approximate λ–range (nm)
(Near)	IRA	700–1400 nm
(Far)	IRB	1400–3000 nm
	IRC	3000–10^6 nm

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	10

BLACK BODY RADIATION SPECTRUM



Hot bodies produce a spectrum of radiation depending upon the temperature.

The peak wavelength, λ_M, of the Black Body radiation spectrum equals $0.2898/T(°K)$ cm. (Wien displacement law)

The radiated power of the Black Body, in watts, equals $\epsilon A \sigma T^4$, where ϵ = emissivity, A = area (cm^2), T in °K, and $\sigma = 5.67 \times 10^{-12}$. (the Stefan-Boltzman constant.)

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	11

- SOURCES INCLUDE:
  - NATURAL
  - ARTIFICIAL
- THE SUN IS A NATURAL SOURCE OF:
  - ULTRAVIOLET
  - VISIBLE
  - INFRARED

2. Sources

a. Natural

Sources of ultraviolet-visible-infrared can be divided into two groups, those occurring naturally and those that are artificial. A naturally occurring source of ultraviolet-visible-infrared radiation is the sun.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	12

ULTRAVIOLET ARTIFICAL SOURCES

LOW-INTENSITY

HIGH INTENSITY

b. Artificial Sources

Artificial ultraviolet sources are of many types, but may be classed by their radiance, or output power, or by the ultraviolet production process involved. However, they are generally divided into two groups, low intensity and high intensity. There is also a natural division of sources into black-body, or incandescent, and line or band spectrum sources.

UV LOW INTENSITY SOURCES

1. LOW PRESSURE MERCURY VAPOR LAMPS
2. FLUORESCENT TUBES
3. GAS DISCHARGE LAMPS
4. CUTTING FLAMES

2. Sources (Contd)

c. Low Intensity

Low-pressure mercury vapor lamps emit several narrow bands; the lower the pressure of mercury vapor the fewer lines emitted. Much of this energy is of 253.7 nm wavelength, which is near the peak of germicidal effectiveness of 265 nm. Hence, it is useful in: control of micro-organisms in operating rooms; in control of airborne infection; in control of bacteria in meat processing; in the prevention of product contamination in pharmaceutical houses and biological laboratories; in irradiation of air-conditioning ducts; and in making water potable.

Fluorescent type ultraviolet lamps also emit germicidal radiation similar to low-pressure mercury vapor lamps.

Discharge-type lamps produce an extremely wide variation in ultraviolet emissions which depend upon the pressure of the gases in which the discharge takes place, and the transmission characteristics of the envelope which encloses the discharge-arc. These are line spectra emitters.

Open oil and gas flames are normally less than 2000°C, would emit little or no ultraviolet. Oxyhydrogen and oxyacetylene flames are much hotter, so solids heated by these two flames may radiate ultraviolet. Black body temperature in excess of 2200°C are needed to produce significant amounts of UV.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	14

HIGH INTENSITY SOURCES

1. HIGH PRESSURE MERCURY VAPOR LAMPS
2. QUARTZ-MERCURY ARCS
3. HIGH PRESSURE XENON ARCS
4. CARBON ARCS
5. PLASMA TORCHES
6. WELDING ARCS

2. Sources (Contd)

d. High Intensity UV Sources

High-pressure mercury vapor lamps are used in photo-chemical reactions, mineral identification, to produce fluorescence, and for diagnosis of dermal and scalp disorders, including porphyria.

Quartz-mercury arcs emit radiation over much of the ultraviolet spectrum, and can cause erythema and conjunctivitis from radiation over the range of 200 to 320 nm.

High-pressure xenon arcs emit a spectrum like that of sunlight. Carbon arcs emit a continuous spectrum from the incandescent electrodes, upon which a broad-band spectrum from the luminous gases is superimposed.

The plasma torch can produce temperatures over 6000 K, the temperature at the surface of the sun, and intense ultraviolet radiation can result. Exposure to radiation from plasma torches can result in keratoconjunctivitis and sunburn if skin and eyes are not protected.

Arc welding produces ultraviolet radiation in broad bands which often appear as a continuous spectrum. The intensities of the various bands depend on many factors; materials used in the electrodes, discharge current, and gases surrounding the arc. Arc welders are commonly found in industry.

INDUSTRIAL USES OF UV RADIATION

- CHEMICAL PROCESSING
- SOLAR SIMULATORS
- ETCHED CIRCUIT BOARD PRODUCTION
- DETECTION OF FLUORESCENT MATERIALS
- LASERS

3. Industrial Uses of UV Light

In addition to the incidental occupational hazards of UV emissions from welding or hot bodies, there are industrial processes that make use of UV light, and for which sources have been developed. In chemical processing of some material surfaces, UV lamps are used. Simulation of the space environment for testing of spacecraft components often involves use of high power xenon UV tubes that can produce irradiances many times that of the sun. In producing semiconductor integrated circuits, conductive interconnecting patterns are applied using materials called "photoresist" that are UV sensitive. Intense UV light is shined on the semiconductor chip through a mask or pattern to expose the photoresist. Then the surface is chemically developed, leaving only the desired interconnection pattern between transistors and other integrated circuit elements.

Another application, among many, of UV is detection of fluorescent material, either that which was marked on some item, as in a shoplifting prevention method, or a natural material such as certain minerals or gems.

Pulsed and CW lasers have been developed which emit in the ultraviolet as monochromatic radiation, either directly or as a secondary harmonic. To date, most commercially available UV lasers emit in the near ultraviolet (UV-A) region only. We shall not deal with the laser problem here, since it is discussed in a section by itself.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	16

POTENTIAL OCCUPATIONAL EXPOSURES

AIRCRAFT WORKERS	FOUNDRY WORKERS	NURSES
BARBERS	FURNANCE WORKERS	OIL FIELD WORKERS
BATH ATTENDANTS	GARDENERS	PIPELINE WORKERS
BRICK MASONS	GAS MANTLE MAKERS	PLASMA TORCH OPERATORS
BURNERS, METAL	GLASS BLOWERS	RAILROAD TRACK WORKERS
CATTLEMEN	GLASS FURNACE WORKERS	RANCHERS
CONSTRUCTION WORKERS	HAIRDRESSERS	ROAD WORKERS
CUTTERS, METAL	HERDERS	SEAMEN
DRUG MAKERS	IRON WORKERS	SKIMMERS, GLASS
ELECTRICIANS	LIFEGUARDS	STEEL MILL WORKERS
FARMERS	LITHOGRAPHERS	STOCKMEN
FISHERMEN	METAL CASTING INSPECTORS	STOKERS
FOOD IRRADIATORS	MINERS, OPEN PIT	TOBACCO IRRADIATORS
		VITAMIN D PREPARATION MAKERS
		WELDERS

4. Occupational Exposure

The chart shows some of the potential occupational exposures to both natural and artificial UV sources.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	17

SOURCES OF VISIBLE LIGHT

1. INCANDESCENT (HOT BODY)
2. GAS DISCHARGE

5. Visible Light

Visible light sources are of two types, incandescent or hot body, and gas discharge.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	18

VISIBLE LIGHT SOURCES

- INCANDESCENT EXAMPLES
  - HIGH INTENSITY LAMPS
    PROJECTOR BULBS AND SPOTLIGHTS
  - WELDING ARCS

5. Visible Light (Contd)

Visible light sources include high intensity incandescent lamps of various types, and welding arcs.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	19

VISIBLE LIGHT SOURCES

- GAS DISCHARGE - LINE/BAND EMISSIONS
  "NEON" TUBES
  FLUORESECENT TUBES
  FLASH TUBES
  PLASMA TORCH SOURCES

Gaseous discharge tubes, utilizing electrical excitation of atoms, are used in some visible light sources.

Gas discharge line emissions are generally less intense, except for flash-tubes or plasma torch sources. (Fluorescent lights emit light from the material coated on the inside of the tube, which absorbs the gas discharge emission photons and reemits in the visible range).

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	20

INFRARED SOURCES

IR IS RADIATED BY HOT OBJECTS

[(WAVELENGTH SPECTRUM MAX) x (TEMPERATURE)]

= CONSTANT (APPROXIMATELY)

6. Infrared Sources

Any object above $0^{O}K$ is a potential emitter of infrared energy; however, the usual sources are hot or incandescent bodies which produce a continuous broad spectrum of infrared. All hot objects radiate in the infrared, according to black-body laws. In particular, the Wein displacement law states that the product of λm, the wavelength having maximum emittance, and, T, the body temperature in ^{O}K, is a constant, 2.88×10^{-3} $m^{O}K$. So a $1000^{O}K$ body ($727^{O}C$ or $1341^{O}F$) has a maximum intensity at 2880 nm.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	21

INFRARED SOURCES

1. OCCUPATIONAL SOURCES
2. EQUIPMENT AND SYSTEMS

In addition to occupational sources of IR, there are systems using IR that may provide exposure.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	22

INFRARED SOURCES

- OCCUPATIONAL EXPOSURE SOURCES
  - WELDING
  - HOT GLASS
  - HOT METALS

6. Infrared Sources (Contd)

Industrial exposures to infrared can occur in almost all industries. They need not be from an incandescent body, but could be from any surface which is hotter than the surrounding atmosphere. For example, heat absorbent glass exposed to solar radiation in turn reemits infrared at a longer wavelength. The more common industrial exposures are found in hot metal operations, glass making, photoengraving, paint and enamel drying, and welding operations. The number of potential sources is increasing every day with our advancing technology.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	23

IR EQUIPMENT AND SYSTEMS

PASSIVE: DETECTION OF IR FROM HOT SOURCES

ACTIVE: LIKE RADAR SYSTEM
HIGH POWER DENSITY
NARROW BEAM

IR Equipment and Systems

IR energy is often observed in industry from operating systems.

Passive systems use sensitive IR detectors to discern the presence of a warm or hot body, for surveillance, homing, or direction finder. The "Snooperscope" or IR image amplifier used by soldiers to find the enemy in the dark is an example of such a passive system. IR intensities in such systems are very low and pose no occupational hazard.

Active operating systems use relatively high-power narrow-beam sources, much as a radar system would operate. These active IR systems represent the greatest hazard to personnel since the IR source generally produces a searchlight type of beam, which is filtered to remove any radiation in the form of visible light. Thus one may be illuminated, i.e., irradiated with IR without being aware of the fact.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	FUNDAMENTALS	24

INFRARED POTENTIAL OCCUPATIONAL EXPOSURES

BAKERS
BLACKSMITHS
BRAZIERS
CHEMISTS
CLOTH INSPECTORS
COOKS
DRYERS, LACQUER
ELECTRICIANS
FIREMEN, STATIONARY
FOUNDRY WORKERS
FURNACE WORKERS
GAS MANTLE HARDENERS
GLASS BLOWERS
GLASS FURNACE WORKERS
HEAT TREATERS
LASER OPERATORS
IRON WORKERS
KILN OPERATORS
MOTION PICTURE MACHINE OPERATORS
PLASMA TORCH OPERATORS
SKIMMERS, GLASS
SOLDERERS
STEEL MILL WORKERS
STOKERS
WELDERS

6. Infrared Sources (Contd)

The chart shows some of the potential occupational exposures to artificial infrared sources.

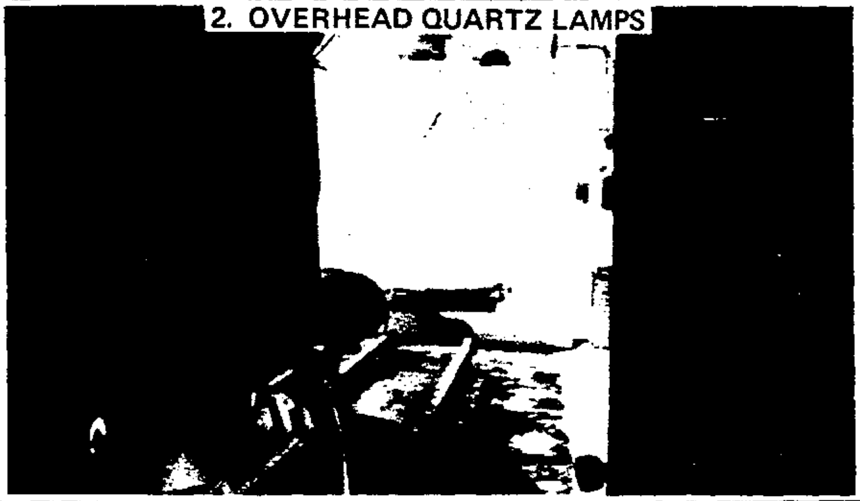
7. Industrial Examples

15	ULTRAVIOLET. VISIBLE & INFRARED RADIATION	FUNDAMENTALS	25

This slide shows the use of quartz lamps in a reproduction operation. The lamps emit intense visible light along with moderate levels of ultraviolet and infrared. An associated hazard with these lamps is the metal housing which becomes quite hot during operation of the lamps.

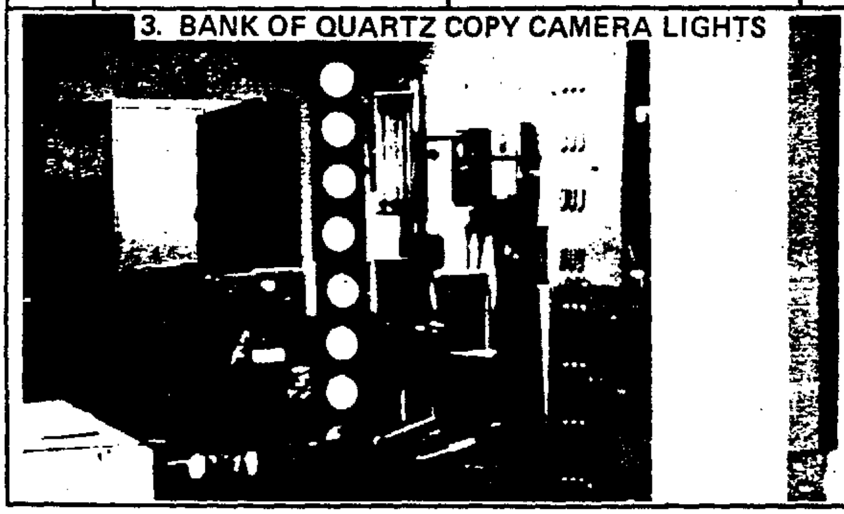
7. Industrial Examples (contd.)

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	26



These lamps produce moderate, but not hazardous, levels of UV—VIS—IR, since they are located at a distance from workers.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	27

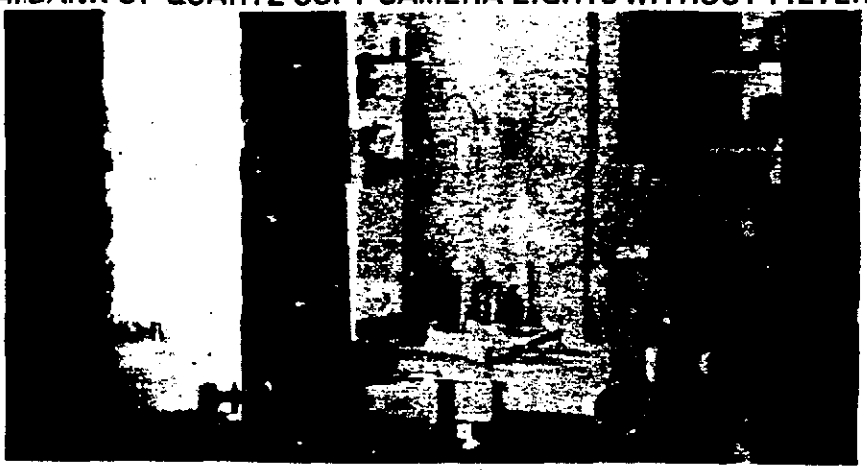


These lamps produce strong IR—VIS, less UV, intensity. The picture was taken with a filter.

7. Industrial Examples (contd.)

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	28

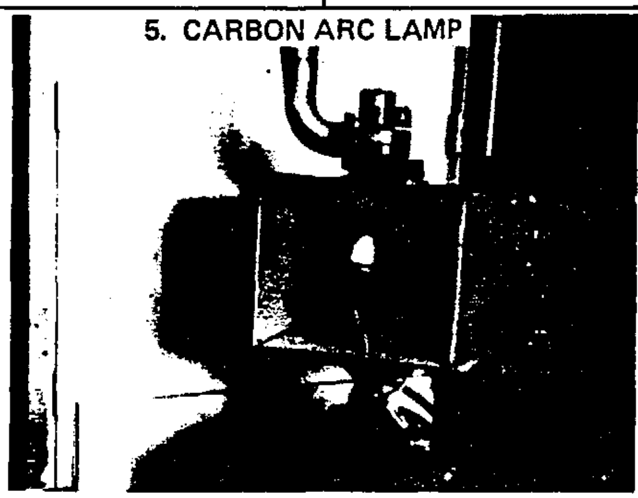
4. BANK OF QUARTZ COPY CAMERA LIGHTS WITHOUT FILTER



This is the same as the previous picture without a filter.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	29

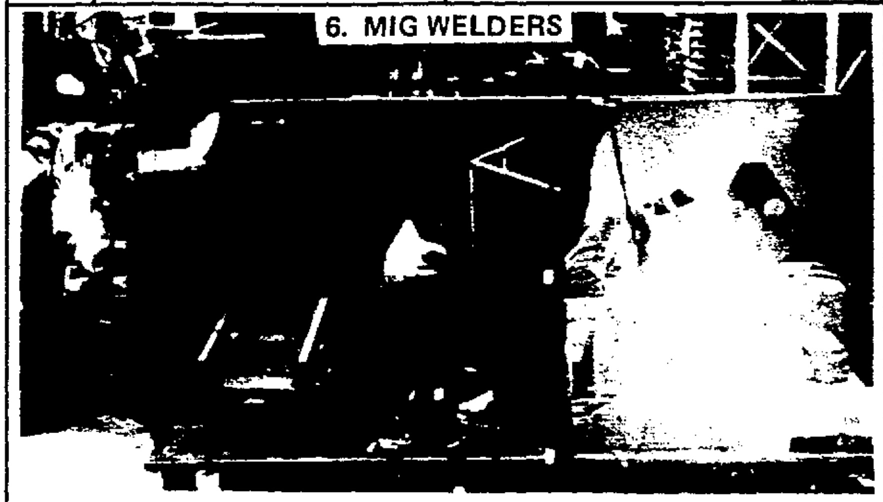
5. CARBON ARC LAMP



Carbon arcs can produce intense IR—VIS—UV radiation.

7. Industrial Examples (contd.)

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	30



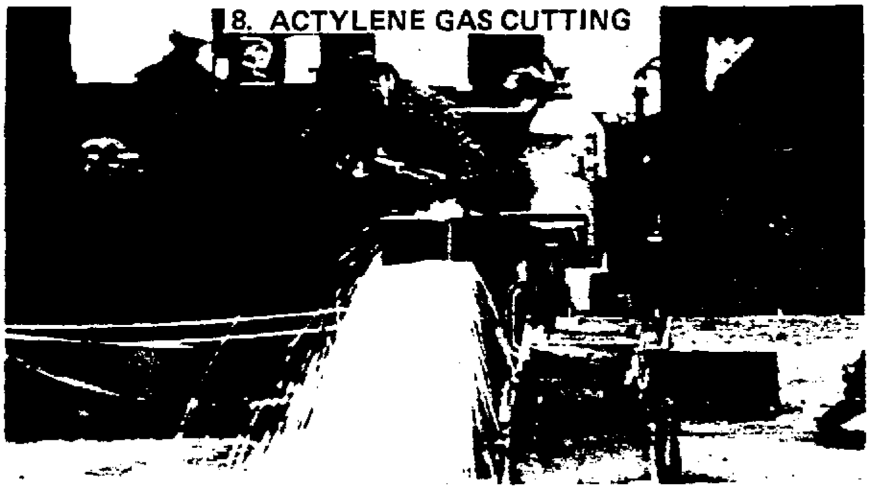
Metallic-Inert-Gas (MIG) welding machines also produce intense IR—VIS—UV radiation; levels depend upon current, type and ratio of gas mixtures, filter material and type of metal.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	31

Gas cutting torches produce low-to-moderate levels of IR—VIS, but not much UV.

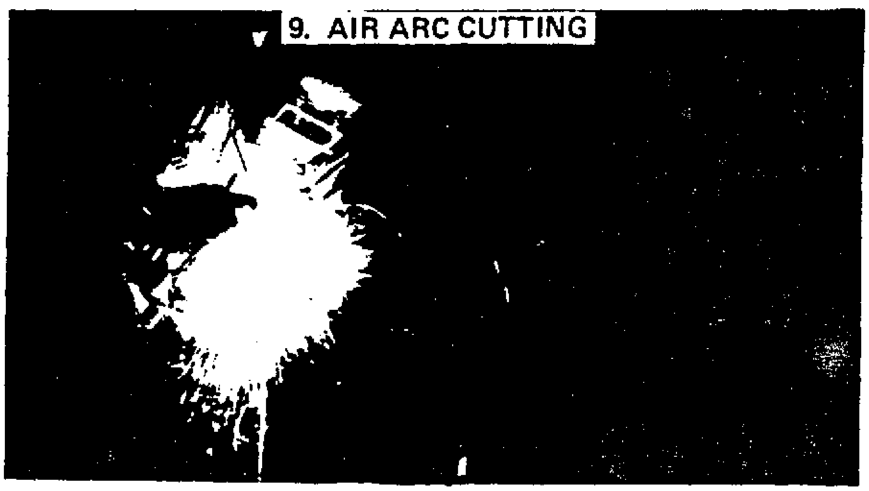
7. Industrial Examples (contd.)

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	32



Acetylene torch cutting produces IR and VIS, but little UV. However, sparks, flame and debris may be hazards.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	FUNDAMENTALS	33



Air arc cutting, using a carbon electrode, produces intense IR-VIS, and UV radiation if current is high.

B. BIOLOGICAL EFFECTS & HAZARDS

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	34

LIGHT IMPINGING UPON BIOLOGICAL TISSUE MAY BE:

- **REFLECTED AT SURFACE (R)**
- **TRANSMITTED THROUGH SURFACE (T)**
- **ABSORBED IN TISSUE (A)**

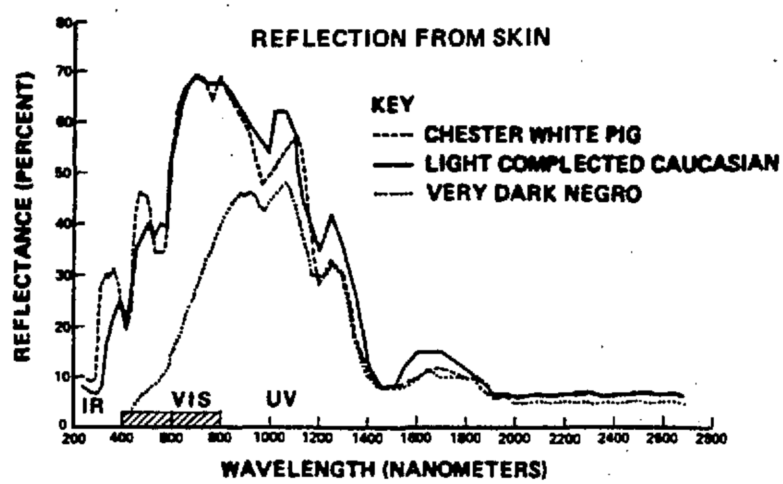
R + T = 1.0

1. Spectral Response

Light impinging upon biological tissue may be reflected, transmitted, or absorbed. The reflection of a beam of light may be specular (mirror-like) but is more likely to be diffuse since most tissue does not present a smooth surface to an impinging beam. Naturally, some scattering of the photons does occur within tissue, but this is probably small and the scattered light eventually is absorbed or transmitted out of the tissue.

The amount of reflection, transmission, and absorption within tissue is dependent upon the wavelength of impinging light and the organ involved.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	35



1. Spectral Response (Contd)

The skin is only slightly transparent to light, a fact which can be illustrated by placing a finger over the beam of a flashlight. The reflection of the skin as a function of wavelength (spectral reflectance) is presented here. Note that the reflectance of skin is greater at those wavelengths of the highest spectral irradiance. The curves of skin reflectance depict the results from experiments conducted with a light-complected Caucasian and an exceptionally dark Negro. There are essentially no differences in spectral reflectance beyond 1800 nm.

Light which is not reflected by the skin is absorbed in or close to the area of impingment, some light being scattered in tissue. The depth of tissue penetrated by the light depends upon the location of skin, whether overlying a bone in close proximity, such as the finger, or a large mass of boneless tissue such as the breast.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	36

PENETRATION OF RADIATION INTO THE HUMAN SKIN*

SPECTRAL REGION	PENETRATION IN MILLIMETERS
FAR ULTRAVIOLET 180-290 nm	SUPERFICIAL 0.01-0.1
NEAR ULTRAVIOLET 290-300nm	SUPERFICIAL 0.1-1
VISIBLE SPECTRUM 390-760 nm	DEEP 1-10
NEAR INFRARED 760-1,500 nm	DEEP 10-1
FAR INFRARED 1,500-15,000 nm	SUPERFICIAL 0.01-0.05

*W.W.Coblentz, J. Am. Med. Assoc., 123,378 (1946)

1. Spectral Response (Contd)

This slide gives the values for the depth of penetration into the skin of different kinds of incident radiation. It shows that the penetration of ultraviolet into the skin is less than that of infrared. However, even within the ultraviolet there ar are tenfold differences. Penetration is discussed later.

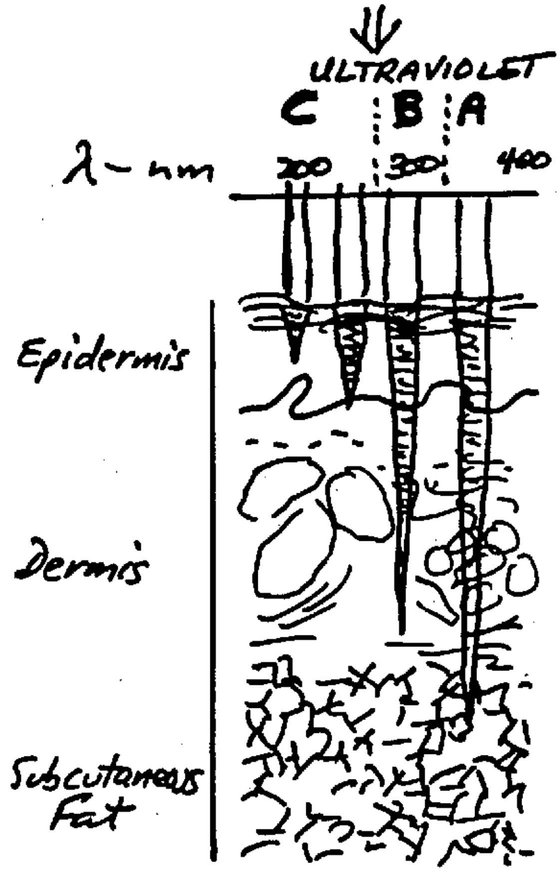
15

36 A

UVA: Penetrating
less carcinogenic
produces "aging"

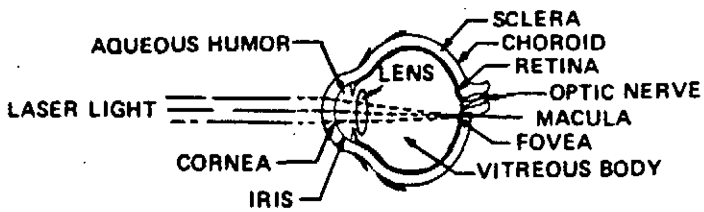
UVB: Into Dermis
carcinogenic

UVC Into Epidermis
carcinogenic



15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	37

THE ORGAN MOST SENSITIVE TO OPTICAL RADIATION

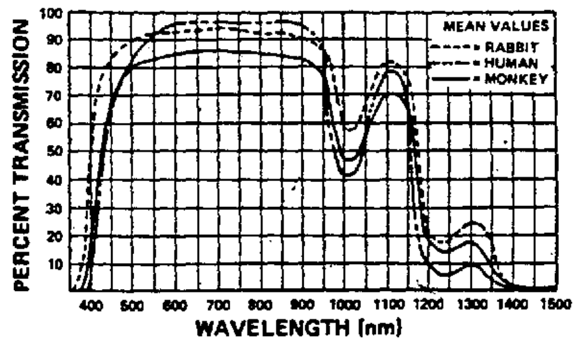


THE EYE

Since the eye is a critical organ for IR-VIS-UV hazards, it is important to know the different parts of the eye affected by these radiations.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	38

PERCENT TRANSMISSION THROUGH OCULAR MEDIA



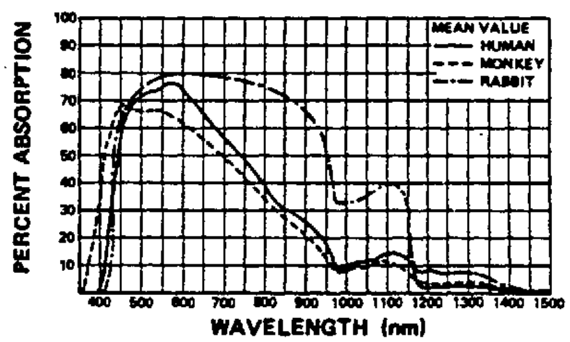
PERCENT TRANSMISSION FOR LIGHT OF EQUAL INTENSITY THROUGH OCULAR MEDIA OF HUMAN, MONKEY, AND RABBIT EYES.

1. Spectral Response (Contd)

The eye differs considerably from skin in its transmission and reflection. Wavelengths between about 400 and 1400 nanometers are readily transmitted through the ocular media although the visual system response range is only about 400-750 nm. As the wavelength of light progresses further away from the 400-1400 nm range, the ocular media becomes less transparent until most of the incident light is absorbed in the first few layers of cornea.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	39

PERCENT ABSORPTION IN RETINAL PIGMENT EPITHELIUM AND CHOROID

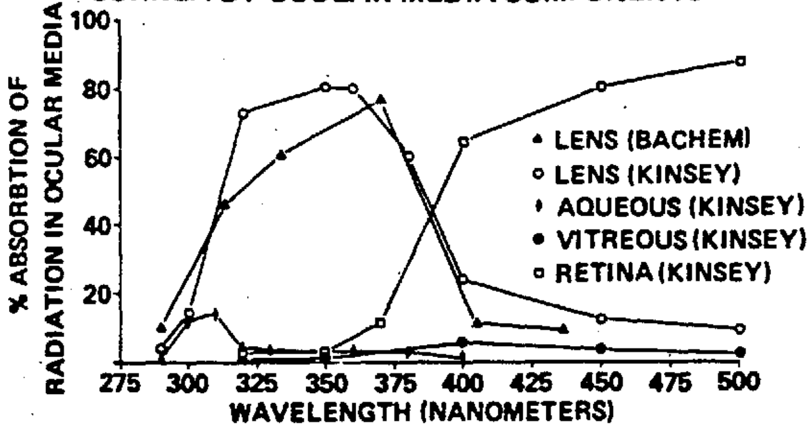


Percent absorption in retina and choroid for light of equal intensity and incident on the cornea of human, monkey, and rabbit eyes.

This figure shows the absorption of light in the retina and choroid.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	40

ABSORBTION OF RADIATION INCIDENT ON CORNEA BY OCULAR MEDIA COMPONENTS



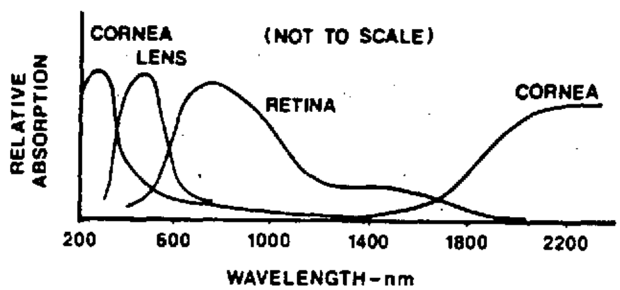
1. Spectral Response (Contd)

This figure presents the spectral absorption of the lens, aqueous, cornea, and conjunctiva in the ultraviolet.

Light in the spectral range of 400-1400 nm is focused by the cornea-lens system onto the retina. If the eye is fixed upon the source of light, the light will be focused onto the fovea of the retina and the irradiance (power per unit area) increased by as much as 10^4 to 10^6 over that falling upon the cornea. It is by virtue of this concentration factor that high-intensity light, whether from a conventional light source or a laser, may pose a serious hazard to the eye.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	41

RELATIVE ABSORPTION IN THE EYE



To summarize the information just given, the chart shows the relative absorption of UV—VIS—IR in various parts of the eye. The cornea is a good visible-near IR transmitter, i.e., a poor absorber; the retina is a good absorber in the same region, especially in the visible. The lens absorbs strongly in the near UV, and is quite transparent at longer wavelengths.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	42

SUFFICIENT AMOUNTS OF LIGHT IMPINGING UPON TISSUE MAY CAUSE DAMAGE RANGING FROM:

SMALL REDNESS TO GROSS LESIONS

2. Damage Mechanisms

It is well known that sufficient amounts of light impinging upon tissue may cause damage to that tissue, ranging in severity from barely detectable impairments to gross lesions.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	43

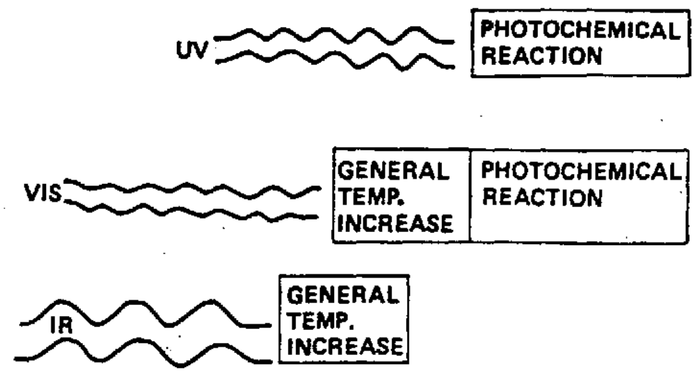
THERE ARE TWO PRINCIPAL DAMAGE MODES

1. GENERAL AND LOCAL TEMPERATURE INCREASES
2. SPECIFIC PHOTOCHEMICAL REACTION

This damage is effected by imparting extra energy to the tissue components. For the sake of convenience, this addition of energy is divided into two principle damage modes; denaturation resulting from general temperature increases and denaturation resulting from a specific photochemical reaction.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	44

TYPE OF DAMAGE VARIES WITH WAVELENGTH



2. Damage Mechanisms (Contd)

The principal mode of damage is dependent upon the tissue involved and the energy of the incident light photon. Far infrared light usually effects damage by a general increase in tissue temperature, whereas far ultraviolet light tends to cause more specific photochemical reactions. Both modes are present in the visible portion of the spectrum.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	45

THERMAL DENATURATION OF TISSUE FROM TEMPERATURE RISE

- **HIGH FEVER – METABOLIC POISONING**
- **TEMP 47° C – ALBUMIN DAMAGE**
- **TEMP 70° C – ENZYMES DESTROYED**

NORMAL BODY TEMPERATURE 36.5°C (98.6°F)

2. Damage Mechanisms (Contd)

Far infrared, near infrared, and visible radiation are emitted by objects at high temperature and are sensed by the body as heat, with shorter wavelengths emitted by objects at higher temperatures. The temperature required to produce tissue damage has been an object of investigation.

Mild heating of tissues above the normal body temperature of 36.5°C (98.6°F) such as encountered in high fever may increase the metabolic rate of the tissue. This metabolic increase may produce metabolic byproduct materials in excess of the cells' capacity for byproduct elimination, and metabolic poisoning may ensue.

Denaturation of organic molecules may result from more severe heating of tissue. Albumin, for example, is denatured at temperatures above 47°C and nearly all enzymes are destroyed at temperatures above 70°C.

Such high temperatures can only be obtained locally by intense, rapid heating by a strong source.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	46

A VERY RAPID RISE IN TEMPERATURE PRODUCES A SHOCK WAVE–RUPTURING A CELL

THIS MAY CAUSE MECHANICAL SHOCK DAMAGE TO CELLS REMOTE FROM THE SITE OF THE ORIGINAL INSULT.

2. Damage Mechanisms (Contd)

When the energy is deposited more rapidly in a region than the sound transit time across this region, pressures can build up in this region and thus produce a shock wave, possibly rupturing an individual cell and causing mechanical shock damage to cells remote from the site of original insult. For example, since pigment epithelium cells provide support for photoreceptor cells, gross physical damage to the pigment epithelium cells may result in damage to neighboring photoreceptor cells.

Steam production may occur if sufficient energy is imparted to tissue water. When steam production does occur, the damage caused by such steam production probably overshadows damage caused by other damage mechanisms such as simple denaturation.

Such catastrophic effects are observed only at very high irradiance levels.

TIME AT SELECTED TEMPERATURES
REQUIRED TO PRODUCE A RED BURN.

TEMPERATURE (°C)	MINUTES	SECONDS
44	420	
45	180	
46	90	
47	45	
48	14	
49	8	
50	5	
51	3	
52	1	30
53	1	00
54		35
55		25
56		15
58		10
60		5
65		2
70		1

2. Damage Mechanisms (Contd)

A classic study of damage temperature was performed by Moritz and Heriques who applied liquids of known temperatures to porcine skin for varying lengths of time. A modified table of their results is given above. Two basic relationships were determined by this and similar studies:

a. There is an inverse relationship between tissue temperature produced by a thermal burn agent and the amount of time required to produce a burn.

b. The rate at which "burning" occurs is almost doubled for each degree rise in temperature between 44°C and 50°C.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	48

LIGHT CAUSES AN INCREASE IN HEAT

IN TISSUES THAT ARE EFFICIENT

ABSORBERS - SUCH AS PIGMENT

EPITHELIUM CELLS

2. Damage Mechanisms (Contd)

The absorption of light is not homogeneous since tissue itself is not homogeneous. The increase in heat resulting from light absorption is generally greatest in and around those portions of tissue that are the most efficient absorbers. The absorption of visible spectrum light in the eye is greatest in the pigment epithelium because of the presence of melanin granules which act as very efficient absorbers. Similar pigment granules are responsible for skin pigmentation and hence determine the absorption of visible spectrum light by the skin.

TERMS USED IN THE BIOLOGICAL EFFECTS OF LIGHT

- **HEAT** — **TOTAL ENERGY RESIDING IN MOLECULAR OR ATOMIC VIBRATIONS**
- **TEMPERATURE** — **MEASURE OF AVERAGE HEAT OF A SUBSTANCE (SUCH AS TISSUE)**

2. Damage Mechanisms (Contd)

Several terms should be discussed at this point since they have been used in describing the results of photon absorption by tissue. The terms are heat and temperature. Heat can be considered as the total energy residing in molecular or atomic vibrations. Such vibrational energy can be transferred to neighboring atoms and molecules from the impact or target site. Thus, if one area of tissue absorbs the energy of incident photons, the energy is soon distributed to surrounding tissue. If the absorbed energy is sufficient, the absorbing atoms or molecules may undergo changes which lead to disruption of the cell life processes. The changes do not occur instantaneously but occur over a period of microseconds or milliseconds. Therefore, the vibrational energy must remain localized for a sufficient period of time before changes in tissue occur. Since loss of energy does occur to surrounding tissue, energy input must be sufficient to compensate for energy lost through transfer before degradation processes can occur in the target site.

Temperature is a measure of the average heat (vibrational energy) of the constituents of a substance such as tissue. This quantity is usually measured by using a device which itself absorbs some of the vibrational energy of the substance. Temperature can also be mathematically calculated, based on broad assumptions of the physical properties of the substance in which measurement is made and the distribution of incident energy on the target site. However, the classical macroscopic concept of temperature fails when applied to small volumes (such as a molecule) or to short periods of time (such as the pulse duration of a short-pulse laser). Therefore, when discussing these short pulse durations from a laser, one must think in terms of the energy or energy history of tissue rather than temperature.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	50

PHOTOCHEMICAL DENATURATION OF TISSUE

RESULT FROM THE DIRECT ABSORPTION BY MOLECULES OF A SINGLE PHOTON OF LIGHT. THE DENATURATION TAKES PLACE WITH LITTLE OR NO TEMPERATURE RISE.

2. Damage Mechanisms (Contd)

Denaturation of organic molecules may result from the direct absorption by the molecules of a single photon of light. Most ordinary (dark or nonphotochemical) chemical reactions involve energies of activation between 0.65 and 2.8 eV/photon. Valence electron excitation, which activates the reactions classified as photochemistry, involves 0.86-4.3 eV/photon. This range of energies of 0.65-4.3 eV/photon is equivalent to the energy of wavelengths between 1,900 and 280 nm which includes all of the visible spectrum. Specific denaturation reactions may thus occur involving little or no increase in cellular temperature but which are still capable of cell destruction as an endpoint.

Research using ultraviolet exposures of rabbits and primates indicate that two or possibly three photochemical reactions are involved in the production of photokeratitis. Further, the effect of ultraviolet light on corneal tissue appears to be the result of absorption of light in the nucleoprotein. Absorption in the eye occurs in the protein material.

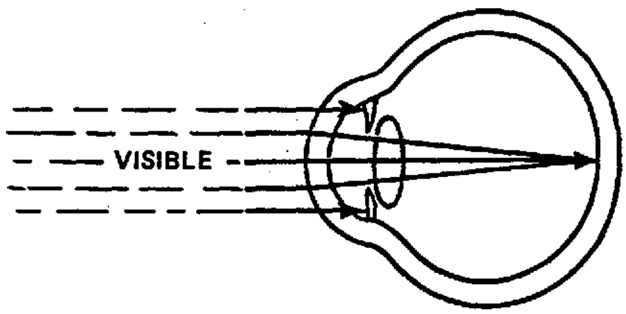
A number of important biological end points have action spectra closely approximated by the absorption in the eye occurring in the protein material.

Also a number of important biological end points have action spectra that are closely approximated by the absorption spectra of nucleic acids while others are more closely described by the absorption spectra of proteins.

Indeed, the process of vision itself is dependent upon molecular degradation. The absorption of a single photon of light by the photopigment results in the breakdown of the latter into one or more active byproducts which are thought to stimulate the receptor cell to release a nerve signal. Since the byproducts have a significantly different absorption spectrum than the original photopigment, the term "bleaching" is used to describe the process. The byproducts are then reformed by various processes into the original photopigment.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	51

VISIBLE SPECTRUM HAZARDS



LIGHT IS REFRACTED AT THE CORNEA
AND LENS AND ABSORBED AT THE RETINA;
DAMAGE MAY BE TEMPORARY OR PERMANENT.

3. Hazards in the Visible Spectrum

The majority of damage research experiments have dealt with the visible portion of the spectrum from 400-700 nm. This segment of the spectrum is transmitted through the ocular media to the retina, and retinal damage is the type of damage of greatest concern here.

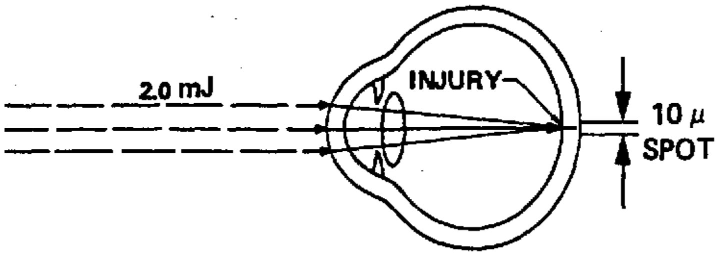
Prolonged exposure to high-intensity visible light sources may result in temporary or permanent impairment of visual function which is not usually detectable by medical observation.

The problem of visible light effects on the retina is of sufficient interest to have stimulated a large number of investigations. Most of the investigators have used, as the criterion for threshold retinal damage, the production of a retinal lesion visible through use of an ophthalmoscope. The reason for the choice of such a criterion is based on the ease of detecting such a lesion. There is a large volume of literature on visible retinal lesions, and numerous safety guidelines have been based on the data from such literature.

Various combinations of light sources, exposure durations, and experiments on animals have been used to determine the threshold level of light which will produce a visible retinal lesion. Unfortunately, since the various experiments reported in the literature were not systematically designed with respect to one another, there are numerous gaps and inconsistencies in reported results. Such parameters as pulse duration and irradiated spot area or diameter on the retina are notably lacking. Methods of measurement are also often left unstated, thereby making an appraisal of accuracy difficult.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	52

THRESHOLD VALUE FOR INJURY
BY VISIBLE LIGHT



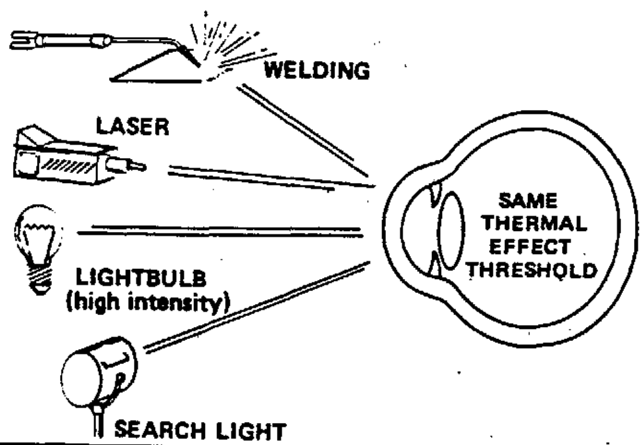
3. Hazards in the Visible Spectrum (contd.)

Ideally, a safety guideline should provide protection to the most susceptible individual. Therefore, the minimal values for threshold injury production reported by the various investigators are used. A report by Ham and colleagues presents the threshold for rabbit retinal lesion production by a 1-sec. 50-μm image exposure to the beam of a He-Ne laser as being an average value of 7mW entering the eye. While this value is much quoted as a threshold value, the report also states that the range of threshold values for the four-animal sampling was 17.5 mW to 1.9 mW. The latter figure is much more meaningful than the 7-mW value. Similarly, the average value for retinal lesion production for a 1-second 50-μm retinal image produced by an argon laser was reported by Frisch and colleagues at 5-6 mW entering the eye, while the most susceptible individual in the experimental population evidenced damage from 2.0 mW entering the eye.

Therefore 2.0 mW-sec is taken as a threshold value for retinal injury.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	53

VISIBLE LIGHT DAMAGE



3. Hazards in the Visible Spectrum (contd.)

The light source used for lesion production may be a factor affecting results. Values have been demonstrated for threshold using carbon arc lamps (searchlights), xenon lamps, He-Ne, ruby, and argon lasers, and all values seem in close agreement. There are insufficient data with enough otherwise uniform conditions (same animal, exposure duration, evaluation time) to prepare a plot which indicates the relative hazards of various sources. There is, however, strong evidence in the literature that the type of tissue damaged is influenced by wavelengths of light; blue-green light affects red blood vessels to a greater extent than does red light. This phenomena can be explained simply by selective absorption which all materials exhibit. Since the damage mechanism producing a visible retinal lesion is thermal, it would seem that, provided one considers similar retinal image diameter, the major factor affecting efficiency of lesion production is that of spectral transmission of the ocular media and the spectral absorption of the retina. These are relatively uniform across the visible spectrum.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	54

VISIBLE LIGHT INJURY MECHANISM

- THERMAL

  VISIBLE LIGHT----➤ HEAT---➤ INJURY

- PHOTOCHEMICAL

  CHRONIC BLUE-LIGHT—➤RETINAL DAMAGE

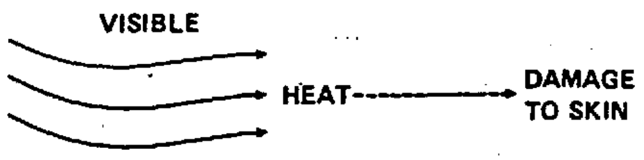
3. Hazards in the Visible Spectrum (contd.)

A number of theories have been proposed to explain the production of visible lesions on the retina from exposure to visible light. Most of the theories have considered thermal injury as being the only means of damage production, although the authors do allude to other mechanisms.

More recently it has become recognized that intense blue light (the high-energy end of the visible spectrum) can produce photochemical changes in retinal cells.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	55

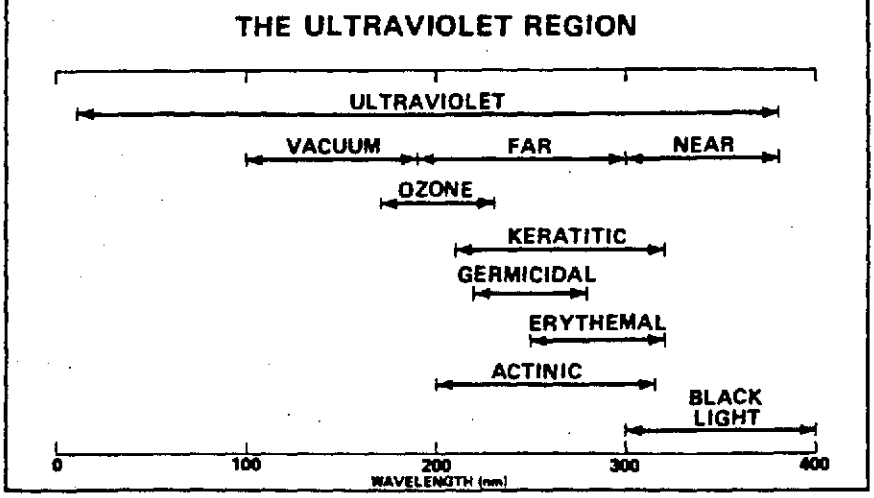
VISIBLE SPECTRUM SKIN DAMAGE IS THERMAL IN NATURE



3. Hazards in the Visible Spectrum (contd.)

Skin damage from visible light is essentially thermal in nature. Some individuals do however exhibit unusual sensitivity to visible light, and some chemicals do cause photosensitization. Threshold damage levels for thermal damage are essentially similar to those of near and far infrared radiation, and more fully discussed later.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	56



1. Introduction

a. The Ultraviolet Region of the Electromagnetic Spectrum

As shown in the chart, the ultraviolet region runs from 10 nanometers (nm = 10^{-9} m) to 400 nanometers. This region has further been divided by physicists into the vacuum region (100 nm - 200 nm), far UV region (200 nm - 280 nm), and near UV region (315 nm - 400 nm). Other names have been associated with certain regions of the ultraviolet region according to photochemical and biological effects of the radiation. For example, the ozone production region (170 - 230 nm) is so named due to the production of ozone when this radiation passes through molecular oxygen. The keratitic (210 nm - 320 nm) region is the region where inflamation of the cornea is greatest. The Germicidal (220 nm - 280 nm) is associated with the greatest effect on bacteria. The erythemal (250 nm - 320 nm) region is so designated due to the pronounced skin reddening and blistering which can occur in this region. In general, the wavelength most affecting man in an adverse way are covered by the actinic region (200 nm - 315 nm). The blacklight region (300 nm - 400 nm) is associated with the fluoresence caused in some materials by these wavelengths.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	57

CRITICAL ORGANS FOR ULTRAVIOLET RADIATION

- EYES
- SKIN

4. Hazards in the Ultraviolet Spectrum

While UV wavelengths shorter than 200 nm are readily produced, they are heavily absorbed in the air and generally are not considered an occupational hazard. The transmission of UV radiation through the ocular media to the retina decreases rapidly at wavelengths shorter than about 400 nm, and insufficient amounts reach the retina to elicit a visual response.

The critical organs are skin and eye — especially the anterior portion of the eye. Sources such as fluorescent lamps, black-light bulbs, high intensity discharge lamps (mercury vapor lamps), as well as some lasers can emit radiation in the ultraviolet.

PRINCIPAL ULTRAVIOLET DAMAGE MECHANISMS

200–320 nm FAR AND MID UV → PHOTOCHEMICAL

> 320 nm NEAR UV → THERMAL

4. Hazards in the Ultraviolet Spectrum (cont.)

The primary reaction of ultraviolet radiation is photochemical in nature. The photochemical reactions which occur in skin are quite similar to those which occur in the eye.

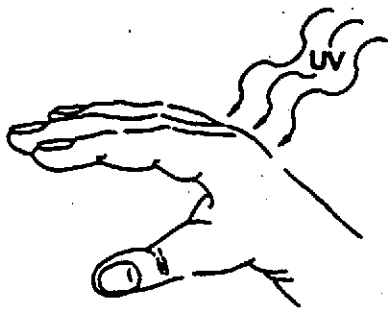
Since the damage mechanisms of 200-320 nm ultraviolet radiation are primarily photochemical rather than thermal in nature, damage would seem dependent upon the total energy absorbed rather than upon the rate of energy absorption, as is the case in the visible and near infrared spectral regions.

Wavelengths longer than 320 nm may cause damage by means other than a photochemical mechanism; the thermal mechanism becomes more prevalent as the radiation increases in wavelength toward 380-400 nm. Where the thermal mechanism does play a prominent role, some consideration must be given to exposure duration.

The injurious effects of UV energy on living systems appear to be related to their ability to be absorbed by either the nucleic acid or unconjugated proteins of the cell, and the photochemical reaction that occurs with some receptors in these fractions. The inability of UV photons to penetrate any appreciable distance into the body limits the areas of concern to the skin and to the eyes.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	59

ULTRAVIOLET EFFECTS ON THE SKIN



RANGE FROM ERYTHEMA TO SERIOUS BURN

4. Hazards in the Ultraviolet Spectrum (cont)

Erythema, or skin reddening, is a response of the normal skin to excess ultraviolet exposure. The radiations responsible are primarily those of wavelengths below about 320 nm, and the effect produced is wavelength and dose-dependent, and accumulative over a period of time. The dose required for a given erythema varies with pigmentation, and the thickness of the corneum. There is a latent period of several hours between exposure and the appearance of symptoms. Symptoms vary with exposure, and may range from simple skin reddening to serious, painful burn and desquamation. Darkening of the skin following such exposures, and thickening of the horny layer of the skin confers some degree of protection against subsequent insults.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	60

CHRONICALLY DAMAGED (BURNED) SKIN CAN DEVELOP INTO

- SKIN CANCERS

OR

- SOLAR KERATOSIS

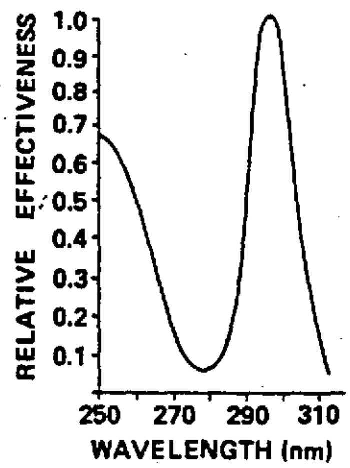
4. Hazards in the Ultraviolet Spectrum (cont)

The comments until now have related specifically to the acute erythemal effect produced on the skin from excessive ultraviolet exposure, which lead to skin burn. No attempt will be made here to discuss the photo-mechanism of action, or the relationship between the acute "sun-burn" effect and the production of the chronically damaged skin from solar radiation, or the eventual production of skin cancers or solar keratosis. The action spectra for these effects have not been fully delineated, but ample evidence exists that the radiations responsible for them lie between the wavelengths 290-320 nm. Similarly, the subject of skin photosensitivity is too broad and complex to be presented here. Although some wavelengths dependence data are available for photo-allergic and photo-toxic reactions caused by specific sensitizers, action spectra have not been determined.

The carcinogenic action spectrum for humans is believed to be in the region between 280-320 nm. Although there is adequate evidence that wavelengths below 320 nm can produce skin cancers directly or indirectly, it is noteworthy that, with the millions of man-hours of exposure to these radiant energies from welding operations, plasma torches, ultraviolet lamps, etc., no cases of industrially induced skin cancer or keratosis have been reported. This may be because the acute manifestations, i.e., skin-burn and conjunctivitis, are such painful experiences that steps are taken to prevent exposure of the skin to doses that could be tumorigenic.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	61

STANDARD ERYTHEMAL CURVE

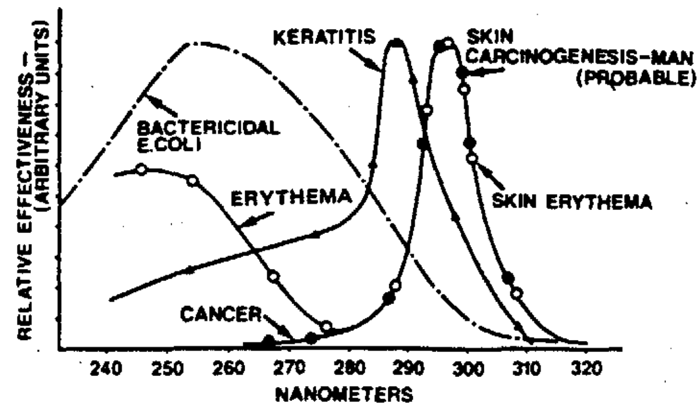


4. Hazards in the Ultraviolet Spectrum (cont)

The "standard erythema curve" is a composite one produced by compiling partial data from several investigators and interpolating for missing wavelengths. Different subjects were studied by each investigator and they were tested at different sites on the body at different times of the year. The time of observation of erythema was variable and variable field sizes were employed. Diverse light sources were utilized and in many instances radiation times were prolonged.

While it may not be the final answer, the standard erythema curve is used in determining the effectiveness of various wavelengths in producing an erythema of the skin.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	62



The standard erythema curve of the previous chart is but one of the UV "action spectra," or curves showing relative effectiveness of the UV spectrum in producing various effects. Above are shown several other action spectra, for bacteriocidal action, for keratitis, and for carcinogenesis, or actinogenic skin cancer.

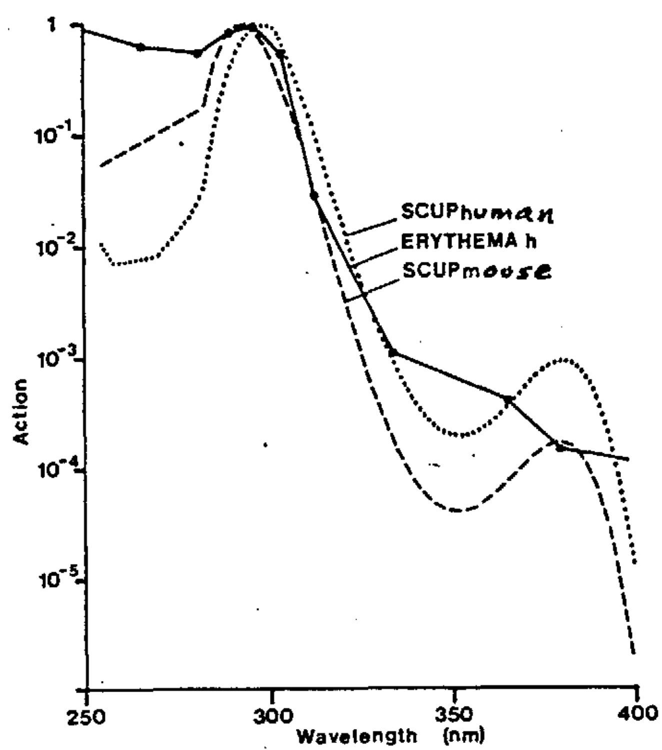
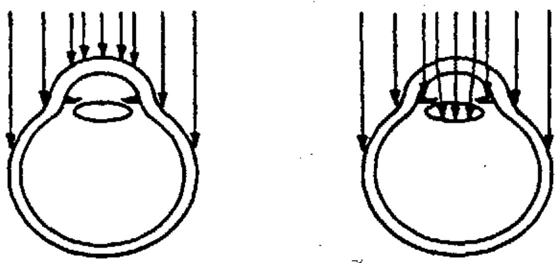


Fig. 1. Comparison of SCUP action spectra with the erythemal action spectrum of Parrish et al. (1982).

SCUP = "Skin Cancer"...

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	63

ULTRAVIOLET EFFECTS ON THE EYE



SHORT ULTRAVIOLET
Absorption occurs principally at the cornea

LONG ULTRAVIOLET
Long ultraviolet is absorbed on cornea and in lens

4. Hazards in the Ultraviolet Spectrum (cont)

The most marked reaction to ultraviolet radiation by the eye takes place in the cornea, corneal epithelium, and conjunctiva, since they receive all of the incident energy and absorb most of it in the spectral range less than 320 nm. Considerably less energy is transmitted to the lens, and a much smaller portion is transmitted on to the retina.

A glucoside in the lens absorbs strongly below about 368 nm. This causes some lens protein denaturing and browning, and may ultimately produce cataracts.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	64

OVEREXPOSURE TO UV CAUSES PHOTOKERATITIS

- LATENT PERIOD
- ERYTHEMA OF FACE AND EYELIDS
- SENSATION OF SAND IN EYES
- THRESHOLD LEVEL ≅ 5mJ/cm^2

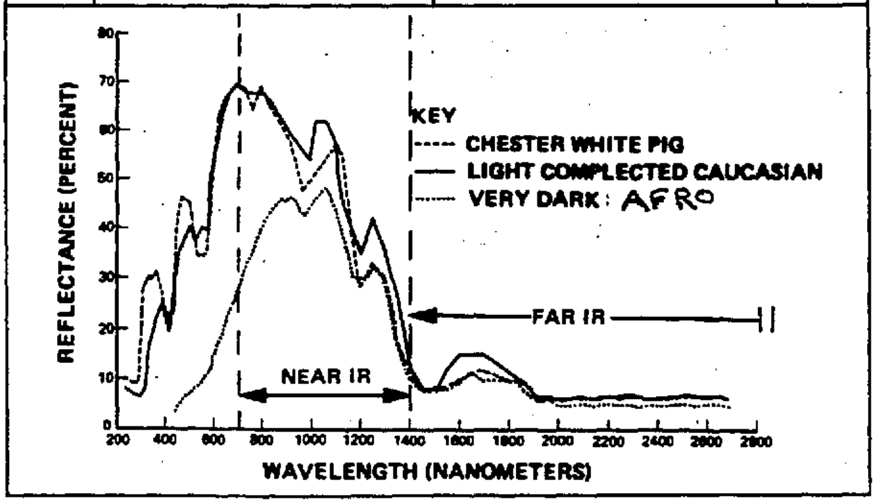
4. Hazards in the Ultraviolet Spectrum (cont)

Overexposure of the eye to ultraviolet radiation produces an inflammatory condition in the cornea referred to as photokeratitis. This process usually follows a characteristic course. As with skin erythema, there is a latent post-irradiation period before the appearance of acute clinical systems, which typically is about 4-8 hours. The symptoms include conjunctivitis accompanied by an erythema of the skin of the face and eyelids. There is the sensation of "sand" in the eyes, photophobia, lacrimation, and blepharospasm.

The cornea is most sensitive to ultraviolet at 270 nm. This finding applied equally to rabbits, monkeys, and humans, with photokeratitis threshold exposures of 5 mJ/cm^2, respectively, at that wavelength.

For mild exposures, recovery occurs in 24—48 hours.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	65



5. Hazards in the Infrared Spectrum

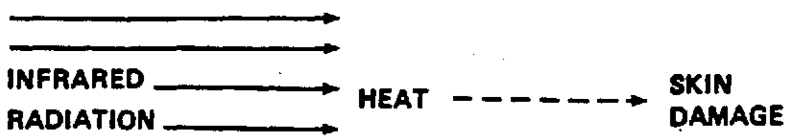
For purposes of bio-effects discussions, that portion of the electromagnetic spectrum between 700 nm and 1400 nm can be termed the Near Infrared. That portion between 1400 nm and 1 millimeter can be termed the Far Infrared.

As can be seen in the chart, a considerable portion of the Near Infrared is reflected off the skin. However, the Far Infrared is highly absorbed.

A reason for this strong absorbtion is the excitation of vibrational and rotational energy states in the various biomolecules. Vibrational states of various organic bonds (H—O, H—N, C—H, C=O, C—C, etc.) involve stretching, rocking and bending, and have broad absorption resonances in the region from 2 μ out to above 16 μ.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	66

INFRARED RADIATION DAMAGES SKIN BY HEAT ACTION



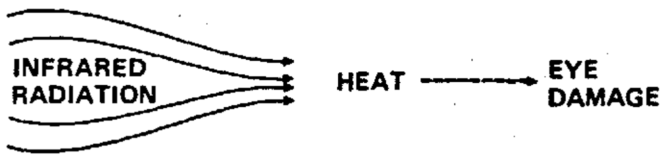
5. Hazards in the Infrared Spectrum (cont)

Skin damage from infrared radiation is essentially thermal in nature. No long-term low-level effects are known, and threshold damage levels are essentially similar to those for skin damage from visible radiation.

Skin absorptance is a function of the wavelengths incident upon it. Energies of wavelengths shorter than 1500 nm are completely absorbed in the surface layers of the skin, where the heat produced is quickly dissipated. The only region of high transmission is between 750-1300 nm, with a maximum at 1100 nm. At this wavelength, 20 percent of the energy incident upon the surface of the corneum of the epidermis will reach a depth of 5mm into the dermis. This value may be increased in highly pigmented skin.

The most prominent direct effects of low-wavelength IR radiations on the skin include the acute skin burn, increased vasolidation of the capillary beds, and an increased pigmentation which can persist for long periods of time. Under conditions of continuous exposure to high intensities of radiation, the erythematous appearance due to vasodilation may become permanent. Many factors mediate the ability to produce actual skin burn, and it is evident that for this immediate effect, the rate at which the temperature of the skin is permitted to increase is of prime importance.

INFRARED EYE DAMAGE MECHANISMS



5. Hazards in the Infrared Spectrum (cont)

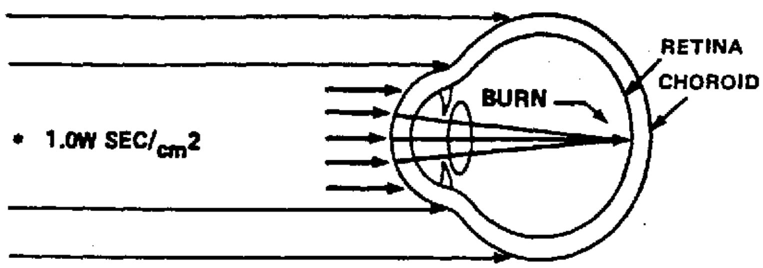
Since the transmission of near infrared radiation through the ocular media to the retina is similar to that of the visible spectrum, the thermal mechanism can produce visible retinal lesions. The process is somewhat less efficient in the near infrared, for the eye does not consciously focus the incoming light. Since the incident photons are not energetic enough to elicit a response from the photoreceptor cells, there is no damage mechanism corresponding to the photoic retinopathy produced by sublesion levels of visible light. However, the production of cataract, or lenticular opacity, has long been associated with the near infrared portion of the spectrum.

Cataract, arising in furnace men, glass blowers, and chain makers, was first described in 1786 by Wenzel and has been discussed in numerous papers. It was Goldman who denied the specificity of wavelengths and proposed that, since little radiation in either the visible or near infrared was absorbed by the lens, the symptom was caused by an increase in lens temperature resulting from radiation absorption in surrounding ing tissue. Goldman proposed that cataract was produced by an increase in temperature of the iris resulting from the iris absorption of radiation. This has been subsequently verified by Langley and associates.

Threshold damage in the far infrared is essentially thermal in nature. Modeling of damage is therefore similar to that done in relation to the visible portion of the spectrum with allowances for differences in absorption, reflection, heat loss, and the like.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	68

INFRARED EFFECT ON RETINA



* APPROXIMATELY THRESHOLD LEVEL

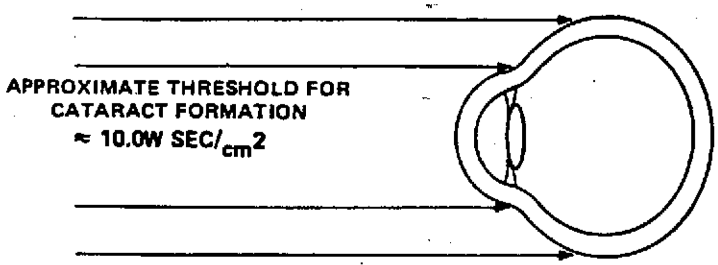
5. Hazards in the Infrared Spectrum (cont)

Absorption by the retina is strongest at the very shortest IR wavelengths, making it almost impossible to separate the effects from those of the visible radiations. The mechanism of retinal damage involves the absorption of energy by the highly pigmented epithelial layer which separates the retina from the choroid, and the rate of conduction of heat from this layer into the adjacent tissues. The production of retinal burn, as with other intraocular tissue is dose-rate dependent. The reduction in retinal irradiance due to selective spectral absorption through all the other ocular media, is more than offset by the focusing effect of the lens and the cornea. Therefore, the size or area of the image on the retinal choroid apparatus and the absorbed irradiance are the predominant factors in the production of burn. One-millimeter burns have been experimentally produced with 0.1-s exposures to retinal irradiances ranging from 20 to 40 W/cm^2. Assuming an iris diameter of 5 nm the probable corneal dose would have been about 1 $W{\cdot}s/cm^2$.

There are wide variations in data obtained by different investigators, but some agreement in the relationship between dose, dose rate, and burn diameter exists, especially in the sizes below 1 mm and exposure of 0.1-s or less. Retinal disability relates to the area in which the burn occurs, the degree to which the underlying choroid and sclera are involved, and the size of the burn. Obviously, even a threshold burn in the foveal area is more serious than one on the periphery of the retina. The probability of eliciting a retinal burn from industrial processes is quite remote. However, where highly intense and compact sources of radiant energy are being used, an insulting dose can occur in fractions of a second, before pain becomes evident.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	69

IR EFFECTS ON EYE



ENERGY IS ABSORBED IN THE CORNEA (FAR IR)
IRIS AND LENS (NEAR IR)

5. Hazards in the Infrared Spectrum (cont)

The cornea of the eye is highly transparent to energies between 750 nm and 1300 nm and becomes opaque to radiant energy above 2000 nm. Thermal damage to the cornea is dependent upon the absorbed dose and probably occurs in the thin epithelium.

An iris dose of about 4.2 W·s/cm^2 has been suggested as the minimum producing damage from a source emitting principally between 800–1100 nm, which would require a dose to the corneal surface of 10.8 W-s/cm^2 for cataract formation. Damage to both the cornea and the iris is an acute occurrence and there are no data available that would indicate chronic effects in these structures. The lens is heated by the heated iris, and unable to keep cool by blood flow at this level of energy absorption. The local heating of the lens is thought to produce cataracts.

Corneal damage occurs at about 7.6 W-sec/cm^2 in the range 800–1100 nm. For the sake of convenience, a cataract can be defined as an opacity of the crystalline lens or of its capsule, which may be developmental or degenerative, obstructing passage of light. The degenerative cataract is a manifestation of aging systemic disease, trauma, or certain forms of radiant energies among others.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	70

ASSOCIATED HAZARDS

- SHOCK
- TOXIC FUMES
- TOXIC VAPORS
- EXPLOSION
- NOISE

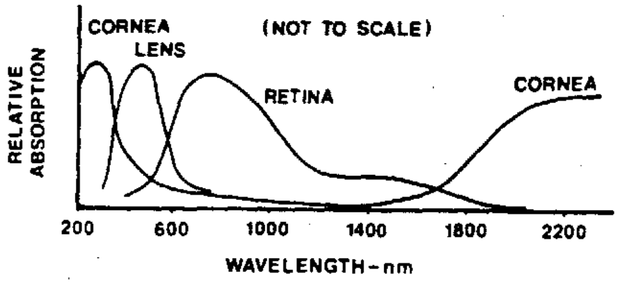
6. Associated Hazards

There are other hazards from some light sources that must also be prevented. There is a shock hazard in some operations involving arcs, because of the high starting voltages required. Wiring and connections must be adequately insulated, and persons handling the equipment must wear gloves and face shields. There must be adequate ventilation to prevent build-up of ozone and oxides of nitrogen. There may also be an explosion hazard from some light operations, and wearing of gloves and face shields will reduce the consequences of an explosion.

Arc welding on plates wet with unsaturated chlorinated hydrocarbons (perchloroethylene and trichloroethyline) must be avoided unless well vented, because of possible production of phosgene and hydrogen chloride.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	BIOLOGICAL EFFECTS AND HAZARDS	71

RELATIVE ABSORPTION IN THE EYE



In summary, recall the effects on the eye of the absorption in the IR—VIS—UV range. Also, recall that skin effects, including cancer production from chronic irradiation, occur due to mid and near UV.

C. STANDARDS, LAWS, AND REGULATIONS

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	72

WHY PROTECTION STANDARDS ?

TO PREVENT ACUTE EFFECTS

TO LIMIT RISKS OF LATE EFFECTS

1. Need

There is a need to set limits on the amount of exposure to radiant energies individuals can accept with safety. Setting protection standards, however, is a very complicated process. The objectives of protection are to prevent acute effects and to limit the risks of late effects. The former can be achieved in normal circumstances while the latter becomes difficult.

Protection standards should be based on scientific evidence, but quite often are the result of empirical approaches to various problems reflecting current qualitative and quantitative knowledge. A numerical value for a standard implies a knowledge of the effect produced at a given level of stress, and that both effect and stress are measurable.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	73

AREAS OF CONSIDERATION WHEN SETTING LIGHT PROTECTION STANDARDS:

1. INJURY THRESHOLD VALUES
2. COMPLETE SPECTRUM COVERAGE
3. VARIABLES SUCH AS FREQUENCY, MODULATION, EXPOSURE TIME, POWER DENSITY, POLARIZATION, ETC.
4. INDIVIDUALS AND GROUP COVERED
5. DEGREE OF RISK AND BENEFITS

1. Need (cont)

To insure uniform and effective control of potential health hazards from non-ionizing radiation exposure, it is necessary to establish uniform effect or threshold values. Threshold values should be predicated on firm human data. If such data are not available, extrapolation from well-designed, adequately performed, and properly analyzed animal investigations are required. Additional research is necessary to establish personnel exposure standards for each part of the spectrum, which takes into consideration frequency effects, type of modulation, exposure time, power density, field effects, wave-polarization effects, and threshold phenomena.

It must also be appreciated that in considering standards for different population groupings, one has to use a certain amount of inference, calculation and judgment. The importance of the application to the individual or groups of individuals and uses such as; defense, industrial, and consumer applications, medicine, agriculture, have to be considered. Characteristics of the personnel that may be exposed, degree of risk of incurring exposures substantially above the planned limits, and their consequences must also be considered.

It is apparent that much work remains to be done with regard to standards. An estimation of the risk involved and an estimation of the benefits must be made.

There is no question that standards should be promulgated when need is demonstrated. They should be developed, however, by those who have sound knowledge and concepts of radiant energy interaction with the body as a whole or specific parts (critical organs) of the body.

OSHA – OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970

2. Occupational Safety and Health Act of 1970

The Occupational Safety and Health Act, passed by Congress in 1970, directs the Secretary of Labor to "by rule promulgate as an occupational safety or health standard any national concensus standard, and any established Federal standard." Where concensus standards and Federal standards conflict, the Secretary is directed to "promulgate the standard which assures the greatest protection of the safety or health of the affected employees."

CODE OF FEDERAL REGULATIONS, TITLE 29, CHAPTER XVII

PART 1910.252 WELDING, CUTTING, AND BRAZING

SPECIFIC REQUIREMENTS

- **BOOTHS**
- **CLOTHING**
- **FILTER LENS AND PLATES**

3. Code of Federal Regulations

One such Federal Standard is contained in Title 29, Chapter XVII, Part 1910 of the Code of Federal Regulations regarding welding cutting and brazing: "Protection From Arc Welding Rays." Where the work permits, the welder should be enclosed in an individual booth painted with a finish of low reflectivity such as zinc oxide (an important factor for absorbing ultraviolet radiations) and lamp black, or shall be enclosed with noncombustible screens similarly painted. Booths and screens shall permit circulation of air at floor level. Workers or other persons adjacent to the welding areas shall be protected from the rays by noncombustible or flameproof screens or shields or shall be required to wear appropriate goggles.

Protective clothing–Employees exposed to the hazards created by welding, cutting, or brazing operations shall be protected by personal protective equipment in accordance with the requirements of §1910.132. Appropriate protective clothing required for any welding operation will vary with the size, nature and location of the work to be performed.

All filter lenses and plates shall meet the test for transmission of radiant energy prescribed in ANSI 87.1-1968–American National Standard Practice for Occupational and Educational Eye and Face Protection.

CODE OF FEDERAL REGULATIONS

EYE PROTECTION

- **ARC WELDING**
- **GAS WELDING OR OXYGEN CUTTING**
- **RESISTENCE WELDING OR BRAZING**
- **BRAZING**

Code of Federal Regulations (cont)

Eye Protection - Selection

a. Helmets or hand shields shall be used during all arc welding or arc cutting operations, excluding submerged arc welding. Goggles should also be worn during arc welding or cutting operations to provide protection from injurious rays from adjacent work, and from flying objects. The goggles may have either clear or colored glass, depending upon the amount of exposure to adjacent welding operations. Helpers or attendants shall be provided with proper eye protection.

b. Goggles or other suitable eye protection shall be used during all gas welding or oxygen cutting operations. Spectacles with outside shields, with suitable filter lenses are permitted for use during gas welding operations on light work, for torch brazing or for inspection.

c. All operators and attendants of resistance welding or resistance brazing equipment shall use transparent face shields or goggles, depending on the particular job, to protect their faces or eyes, as required.

d. Eye protection in the form of suitable goggles shall be provided where needed for brazing operations not covered in a., b., and c. of this subdivision.

CODE OF FEDERAL REGULATIONS

SPECIFICATIONS FOR PROTECTORS

MATERIALS	DESIGN
PROTECTIVE PROPERTIES	ADEQUATE COVER
FLAMABILITY	VENTILATION
STERILIZATION	LENSES
NON-CORROSIVE & NON-STAINING	

3. Code of Federal Regulations (cont)

Specifications For Protectors

a. Helmets and hand shields shall be made of a material which is an insulator for heat and electricity. Helmets, shields and goggles shall be not readily flammable and shall be capable of withstanding sterilization.

b. Helmets and hand shields shall be arranged to protect the face, neck and ears from direct radiant energy from the arc.

c. Helmets shall be provided with filter plates and cover plates designed for easy removal.

d. All parts shall be constructed of a material which will not readily corrode or discolor the skin.

e. Goggles shall be ventilated to prevent fogging of the lenses as much as practicable.

f. Cover lenses or plates should be provided to protect each helmet, hand shield or goggle filter lens or plate.

g. All glass for lenses shall be tempered, substantially free from striae, air bubbles, waves and other flaws. Except when a lens is ground to provide proper optical correction for defective vision, the front and rear surfaces of lenses and windows shall be smooth and parallel.

h. Lenses shall bear some permanent distinctive marking by which the source and shade may be readily identified.

CODE OF FEDERAL REGULATIONS

SHADE RECOMMENDATIONS FOR WELDING OPERATIONS

3. Code of Federal Regulations (cont)

The following guide for the selection of the proper shade numbers is contained in the Code. These recommendations may be varied to suit the individual's needs.

welding Operation	Shade No.
Shielded metal-arc welding–1/16-, 3/32-, 1/8-, 5/32-inch electrodes	10
Gas-shielded arc welding (nonferrous)–1/16-, 3/32-, 1/8-, 5/32-inch electrodes	11
Gas-shielded arc welding (ferrous)–1/16-, 3/32-, 1/8-, 5/32-inch electrodes	12
Shielded metal-arc welding:	
3/16-, 7/32-, 1/4-inch electrodes	12
5/16-, 3/8-inch electrodes	14
Atomic hydrogen welding	10-14
Carbon arc welding	14
Soldering	2
Torch brazing	3 or 4
Light cutting, up to 1 inch	3 or 4
Medium cutting, 1 inch to 6 inches	4 or 5
Heavy cutting, 6 inches and over	5 or 6
Gas welding (light) up to 1/8 inch	4 or 5
Gas welding (medium) 1/8 inch to 1/2 inch	5 or 6
Gas welding (heavy) 1/2 inch and over	6 or 8

NOTE: In gas welding or oxygen cutting where the torch produces a high yellow light, it is desirable to use a filter or lens that absorbs the yellow or sodium line in the visible light of the operation.

CODE OF FEDERAL REGULATIONS
PERSONNEL PROTECTIVE EQUIPMENT

APPLICATION

EMPLOYEE–OWNED EQUIPMENT

DESIGN

3. Code of Federal Regulations (cont)

General Requirements 29 CFR 1910.132

a. Application–Protective equipment, including personal protective equipment for eyes, face, head and extremities, protective clothing, respiratory devices and protective shields and barriers, shall be provided, used, and maintained in a sanitary and reliable condition wherever it is necessary by reason of hazards of processes or environment, chemical hazards, radio-logical hazards, or mechanical irritants encountered in a manner capable of causing injury or impairment in the function of any part of the body through absorption, inhalation or physical contact.

b. Employee-owned Equipment–Where employees provide their own protective equipment, the employer shall be responsible to assure its adequacy, including proper maintenance and sanitation of such equipment.

c. Design–All personal protective equipment shall be of safe design and construction for the work to be performed.

AMERICAN NATIONAL STANDARDS INSTITUTE

ANSI Z87.1 - 1968

AMERICAN NATIONAL STANDARD PRACTICE FOR OCCUPATIONAL AND EDUCATIONAL EYE AND FACE PROTECTION

4. American National Standards Institute

The American National Standards Institute (ANSI) has developed regulations and procedures for ultraviolet, visible and infrared radiation which are considered a national concensus standard and as such are enforceable by the Secretary of Labor under the Occupational Safety and Health Act of 1970.

ANSI Z87.1 is applicable to face and eye protection.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	81

ANSI Z87.1.4

GENERAL REQUIREMENTS

(a) EYE AND FACE PROTECTION SHALL BE REQUIRED

(b) SUITABLE EYE PROTECTION SHALL BE PROVIDED

(c) PROTECTION SHALL BE MARKED

4. American National Standards Institute (cont)

General Requirements

a. Eye and face protection in a manner provided by this standard shall be required where there is a reasonable probability of injury that can be prevented by such protection.

b. In such cases, employers or educational authorities shall make conveniently available a type of protector suitable for the work to be performed, and employees or students shall use such protectors.

c. No unprotected person shall knowingly be subjected to a hazardous environmental condition.

d. Protectors shall meet the following minimum requirements:

    (1) They shall provide adequate protection against the particular hazards for which they are designed..

    (2) They shall be reasonably comfortable when worn under the designated conditions.

    (3) They shall fit snugly and shall not unduly interfere with the movements of the wearer.

    (4) They shall be durable.

    (5) They shall be capable of being disinfected.

    (6) They shall be easily cleanable.

ANSI Z87.1.4

4. GENERAL REQUIREMENTS

(a) EYE AND FACE PROTECTION SHALL BE REQUIRED

(b) SUITABLE EYE PROTECTION SHALL BE PROVIDED

(c) PROTECTION SHALL BE MARKED

4. American National Standards Institute (cont)

e. Protectors should be kept clean and in good repair.

f. Suitable eye protectors shall be provided where machines or operations present the hazard of flying objects, glare, liquids, injurious radiation, or a combination of these hazards.

g. Persons whose vision requires the use of corrective lenses in spectacles, and who are required by this standard to wear eye protection, shall wear goggles or spectacles of one of the following types:

(1) Spectacles whose protective lenses provide optical correction.

(2) Goggles that can be worn over corrective spectacles without disturbing the adjustment of the spectacles.

(3) Goggles that incorporate corrective lenses mounted behind the protective lenses.

h. Every protector shall be distinctly marked to facilitate identification only of the manufacturer.

i. When limitations or precautions are indicated by the manufacturer, they shall be transmitted to the user and care taken to see that such limitations and precautions are strictly observed.

ANSI Z87.1.5

WELDING HELMETS,AND HAND SHIELDS, AND FACE SHIELDS

GENERAL REQUIREMENTS
- **(a) FUNCTION**
- **(b) TYPES**
- **(c) STYLES**

4. American National Standards Institute (cont)

Welding Helmets, Hand Shields and Face Shields

a. Function–The devices described in this section are designed to provide protection for the eyes, face, ears, and neck against intense radiant energy and weld spatter. Typical operations which require helmets or hand shields include various kinds of arc welding, heavy gas cutting, and scarfing.

b. Types–The helmet and the hand shield are the only permissible types.

c. Styles–The helmet and the hand shield are made to the same basic design and of the same basic materials–opaque, bowl-shaped, or modified bowl-shaped, device containing a window with filter plate which allows the wearer to see the radiant object, yet prevents harmful intensities of radiation from reaching his eyes. The helmet is supported on the head by an adjustable headgear, while the hand shield has a handle attached to the bottom by which it is held in the hand. The basic designs may be modified to provide protection against special hazards, but modified equipment shall meet the same requirements as the basic design.

ANSI Z87.1.5

DETAILED REQUIREMENTS

(a) HELMET BODY

(b) WEIGHT

(c) HEADGEAR

4. American National Standards Institute (cont)

Detailed Requirements–Rigid Helmet

a. Helmet Body–The helmet body shall be of such size and shape as to protect the face, forehead, ears, and neck to a vertical line back of the ears. It shall have an opening or openings in the front for filter plates or filter lenses. The helmet body shall be attached to the headgear in such a way that it will not come in contact with any part of the head and that it can be lifted up from in front of the face and hold its position in front of the head. The helmet body shall be made of vulcanized fiber, reinforced plastic, or other suitable material which shall be thermally insulating, noncombustible or slow burning; opaque to visible, ultraviolet, and infrared radiations; and capable of withstanding disinfection. The inside of the helmet body shall have a low light-reflecting finish. Rivets or other metal parts, if terminating on the inside surface, shall be adequately separated from the wearer's head.

b. Weight–The helmet or hand shield, exclusive of filter or cover plates, shall weigh not more than 28 ounces (793 grams).

c. Headgear–The helmet shall have a headgear or cradle that shall hold the helmet body comfortably and firmly on the wearer's head, but shall permit the helmet body to be tilted back over the head. The headgear shall be readily adjustable.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	85

ANSI Z87.1.5

DETAILED REQUIREMENTS

(d) HEADGEAR SUBSTITUTE

(e) FILTER AND COVER PLATE MOUNTING

4. American National Standards Institute (cont)

d. Headgear Substitutes–The headgear may be replaced by an impact-resistant hat or cap, or other suitable device to which the helmet body is connected, provided that the helmet body can be lifted and adjusted to permit unobstructed vision or lowered to furnish complete protection, as required.

e. Filter-and-Cover-Plate Mounting–The front of the helmet body shall be provided with a light-tight plate-mounting frame or frames made of metal, plastic, or other suitable material, which shall be attached securely to the body of the helmet or shall be an integral part of the helmet. The frame shall provide a window through which the welding or cutting operation may be seen by the wearer; the window opening shall be not less than 3 5/8 inches wide and 1 5/8 inches high, or equivalent in area and visual field. The frame shall permit the removal and replacement of filter and cover plates without the use of tools and without damage to the plates or frame. The mounting shall be so designed that the filter plate will be not less than 2 inches (50.8 millimeters) from the eyes of the wearer.

ANSI Z87.1.6

EYE PROTECTION

a. GOGGLES

(1) STYLES

(2) VENTILATION

(3) MARKINGS

b. SPECTACLES

4. American National Standards Institute (cont)

Styles—Goggles, Eyecup

a. Basic Types—Eyecup goggles shall comprise two basic types as follows:

   (1) Cup—Type goggles designed to be worn by individuals who do not wear corrective spectacles.

   (2) Cover—Cup Type goggles designed to fit over corrective spectacles.

b. Models—The two basic types of eyecup goggles shall be subdivided into the following classes:

   (1) Chipper's models providing impact protection against flying objects.

   (2) Dust and Splash models providing protection against relatively fine dust particles or liquid splashes and impact.

   (3) Welder's and Cutter's models providing protection against glare, injurious radiations, and impact.

The basic designs may be modified to provide more protection against special hazards, but the modified equipment shall meet the same requirements as the basic design.

Ventilation

Welder's and Cutter's Models—Eyecups shall be ventilated in a manner to permit circulation of air and shall be opaque from 1,900 to 12,000 angstrom units. The ventilation opening shall be baffled to prevent the passage of light rays into the interior of the eyecups.

The equivalent area of openings of ventilation in each eyecup shall be not less than the area of a 1/4-inch (6.35 millimeter) diameter hole.

ANSI Z87.1.6

EYE PROTECTION

a. GOGGLES

b. SPECTACLES

(1) DESCRIPTION

(2) PROTECTION

(3) MARKINGS

4. American National Standards Institute (cont)

Markings

All filter lenses shall be marked with the shade designation and a permanent and legible marking by which the manufacturer may be readily identified. In addition, all glass filter lenses, when treated for impact resistance shall be marked with the Letter "H".

b. Spectacles; Metal, Plastic, and Combination Metal and Plastic

1. Description--Safety spectacles require special frames, therefore combinations of street-wear frames with safety lenses meeting this standard are definitely not in compliance.

2. Protection—Spectacles shall provide protection to the eye from flying objects, and when required from, glare and injurious radiations. Spectacles without sideshields are intended to provide frontal protection. Where side as well as frontal protection is required, the spectacles shall be provided with sideshields.

3. Markings—These frames shall be designed for industrial exposure and shall bear a trademark identifying the maufacturer on both fronts and temples. The frame front shall carry a designation of the eye size and bridge size (where applicable). Temples will be marked as to the overall length or fitting value.

ANSI Z87.1.6

DETAILED REQUIREMENTS FOR PROTECTIVE LENSES

(a) ABSORPTIVE LENSES

(b) FILTER LENSES

(c) CLEAR LENSES

(d) PROTECTIVE–CORRECTIVE LENSES

4. American National Standards Institute (cont)

Lenses

a. Types of Lenses–Lenses intended for use in protectors covered by this code shall be comprised of four basic types, as follows:

(1) Clear Lenses–Impact-resisting, providing protection against flying objects.

(2) Absorptive Lenses (Shades 1.7 through 3.0).

(a) Impact-resisting, providing protection against flying objects and glare.

(b) Impact-resisting, providing protection against flying objects, and narrow-band spectral transmittance against injurious radiation.

(3) Protective-Corrective Lenses–Impact-resisting, either clear or absorptive, as specified for persons requiring visual correction.

(4) Filter Lenses–Impact-resisting, providing protection against flying objects and injurious radiation.

b. Transmittance

(1) Absorptive Lenses (Shades 1.7 through 3.0)–Absorptive lenses shall meet the radiant-energy-transmission requirements hereinafter specified. They shall be supplied in pairs. For shades 1.5 to 2, inclusive, both lenses of a pair shall have the same luminous transmittance within 10 percent; for shades 2.5 and darker, both lenses of a pair shall have the same luminous transmittance within 20 percent.

(2) Filter Lenses (Shades 4.0 through 14.0)–Filter lenses shall meet radiant-energy-transmission requirements. They shall be supplied in pairs and both lenses shall have the same luminous transmittance within 20 percent.

(3) Clear Lenses–Clear lenses shall transmit not less than 89 percent of the incident luminous radiation.

ANSI EYE PROTECTION FILTERS

- SHADE (S)
- OPTICAL DENSITY (OD)

$S = \frac{7}{3} OD + 1$

$OD = \log_{10} (E_0/E)$

4. American National Standards Institute (cont)

Eye Protection

Eye protection filters for glass workers, steel and foundry workers, and welders were developed empirically; however, optical transmission characteristics are now standardized as shades and specified for particular applications. Although maximum transmittances for ultraviolet and infrared radiation are specified for each shade, the visual transmittance or visual optical density OD defines the shade number (S).

$$S = \frac{7}{3} OD + 1$$

where

$$OD = \log_{10} \frac{Eo}{E}$$

Since the luminance of acetylene flames is typically of the order of 10 $cd \cdot cm^{-2}$, a density of 1, corresponding to shade 3 or 4, is applicable. Electric welding arcs have luminances of the order of 10^4 to 10^5 $cd \cdot cm^{-2}$ and filter densities ranging from 4 to 5 corresponding to shades 10 to 13 are required for comfortable viewing. Likewise a shade of at least 13 is required to view the sun, which has a luminance of approximately 10^5 $cd \cdot cm^{-2}$. These densities are far in excess of those necessary to prevent retinal burns but are required to reduce the luminance to 1 $cd \cdot cm^{-2}$ or less for viewing comfort. The user of the eye protection should therefore be permitted to choose the shade most desirable to him for his particular operation. Actinic ultraviolet radiation from welding arcs is effectively eliminated in all standard welding filters. High ambient light levels and the use of specialized filters to further attenuate intense spectral lines (e.g., class II, didymium welder's goggles, which attenuate the sodium doublet) are the primary techniques to reduce glare in welding.

ANSI TRANSMITTANCES AND TOLERANCES IN TRANSMITTANCE OF VARIOUS SHADES OF ABSORPTIVE LENSES, FILTER LENSES, AND PLATES

Shade Number	Optical Density			Luminous Transmittance			Maximum Infrared Transmittance	Maximum Spectral Transmittance in the Ultraviolet and Violet			
	Maximum	Standard	Minimum	Maximum Percent	Standard Percent	Minimum Percent	Percent	313 mμ Percent	334 mμ Percent	365 mμ Percent	405 mμ Percent
1.5	0.26	0.214	0.17	67.0	61.5	55.0	25.0	0.2	0.8	25.0	65.0
1.7	0.36	0.300	0.26	55.0	50.1	43.0	20.0	0.2	0.7	20.0	50.0
2.0	0.54	0.429	0.36	43.0	37.3	29.0	15.0	0.2	0.5	14.0	35.0
2.5	0.75	0.643	0.54	29.0	22.8	18.0	12.0	0.2	0.3	5.0	15.0
3.0	1.07	0.857	0.75	18.0	13.9	8.5	9.0	0.2	0.2	0.5	6.0
4.0	1.50	1.286	1.07	8.5	5.18	3.16	5.0	0.2	0.2	0.5	1.0
5.0	1.93	1.714	1.50	3.16	1.93	1.18	2.5	0.2	0.2	0.2	0.5
6.0	2.36	2.143	1.93	1.18	0.72	0.44	1.5	0.1	0.1	0.1	0.5
7.0	2.79	2.571	2.36	0.44	0.27	0.164	1.3	0.1	0.1	0.1	0.5
8.0	3.21	3.000	2.79	0.164	0.100	0.061	1.0	0.1	0.1	0.1	0.5
9.0	3.64	3.429	3.21	0.061	0.037	0.023	0.8	0.1	0.1	0.1	0.5
10.0	4.07	3.857	3.64	0.023	0.0139	0.0085	0.6	0.1	0.1	0.1	0.5
11.0	4.50	4.286	4.07	0.0085	0.0052	0.0032	0.5	0.05	0.05	0.05	0.1
12.0	4.93	4.714	4.50	0.0032	0.0019	0.0012	0.5	0.05	0.05	0.05	0.1
13.0	5.36	5.143	4.93	0.0012	0.00072	0.00044	0.4	0.05	0.05	0.05	0.1
14.0	5.79	5.571	5.36	0.00044	0.00027	0.00016	0.3	0.05	0.05	0.05	0.1

4. American National Standards Institute (contd.)

The chart above gives the transmittances and tolerances in transmittance of various shades of absorptive lenses, filter lenses, and plates.

ANSI RECOMMENDED EYE AND FACE PROTECTORS

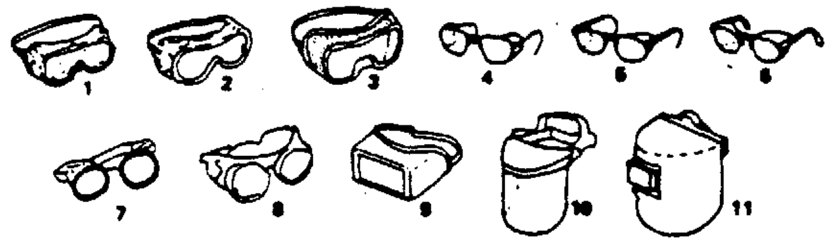
1. GOGGLES
2. SPECTACLES
3. WELDING GOGGLES
4. WELDING HELMETS

Based on past experience, ANSI has published a chart which recommends eye and face protectors for use in Industry, Schools and Colleges.

This chart is helpful in determining whether spectacles, goggles or helmets should be used for a particular operation.

SELECTION CHART

Recommended Eye and Face Protectors for Use in Industry, Schools, and Colleges



1. GOGGLES, Flexible Fitting, Reguler Ventilation
2. GOGGLES, Flexible Fitting, Hooded Ventilation
3. GOGGLES, Cushioned Fitting, Rigid Body

* 4. SPECTACLES, Metal Frame, with Sideshields

* 5. SPECTACLES, Plastic Frame, with Sideshields

* 6. SPECTACLES, Metal–Plastic Frame, with Sideshields

** 7. WELDING GOGGLES, Eyecup Type, Tinted Lenses

** 8. WELDING GOGGLES, Coverspec Type, Tinted Lenses

** 9. WELDING GOGGLES, Coverspec Type, Tinted Plate Lens

10. FACE SHIELD (Available with Plastic or Mesh Window)

** 11. WELDING HELMETS

• Non-sideshield spectacles are available for limited hazard use requiring only frontal protection.

** See appendix chart, "Selection of Shade Numbers for Welding Filters."

APPLICATIONS

OPERATION	HAZARDS	RECOMMENDED PROTECTORS (Bold Type Numbers Signify Preferred Protection)
ACETYLENE-BURNING ACETYLENE-CUTTING ACETYLENE-WELDING	SPARKS, HARMFUL RAYS, MOLTEN METAL, FLYING PARTICLES	7, 8, 9
ELECTRIC (ARC) WELDING	SPARKS, INTENSE RAYS, MOLTEN METAL	9, 11 (11 in combination with 4, 5, 6, in tinted lenses advisable)
FURNACE OPERATIONS	GLARE, HEAT, MOLTEN METAL	7, 8, 9 (for severe exposure, add 10)
MOLTEN METALS	HEAT, GLARE, SPARKS, SPLASH	7, 8 (10 in combination with 4, 5, 6, in tinted lenses)
SPOT WELDING	FLYING PARTICLES' SPARKS	1, 3, 4, 5, 6, 10

4. American National Standards Institute (cnnt)

The chart above gives the recommended eye and face protectors for various operations involving UV-VIS-IR radiation.

RECOMMENDED STANDARD

FOR

OCCUPATIONAL EXPOSURE

TO

ULTRAVIOLET RADIATION

BY

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH (NIOSH)

5. National Institute for Occupational Safety and Health

The Occupational Safety and Health Act of 1970 also established the National Institute for Occupational Safety and Health (NIOSH) which empowered the Secretary of Health Education and Welfare to:

a. develop and establish recommended occupational safety and health standards; and,

b. conduct research, training and employee education functions.

Thus far NIOSH has recommended standards for occupational exposure to UV. It should be noted that these are only recommendations and as such do not carry the force of law.

Exposure standards, based on the actinic region and blacklight, recommends that occupational exposure to ultraviolet energy in the workplace be controlled. Ultraviolet radiation is defined as that portion of the electromagnetic spectrum described by wavelengths from 200 to 400 nm. Adherence to the recommended standards will prevent adverse acute and chronic cutaneous and ocular changes precipitated or aggravated by occupational exposure to ultraviolet radiation.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	94

RADIANT EXPOSURE

STANDARDS

AND

WORK PRACTICES

ARE PROVIDED IN THE STANDARDS

FOR CONTROL OF U V HAZARDS AS

RECOMMENDED BY NIOSH

5. National Institute for Occupational Safety and Health (cont)

Sufficient technology exists to prevent adverse effects on workers, but technology to measure ultraviolet energy for compliance with the recommended standard may not be adequate. Therefore work practices, as well as the radiant exposure standard, are provided for the control of UV exposure.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	95

NIOSH RECOMMENDATION UV STANDARD

NEAR UV

WAVELENGTH	TOTAL IRRADIANCE ON SKIN OR EYES	TIME OF EXPOSURE
1) 315 - 400nm	1.0 mW/cm^2	> 1000 SEC
	TOTAL RADIANT ENERGY	
2) 315 - 400nm	1000 mW SEC/cm^2 (1.0 J/cm^2)	< 1000 SEC

For the ultraviolet spectral region of 315 to 400 nm, total irradiance incident on unprotected skin or eyes, based on either measurement data or on output data, shall not exceed 1.0 mW cm^2 for periods greater than 1000 seconds, and for exposure times of 1000 seconds or less the total radiant energy shall not exceed 1000 mW sec/cm^2 (1.0 J/cm^2).

NIOSH UV STANDARD – ACTINIC

TOTAL PERMISSIBLE 8–HOUR DOSES AND RELATIVE SPECTRAL EFFECTIVENESS OF SOME SELECTED MONOCHROMATIC WAVELENGTHS

Wavelength (nm)	Permissible 8–hour dose (mJ/cm²)	Relative spectral effectiveness (S_λ)
200	100.0	0.03
210	40.0	0.075
220	25.0	0.12
230	16.0	0.19
240	10.0	0.30
250	7.0	0.43
254	6.0	0.50
260	4.6	0.65
270	3.0	1.00
280	3.4	0.88
290	4.7	0.64
300	10.0	0.30
305	50.0	0.06
310	200.0	0.015
315	1000.0	0.003

5. National Institute for Occupational Safety and Health (cont)

For the ultraviolet spectral region of 200 to 315 nm, total irradiance incident on unprotected skin or eyes, based on either measurement data or on output data, shall not exceed the levels shown above for a daily 8-hour exposure to a narrow-band or monochromatic source.

NIOSH UV STANDARD – BROAD BAND ACTINIC

$$I_{eff} = \Sigma\ I_\lambda\ S_\lambda\ \Delta\lambda, \quad \text{AND } T\ (\text{sec}) = \frac{.003\ J/cm^2}{I_{eff}}$$

where I_{eff} = effective irradiance relative to a monochromatic source at 270 nm.

I_λ = spectral irradiance in $W/cm^2/nm$.

S_λ = relative actinic spectral effectiveness (unitless); see Figure 87 for values of S_λ at different wavelengths.

$\Delta\lambda$ = band width in nm.

and T = Max. exposure time (sec)

5. National Institute for Occupational Safety and Health (cont)

If the ultraviolet energy is from a broad-band source, the effective irradiance (I_{eff}) relative to a 270-nm monochromatic source shall be calculated from the formula below. The permissible exposure time in seconds for unprotected skin or eyes shall be computed by dividing 0.003 J/cm^2, the permissible dose of 270-nm radiation, by I_{eff} in W/cm^2, where:

$$I_{eff} = \Sigma\ I_\lambda S_\lambda \Delta_\lambda$$

where I_{eff} = effective irradiance relative to a monochromatic source at 270 nm.

I_λ = spectral irradiance in $W/cm^2/nm$.

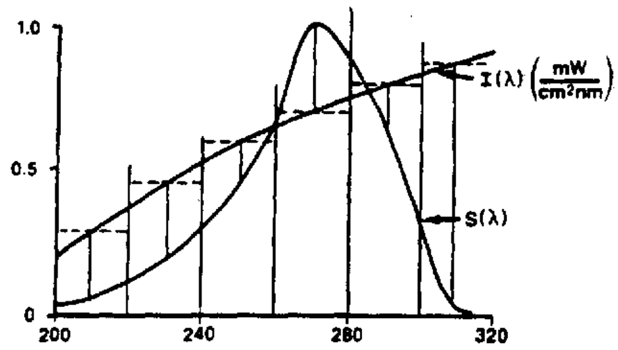
S_λ = relative spectral effectiveness (unitless); see previous table for values of S_λ at different wavelengths.

Δ_λ = band width in nm.

and the sum is over the entire source wavelength band. Thus, permissible exposure time in seconds is

$$T = \frac{0.003\ J/cm^2}{I_{eff}\ (W/cm^2)}$$

CACULATION OF I_{EFF}



The chart shows how to set up the computation of I_{eff}, using S (λ) and a given I (λ) spectral irradiance. One forms products of I (λ) and S (λ) for various intervals, $\Delta\lambda$, in this case 20 nm wide. Then $\Sigma\ I(\lambda)\ S(\lambda)\ \Delta\lambda = I_{eff} =$

$$(0.3\ \frac{mW}{cm^2 - nm})(0.075)(20\ nm) + (0.45)(0.19)(20) + (0.6)(0.43)(20) + (0.7)(1.0)(20)$$

$$+ (0.8)(0.64)(20) + (0.88)(0.30)(20) = 36.84\ mW/cm^2.$$

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS, AND REGULATIONS	99

NIOSH RECOMMENDED UV STANDARD – ACTINIC

MAXIMUM PERMISSIBLE EXPOSURE TIMES FOR SKIN AND EYES FOR SELECTED VALUES OF I_{eff}

Duration of Exposure per day	Effective Irradiance, I_{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	5.0
5 min	10.0
1 min	50.0
30 sec	100.0

5. National Institute for Occupational Safety and Health (cont)

This figure shows permissible exposure times corresponding to selected values of I_{eff} in $\mu W/cm^2$. These are computed using the formula and chart data from previous slides.

Another way of stating this broadband actinic UV standard is that the integrated energy density weighted by the action spectrum over the 200—315 nm band, on unprotected skin or eyes, should not exceed 3 mJ/cm^2 in 8 hours.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	100

NIOSH RECOMMENDED UV STANDARD

INVERSE SQUARE LAW MAY BE
USED WHEN THE INTENSITY FROM
A POINT SOURCE IS KNOWN AT
SOME DISTANCE FROM THE WORKERS

$$I_1 (D_1)^2 = I_2 (D_2)^2$$

5. National Institute for Occupational Safety and Health (cont)

If radiation intensity from a point source is known at some distance from the worker, for example, from measurement at another point or from output data at a known distance from the ultraviolet source, attenuation of radiation from that point to the worker can be calculated from the principle that radiation intensity decreases with the square of the distance it must travel.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	101

NIOSH RECOMMENDED UV STANDARD

EXAMPLE –

$$I_1 (D_1)^2 = I_2 (D_2)^2$$

GIVEN: I_1 = INTENSITY AT 1 FT = 100 mW/cm^2

FIND: I_2 = INTENSITY AT 2 FT = ?

$$I_2 = \frac{100 \text{ mW/cm}^2 \times (1 \text{ FT})^2}{(2 \text{ FT})^2}$$

$$I_2 = 25 \text{ mW/cm}^2$$

5. National Institute for Occupational Safety and Health (cont)

For example, an object 3 feet away from a radiation source receives 1/9 the energy of an object 1 foot away. This assumption is conservative in some instances, since ultraviolet radiation, especially at very short wavelengths, may be absorbed by some components of the atmosphere. Where information on atmospheric absorption of ultraviolet radiation is known, further corrections may be applied. The calculation of intensity of radiation at any given point by use of the inverse square formula explained above does not take into consideration reflected energy.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	STANDARDS, LAWS AND REGULATIONS	102

AMA THRESHOLD DOSE FOR KERATITIS AND ERYTHEMA

THRESHOLD DOSE (μW. SEC/CM^2)

	WAVELENGTH OF MAXIMUM EFFECTIVENESS 288 NM	WAVELENGTH OF GERMICIDAL LAMP 253.7 NM
KERATITIS	RABBIT 1.5×10^4	HUMAN 1.2×10^4
	HUMAN 0.3×10^4 (CALCULATED FROM 253.7 nm DOSE AND RELATIVE EFFECTIVENESS FROM RABBIT DATA)	
ERYTHEMA	296.7 nm HUMAN 2.0×10^4 (MEASURED ON UPPER ARM, SOME PARTS OF BACK)	HUMAN 3.0×10^4

	DURATION OF EXPOSURE/DAY	TOTAL DOSE/DAY (253.7 NM)
AMA COUNCIL ON PHYSICAL MEDICINE	7 HR	1.2×10^3
	24 HR	0.9×10^3

6. Council on Physical Medicine of the American Medical Association

Other recommendations for safe exposure exist. In 1948, the Council on Physical Medicine of the American Medical Association issued threshold doses and criteria for safe exposure to radiant energy from germicidal lamps. This group recommended that for the primarily used wavelength, 253.7 nm exposures should not exceed 0.5 μW/cm^2 for periods of 7 h or less, nor 0.1 μW/cm^2 in the case of continuous exposure. The threshold dose for erythema and its relationship to wavelength vary considerably with the part of the body studied. On the more sensitive skin of the abdomen, the shortest wavelength studied, 250 nm, was the most effective, and the threshold dose for erythema at that wavelength was about 0.6×10^4 μW·Sec/cm^2. The AMA recommends an intensity limit of 0.5 μW/cm^2 for exposures of 7 h or less per day, and the value in the slide represents the total dose delivered in 7 h at that rate.

A ten-fold margin of safety has been allowed in the recommended exposure limits relative to the threshold dose for production of keratitis by 253.7-nm radiation. It must be recognized that this standard applies only to 253.7-nm radiation, and evaluation of the hazard from sources of UV other than germicidal lamps must take into account the relative effectiveness of the wavelengths produced.

VISIBLE AND NEAR–IR

- ACGIH (1978) TLV's FOR TWO RETINAL INJURY MODES
  - (1) THERMAL (BROAD BAND)
  - (2) PHOTOCHEMICAL (BLUE)
- SAFE IF SOURCE LUMINANCE < 1 cd/cm^2
- MOST ARC LAMPS OK BECAUSE OF BLINK REFLEX

7. American Conference of Government Industrial Hygienists

In 1978, the ACGIH published intended changes for TLV's including standards for visible and near infra-red light. There had previously been no standards for this part of the spectrum unless the source is a laser. The TLV's given are conservatively based on data and are thought to be levels below which exposed workers will suffer no ill effects. As with TLV's generally, they do not represent a boundary line between safe and unsafe.

In general these TLV standards will be met if the source luminance is less than one candela/cm^2. Two TLV's are promulgated: (1) for broad band visible and near–IR (400—1400 nm) that could produce thermal injury to the retina; and (2) for chronic blue light exposure that could cause retinal photochemical injury.

Fortunately few arc sources are sufficiently large and sufficiently bright to be a retinal burn hazard under normal viewing conditions. Only when an arc or tungsten filament is greatly magnified as in an optical projection system can hazardous irradiances be imaged on a sufficiently large area of the retina to cause a burn. Furthermore, individuals would normally not step into a projected beam at close range or view an arc with binoculars or a telescope. Almost all conceivable accident situations require a hazardous exposure to be delivered within the period of the blink reflex. If an arc were initiated while an individual were located at a very close viewing range, he could receive a retinal burn. Such situations require viewing distances of a few meters for all but the most powerful xenon searchlights or a few inches for a welding arc, and most movie projection equipment, or movie lamps.

(A candela is the international unit of candlepower; for a white light spectrum 1.0 cd/cm^2 represents brightness of 2920 ft-lamberts. A foot lambert is a lumen/sq. ft.)

VISIBLE AND NEAR–IR TLV's

RETINAL BURN TLV

$$\sum_{400}^{1400} L_\lambda R_\lambda \Delta_\lambda < \frac{1}{a\sqrt{t}}$$

Where:

L_λ (W/cm²-sr-nm) is LAMP SPECTRAL RADIANCE

a (radians) is MAX. ANGULAR SUBTENSE OF LAMP

t (seconds) is VIEWING TIME (1 μs – 10 s)

R_λ is BURN HAZARD WEIGHTING FUNCTION

Δ_λ is WAVELENGTH INTERVAL

The empirical formula governing safe viewing at a broad-band visible-near-IR lamp is given. The sum extends over 400—1400 nm. Alpha (a) is the angle subtended at the eye by the largest lamp dimension. R_λ is the Burn Hazard Weighting function tabulated in Chart 106. For a known, e.g., measured, lamp spectral radiance, one may calculate the safe viewing time.

VISIBLE AND NEAR–IR TLV

- BLUE LIGHT PHOTOCHEMICAL RETINA DAMAGE
- TWO FORMULAS GOVERN SAFE VIEWING FOR BROAD BAND

$$\sum_{400}^{1400} L_\lambda t \, B_\lambda \, \Delta_\lambda \leq 100 \text{ J/cm}^2\text{–sr } (t \leq 10^4 \text{ s})$$

$$\sum_{400}^{1400} L_\lambda \, B_\lambda \, \Delta_\lambda \leq 10^{-2} \text{ W/cm}^2\text{– sr } (t > 10^4 \text{ s})$$

- IF SOURCE RADIANCE, L, > 2 mW/cm² – sr IN BLUE REGION, THEN

$$t_{max} = (100 \text{ J/cm}^2 - \text{sr}) \div L \text{ (BLUE)}$$

The two formulas given govern the safe viewing of a broad band lamp to avoid photochemical damage to the retina from blue light. B_λ is tabulated in Chart 106. For a source that has more than 2 mW/cm² in its blue spectral region (400–500 nm), the remainder of the spectrum may be neglected, and the blue irradiance, L(Blue), in W/cm² – sr, used in the last formula shown to obtain the maximum viewing time.

VISIBLE AND NEAR–IR TLV

WAVELENGTH (nm)	B_λ	R_λ	WAVELENGTH (nm)	B_λ	R_λ
400	0.10	1.0	460	0.80	8.0
405	0.20	2.0	465	0.70	7.0
410	0.40	4.0	470	0.62	6.2
415	0.80	8.0	475	0.55	5.5
420	0.90	9.0	480	0.45	4.5
425	0.95	9.5	485	0.40	4.0
430	0.98	9.8	490	0.22	2.2
435	1.0	10	495	0.16	1.6
440	1.0	10	500–600	$10^{[(450-\lambda)/50]}$	1.0
445	0.97	9.7	600–700	0.001	1.0
450	0.94	9.4	700–1049	0.001	$10^{[(700-\lambda)/505]}$
455	0.90	9.0	1050–1400	0.001	0.2

The Blue-light Retinal Photochemical Hazard weighting function, R_λ; and the Broad-Band Retinal Thermal Burn weighting function, B_λ, are tabulated as functions of wavelength. Use these values in calculating safe viewing conditions with the formulas of charts 104 and 105.

INFRARED TLV

- ACGIH TLV FOR LATE CATARACTOGENESIS
- TLV FOR $\lambda > 770$ nm: 10 mW/cm^2 TO EYE
- TLV FOR IR LAMPS WITHOUT VISIBLE:

$$\sum_{770}^{1400} L_\lambda \Delta_\lambda \leq \frac{0.6}{a}$$

FOR CHRONIC (LONG-TERM) VIEWING.

For long duration viewing of IR sources, to avoid late formation of cataracts, the dose rate to the lens from wavelength above 770 nm should not exceed 10 mW/cm^2. If there is too little visible light to evoke the blink response, the formula given sets the limit on the near IR spectral radiance as viewed by the eye.

D. EVALUATION OF HAZARDS

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	108

PREPARATION FOR SURVEYING

- **KNOWLEDGE OF EQUIPMENT OR OPERATION**
- **METHOD OF ATTACK**

1. General

Later in this section is a more detailed description of surveying procedures for UV-VIS-IR Radiation. This section summarizes the when, where and whys that are generally applicable to all surveys.

Preparation for Surveying

a. Acquire a thorough knowledge of the nature of the equipment or operation to be surveyed.

b. Discuss the method of attack with affected personnel.

(1) What is the expected hazard? (UV, VIS, IR or all three).

(2) What is the physical size of the working space?

(3) What protective clothing and equipment is necessary?

(4) Will other work nearby affect the status of the job, or vice versa?

INSTRUMENTATION

- **PROPER TYPE**
- **SUFFICIENT QUANTITY**

2. Instrumentation

Two aspects should be considered in selecting instruments for radiation surveying:

a. Selection of proper type or types of instruments appropriate for hazard present.

b. Provision or sufficient instruments to last out the job. In the planning of quantity, consideration should be given to the reliability of the portable instruments used, weather conditions if outdoors, remoteness of job from nearest source of replacements, and the cost of delaying the job, both waiting-time costs and potential recovery costs.

. TYPES OF INSTRUMENTS

- PHOTON DEVICES
- THERMAL DEVICES

2. Instrumentation (Cont'd.)

The wide variety of UV-VIS-IR sources now available with their different wavelengths, pulse durations, power densities and energy densities makes detection with one particular instrument difficult. Thus, a variety of detectors have been utilized and can be classified under one of two general categories; photon devices and thermal devices. These two classifications of light detectors are based on the two ways in which light interacts with matter. Photon devices interact via the photoelectric effect, photoconductive effect, and photovoltaic effect. Thermal devices utilize the heating effect and corresponding temperature rise caused by energy absorption.

PHOTON DETECTORS

- **PHOTOELECTRIC**
- **PHOTOCONDUCTIVE**
- **PHOTOVOLTAIC**
- PHOTOEMISSIVE

2. Instrumentation (Cont'd.)

b. Photon Devices

Photon devices measure the rate at which light quanta are absorbed. The response at any particular wavelength is proportional to the rate at which photons of that wavelength are absorbed. These detectors have a strong wavelength dependence in that the energy output of the UV-VIS-IR source is directly related to the number of photoelectrons produced.

There are four ways to categorize photon devices; photoelectric, photoconductive, photoemissive and photovoltaic. Electrons in a material may absorb energy from incident light quanta. When the electron is ejected or completely removed from the material upon absorption of a light photon, the photoelectric effect has occurred. If, however, the electron is liberated from a particular atom into the bulk of the material, this is termed the photoconductive effect. (This electron in the material is able to conduct electricity.) When the photoconductive effect occurs at the P-N boundary of semiconductors or at the boundary between a metal and a semiconductor, a potential difference will develop. This is classified as the photovoltaic effect, and is the basis for one of the solar energy technologies. If the electron is ejected from a surface into a vacuum, the effect is called photoemission.

PHOTOELECTRIC DETECTORS

- **VACUUM PHOTODIODE**
- **PHOTOMULTIPLIER TUBE**

2. Instrumentation

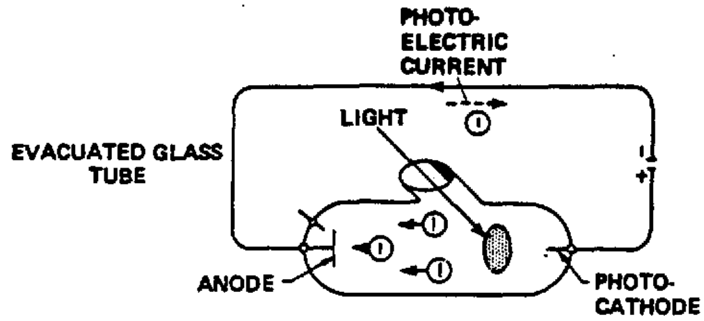
b. Photon Devices (cont)

Photoelectric detectors can be divided into two different types:

(1) Vacuum Photodiode

(2) Photomultiplier tube

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	113



VACUUM PHOTODIODE

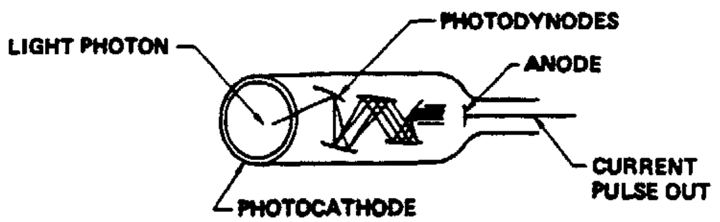
2. Instrumentation (Cont'd.)

   c. Photoelectric

      A single light photon is absorbed by a photocathode and a photoelectron is emitted. This electron is then attracted to a positive anode. The resulting current or voltage can then be measured.

      The light-sensitive photocathode is usually placed inside an evacuated glass tube (see slide). This is called a vacuum photodiode. It has good stability and good range (linearity over large intensity range).

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	114



PHOTOMULTIPLIER TUBE

2. Instrumentation

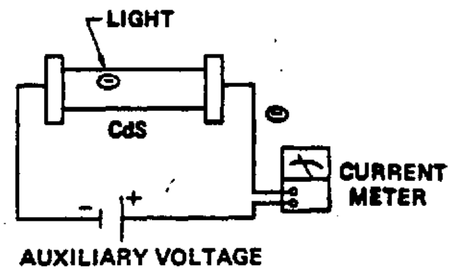
c. Photoelectric (cont)

Photomultiplier Tube

The most sensitive of all the light detectors is the photomultiplier tube (PMT). Similar to the vacuum photodiode, the PMT consists of a photocathode and a positive anode. In addition, however, it contains accelerating photodynodes which amplify the number of electrons emitted from the photocathode (see slide).

Since the photocathode is so sensitive, it can only be used to detect very low power levels (around 10^{-5} watts or less). (There are photomultiplier tubes which are able to detect one photon.) The sensitivity derives from the high gain or amplification that comes from the dynodes; with 13 states, gains of 10^{-6} to 10^{-7} can be realized. There are two major disadvantages; different photocathodes have different spectral responses (dependence on the incident wavelength), and PMT's tend to lack linearity over wide intensity ranges.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	115



DIRECT CURRENT READING

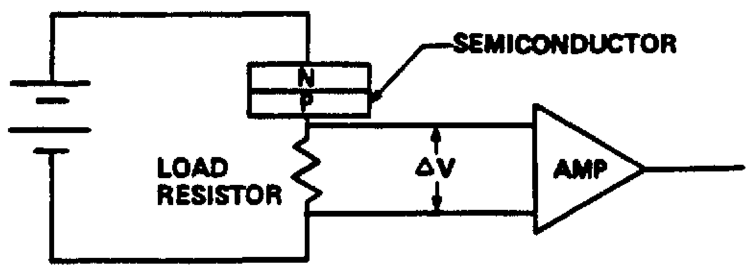
2. Instrumentation (cont)

d. Photoconductive Detector

Photoconductive materials do not generate electricity (electron current) as do the photoelectric devices. Instead, these detectors possess the very useful characteristic of changing resistance when absorbing light. This resistance change may be on the order of millions between light and dark exposures. Characteristic photoconductive cells are cadmium sulphide and cadmium selenide (see slide).

Note that an auxiliary voltage supply is required for the photoconductive detectors. They also are wavelength-dependent.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	116



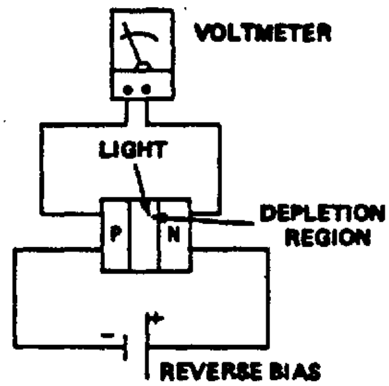
LOAD RESISTOR READING

2. Instrumentation

d. Photoconductive Detector (cont)

The photoconductive effect is the simplest photon effect. When this occurs in a semiconductor the electron is not removed from the material but merely liberated from a particular atom (electrons are moved from the valence band or "doped" electron energy lever into the conduction band). The resistance to electron flow is then greatly reduced, and the conductivity greatly increased. This change in resistance or conductivity can be easily measured. The slide shows voltage measurement across a resistor in series with the semiconductor.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	117



SEMICONDUCTOR PHOTODIODE

2. Instrumentation

d. Photoconductive Detector (cont)

The silicon semiconductor photodiode is another popular detector. The semiconductor silicon acts as a current generator, with the current dependent on the incident light. When a semiconductor is "back-biased" it operates in the photoconductive mode.

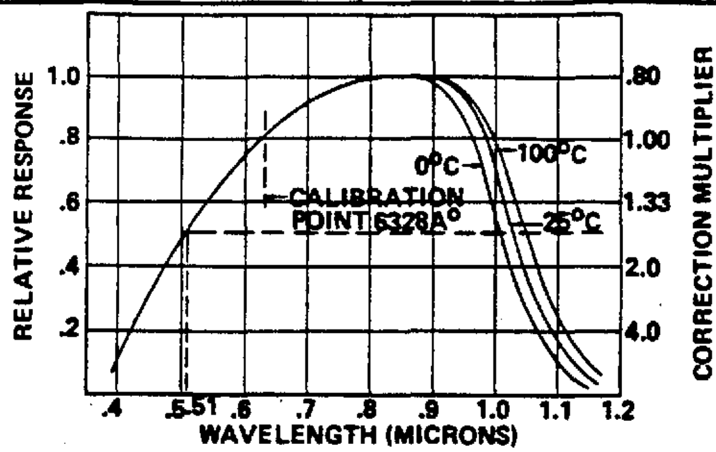
The semiconductor photodiodes are operated with an applied reverse bias (voltage) so that a very low concentration of charge carriers exist at the interface between the two semiconductor regions. When a light photon is absorbed, the charge from the electron-hole pair creation is separated by the applied electric field. This effect produces a measurable voltage across the interface, called the depletion region. Measuring this voltage change gives an indication of the power or energy of the incident light (see slide).

Some of the advantages are: (1) good linearity over seven orders of magnitude; (2) reasonable spectral response, though not good in the ultraviolet region; (3) fast response time with a 4 to 5 nsec rise time and a 10 nsec decay time. The semiconductor photodiode's small size can be advantageous in monitoring small beam areas or fields.

Efficiency is such that power levels down to 50 microwatts can be measured directly without an amplifier.

Some disadvantages are the wavelength dependence and the small area of the detector. For large power densities, filter, gratings, or beam splitters can be used to attenuate the beam (or sample a smaller area) and then calculate the actual power level from the sampled portion.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	118



SPECTRAL RESPONSE OF SILICON CELL

2. Instrumentation

   d. Photoconductive Detector (cont)

      Spectral Response of Silicon Cell

      The slide illustrates a spectral response curve for a silicon cell. Note that the relative response of the cell is strongest in the infrared region around 860 nm (0.86 μm).

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	119

PHOTOVOLTAIC DETECTORS

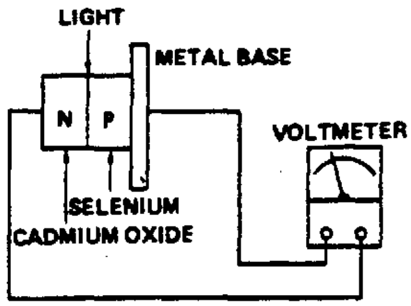
- **PHOTOCELLS**
- **SOLAR CELLS**

2. Instrumentation (cont)

e. Photovoltaic Detectors

All practical photovoltaic cells consist of a junction between two dissimilar semiconductor materials. When light is absorbed at this boundary, an electron will be liberated from an atom, but not ejected from the material (photoconductive effect). There will also be a potential difference arising which can be detected (photovoltaic effect). No battery or electrical power supply is necessary. Photovoltaic detectors may be classified in two ways; photocells and solar cells.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	120



PHOTOCELL

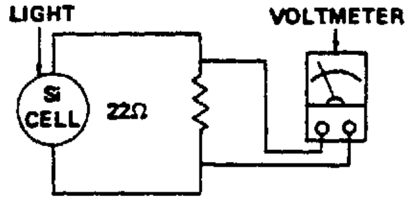
2. Instrumentation

e. Photovoltaic Detectors (cont)

Photocell (Selenium)

Photocell or selenium cells have found widespread application as light meters in cameras and as automatic exposure devices. Cadmium oxide is usually coated on a selenum base, fastened to a metal baseplate. As light is absorbed, a potential difference arises between the cadmium oxide and baseplate which can be measured, as in the slide. The response of the selenium cell to light is similar to that of the human eye.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	121



SOLAR CELL CURRENT MEASUREMENT

2. Instrumentation

e. Photovoltaic Detectors (cont)

Solar Cell (Silicon - A semiconductor)

Another type of cell, used as a source of electrical power for rockets and satellites, is the solar cell. This is made of the most common element on our planet, silicon. In actuality, this can be classified as a photoelectric device since an electron current is generated when light is absorbed. However, since no external voltage supply is necessary, this is usually classified as photovoltaic. The current can be measured directly or as a voltage across a load resistor (see slide).

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	122

THERMAL DEVICES

- CALORIMETERS
- BOLOMETERS
- THERMOCOUPLES

2. Instrumentation (cont)

f. Thermal Devices

Thermal devices measure the effect of heat and temperature changes on materials when absorbing light energy. There are three general categories; calorimeters, bolometers, and thermocouples.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	123

CALORIMETERS

THESE DEVICES ABSORB THE TOTAL LIGHT ENERGY, AND THE CORRESPONDING TEMPERATURE RISE INDICATES THE AMOUNT OF ENERGY ABSORBED.

2. Instrumentation (cont)

g. Calorimeters

Calorimeters absorb the total light energy, and the corresponding temperature rise indicates the amount of energy absorbed. The response time is slow; they should not be used for measurement of rapid trains of pulse since it takes some time for the calorimeters to equilibrate to ambient temperature. Wavelength dependence is determined by the absorbing medium. They are also used as conventional standards in photometry and radiometry.

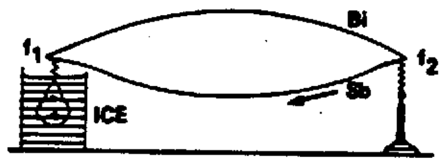
BOLOMETERS

DETECTORS WHOSE RESISTANCE CHANGES WHEN HEATED

2. Instrumentation (cont)

h. Bolometers

Bolometers are detectors whose resistance changes when heated. Measuring this change in resistance provides a means of determining the incident power of the absorbed radiation. The most common bolometer is the thermistor. A thermistor consists of a small bead of semiconducting metal on the end of short lengths of fine wire. As radiation impinges on the bead, the temperature rises, and resistance to electron flow decreases. Measuring the change in resistance (caused by heating the thermistor) is an indication of the incident light energy. The advantages of a thermistor are its uniform response to all wavelengths of light, and its simplicity of operation. The major disadvantage is its very slow response time. Another device similar to the thermistor is the baretter. In a baretter, an increase of temperature causes an increase in resistance.



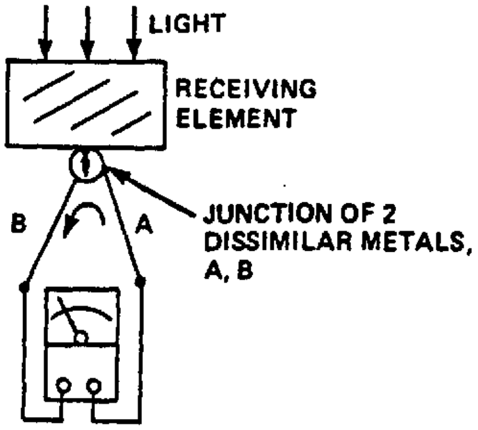
THERMOCOUPLE

2. Instrumentation (cont)

i. Thermocouple

Another thermal device to measure temperature rise is the thermocouple. A thermocouple consists of a pair of junctions between two different metals, such as antimony and bismuth. Since the two metals have different thermal properties, a small voltage difference can be produced when their junctions are at different temperatures. If a closed loop of two dissimilar metals is made, current will be observed to flow around the loop when the junctions are kept at different temperatures. The current will flow across the hot junction, and will depend on the thermal properties of the metals used. In the picture, the current flows from bismuth to antimony. Depending upon the two materials used, the direction of flow follows the order; bismuth, nickel, cobalt, platinum, copper, lead, zinc, cadmium, iron and antimony. Any pair of these metals is called a thermocouple.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	126



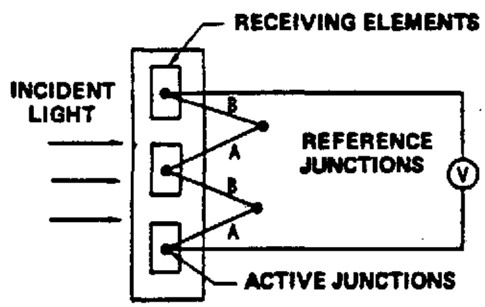
THERMOCOUPLE USE

2. Instrumentation

   i. Thermocouple (cont)

   Normally, the thermocouple is in contact with a receiving element which absorbs the incident radiation (see slide).

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	127



THERMOPILE

2. Instrumentation

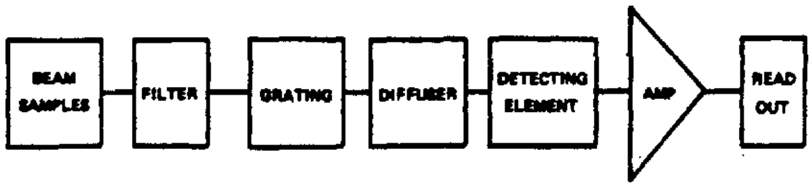
   i. Thermocouple (cont)

   As incident light is absorbed by the receiving element, the corresponding temperature rise is quantitatively measured by the thermocouple, the measured voltage being proportional to the temperature rise. The thermal voltages can be quite small, however, and a larger net voltage can be obtained by connecting several thermocouples in series. This is called a thermopile (see slide). The total thermally produced voltage across the output terminals is the sum of the individual thermocouple voltages. As the receiving elements absorb incident radiation, the temperature of each junction is increased and the thermopile voltage increases accordingly.

   Since the receiver element is quite sensitive, care must be taken; high levels of 1 watt/cm^2 or greater will deteriorate the surface. (Common receiver coatings are goldblack, lampblack and Parson's black.)

   Thermopiles are generally unaffected by the beam orientation, the wavelength of the incident light, the pulse length, or the beam diameter. However, they are not as sensitive as the photon devices.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	128



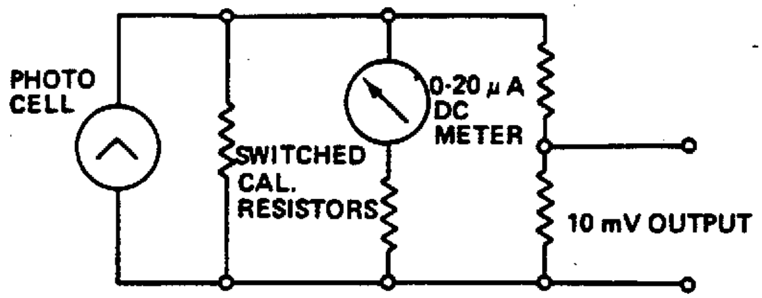
BEAM SAMPLING SYSTEM

2. Instrumentation (cont)

j. Detection Accessories

Several detection accessories are very useful for versatile measurements. (1) Filters can be used to select specific wavelengths; they also attenuate the beam so the full energy of the UV-VIS-IR source does not damage the detector (such as the photodiode detector), (2) The use of filters can be eliminated if the sensing element is coupled with a monochrometer. Monochrometers allow the sensing element to look at single wavelengths and are made using diffraction gratings and prisms. The response of the sensing element is known to the particular wavelengths being monitored, then the irradiance of the source may be calculated by summing the irradiance of the individual wavelength components, (3) When the beam of UV-VIS-IR is small compared to the active detector area, diffusers spread the beam over the entire detector surface, (4) Measuring high power UV-VIS-IR calls for a beam sampler to split the beam and select only a fraction to be incident on the detector. This percentage can then be extrapolated to the total power, (5) Another handy accessory is the ambient light compensator which permits ambient light to be electronically dialed out. The slide shows a possible detection system.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	129



ELECTRICAL CIRCUIT

2. Instrumentation

k. Detection Accessories (cont)

The slide depicts the electrical configuration of a practical detector. Light incident on the photocell will produce a proportional current that can be measured on the 20 microampere DC meter. It should be stressed that most photocells have a strong wavelength dependence, and most instruments are calibrated for only one particular wavelength.

SUMMARY OF DETECTORS

DETECTOR	APPROXIMATE INTENSITY RANGE	COMMENTS
VACUUM PHOTODIODE	0.1 μW – 10 W	BEST STABILITY, WAVELENGTH DEPENDENT
PHOTOMULTIPLIER TUBE	< 10 μ W	MOST SENSITIVE, WAVELENGTH-DEPENDENT, LACK OF LINEARITY OVER INTENSITY RANGES
PHOTOCONDUCTIVE DETECTOR (SILICON BACK–BIASED)	10^{-9} – 10 W	GOOD LINEARITY, WAVELENGTH DEPENDENT, REQUIRES SEPARATE POWER SOURCE
PHOTOVOLTAIC DETECTOR	0.03 – 1000 mW	SELF–POWERED
CALORIMETER	0 – 1 W 1 – 10,000 W 1 – 100 J	COOLED BY AIR, WATER, OR OIL; LABORATORY STANDARD; WAVE–LENGTH RANGE DEPENDS ON ABSORBING SURFACE
THERMOPILE	0.25 W max.	CAN BE WATER–COOLED, NOT AS SENSITIVE AS PHOTON DEVICES STANDARD
BALLISTIC THERMOPILE	10^{-3} – 500 J	LABORATORY STANDARD, WAVE LENGTH RANGE DEPENDS ON ABSORBING MATERIAL

2. Instrumentation

j. Detection Accessories (cont)

This table shows the intensity range and some of the advantages and disadvantages of several commercially available detectors.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	131

DETECTOR TYPE	RESPONSE TIME	WAVELENGTH REGION	SENSITIVITY
Phototube	1 μsec	150 to 1500 nm	Medium
PM Tube	1 μsec	200 to 1000 nm	High
Photoconductivity Cell	10 μsec	350 to 4000 nm	Medium
Photovoltaic Cell	10 μsec	350 to 750 nm	Medium
Phototransistor	< 1 μsec	250 to 1100 nm	Medium
Bolometer	1 msec	1 to 40 μm	Low
Thermocouple	10 msec	1 to 40 μm	Low

2. Instrumentation

j. Detection Accessories (cont)

This slide shows the response time, wavelength region and sensitivity of several types of detectors. The response time varies from 1 sec for the Phototransistor to 10 msec for the Thermocouple. Of interest is the fact that the detectors numbered 1 through 5 all have wavelength regions that detect in 2 or more of the UV-VIS-IR regions.

SUMMARY – ITEMS TO CONSIDER

- SPECTRAL RESPONSE OF THE DETECTOR
- SOLARIZATION AND AGING
- AIR CONTAMINATES
- DIRECTIONALITY
- REFLECTION

2. Instrumentation (cont)

k. Summary

To avoid errors of major magnitude in assessing UV-VIS-IR radiation the following items must be given serious consideration:

a. The spectral output of the specific source being evaluated and the spectral response of the phosphor or phototube that is being utilized in the measurement should be considered. The selection of a meter or phototube should be one that is sensitive in the range most nearly covering that part of the spectrum under consideration.

b. Solarization and aging of lenses, tube envelopes, or cells which can be only determined by calibration against a source of known wavelengths and intensity.

c. Contaminants in the atmosphere may cause absorption of the radiation. For example, water vapor may cause absorption of ultraviolet radiation as well as affecting the electronic circuitry.

d. The directionality response of the meters should be considered especially with the use of phototubes.

e. The reflection of UV-VIS-IR radiation from nearby surfaces can affect most of the phototubes and cells that are presently used for measurement. These factors are of particular importance when measuring an intense wide-band source of UV-VIS-IR radiation.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	EVALUATION OF HAZARDS	133

RADIATION SURVEY

- CHECK INSTRUMENTS FOR OPERATION
- WEAR PROTECTIVE CLOTHING
- INSPECT PROTECTIVE CLOTHING OF OTHER PERSONNEL
- TAKE MEASUREMENTS IN OCCUPIED AREAS
- TAKE MEASUREMENTS OF REFLECTIONS
- MAKE NOTES
- MAKE A SKETCH
- MAKE RECOMMENDATIONS

3. Radiation Survey

   a. The instruments should be checked for response and calibration before entering a hazardous area.

   b. Wear sufficient protective clothing.

   c. Protective clothing of other personnel should be inspected to ensure adherence to requirements.

   d. Take measurements in areas normally occupied by personnel.

   e. Take measurements of reflections from shiny or reflective surfaces.

   f. Complete notes should be taken (such as Where, When, What, How, Who and Why) to aid in making a complete written report.

   g. Make a sketch or take a picture of the area and equipment which shows readings at points of interest.

   h. When readings exceed those outlined (see Section 4 - "Protection Standards") recommend protective screens or shielding. If this is not feasible, then eye and skin protection should be recommended.

PROCEDURE FOR WRITING RADIATION SURVEYS

- IDENTIFICATION
- DESCRIPTION
- TYPE OF SURVEY
- TYPE OF INSTRUMENT
- RADIATION READINGS
- UNUSUAL CONDITIONS
- HIGHEST RADIATION READING
- SIGNATURE

4. Survey Report

a. Procedure for Writing Radiation Surveys

(1) Identification - List the city, street address, building number, room number, date, and the starting time of the survey.

(2) Description - Inform whether the survey is a laboratory survey or operation survey (which lab, what operation, etc.). If it is an operation survey, describe the type of operation that is being surveyed.

(3) Indicate what type of survey you made (UV-VIS-IR).

(4) Indicate the types of instruments used.

(5) Record all relevant readings to the particular survey. These would include all items surveyed, the maximum and minimum dosage rates to personnel, and any unusual conditions.

(6) Explain unusual conditions, background data, final status of area, follow-up procedures required etc. Careful attention should be used.

(7) Record the highest reading detected during the complete survey.

(8) Complete survey form by signing your name.

Remember when you write a survey report, it will tell a story of events. An image will be created in the mind of anyone who reads your survey, but it will be that person's interpretation of what he reads. If your writing is orderly, accurate, concise, and complete. the interpretation will be close to that which you intended.

REASONS FOR WRITING A SURVEY REPORT

1. LEGAL
2. OFFICIAL RECORD
3. NEW DESIGNS
4. PERFORMANCE AND GOALS

4. Survey Report (cont)

b. Reasons for Writing a Survey Report

(1) Records are important legally; they provide legal protection for you and your fellow workers.

(2) It is the only official record of surveying activities.

(3) New design or engineering improvements may depend, to some degree, on survey records.

Personnel who are responsible for designs involving radiation protection problems expect to obtain information and assistance from people who are familiar with those problems. A good written record of activities involving such problems is necessary to back up oral and written recommendations to these people. Since special design features often cost more money, good well-proven reasons must be presented to justify that cost.

(4) These records have a long-range effect on the performance and goals of your operations.

Records provide a reference to past activities. They allow you to check your present performance against what you have done before, and to apply necessary corrective action. They also help you to direct your future activities toward problems which can be predicted on the basis of past experience. Records help to estimate what you can expect to achieve because they tell what has been achieved in the past.

E. PROTECTION AND CONTROL

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	136

WHY PROTECT PERSONNEL FROM THE HAZARDS OF ULTRAVIOLET VISIBLE-INFRARED RADIATION?

- **BIOLOGICAL ASPECTS**
- **DECREASE IN PRODUCTION RATE**
- **LEGAL REQUIREMENTS**

1. General

Why do we protect personnel from the hazards of Ultraviolet-Visible-Infrared radiation? First, there are the biological aspects. In Section B, it was shown that overexposure can result in personal injury. Secondly, personal injury can result in decreased production rates in business and industry. Third, there are federal laws requiring protection of personnel. (These were disucssed in Section C of this lecture.)

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	137

TRAINING AND EDUCATION

- KNOWLEDGE OF HAZARDS
- PROPER PROTECTIVE EQUIPMENT
- RECOGNIZE THE SYMPTOMS
- ASSOCIATED CHEMICAL AND PHYSICAL HAZARDS

2. Education and Training (cont)

b. Employee Information

Inform Employees of Hazards from Exposure to UV-VIS-IR.

Each employee who may be exposed to high intensity artificial sources of UV-VIS-IR should be acquainted with all hazards, relevant symptoms and precautions concerning exposure. This should include:

(1) Information as to the proper eye protection and protective clothing to be used.

(2) Instruction on how to recognize the symptoms of eye and skin damage due to ultraviolet VIS-IR radiation.

(3) Information as to special caution to be exercised in situations where employees are exposed to toxic agents and/or other harmful physical agents which may be present in addition to and simultaneously with, ultraviolet VIS-IR radiation.

An ideal time to acquaint employees of these conditions is during a training course on the operation of the machine or equipment.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	138

MEDICAL PROGRAM

- **MEDICAL HISTORY**
- **RESTRICTED JOB ASSIGNMENT**
- **EXAMINATION**

3. Medical Program

A person's past medical history should be examined to determine if he suffers from any condition that is exaggerated or aggravated by exposure to UV-VIS-IR radiation.

Anyone having a history of such a condition should not be permitted to work in an area exposed to ultraviolet VIS-IR radiation and should be advised that any blemish on the skin or change of vision following acute or chronic exposure to UV-VIS-IR radiation be examined by a physician.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	139

ULTRAVIOLET PROTECTION AND CONTROL

- **SUNSCREENS**
- **PROTECTIVE CLOTHING**
- **BARRIER CREAMS**
- **TRANSPARENT MATERIAL FOR SKIN AND EYE PROTECTION**
- **REFLECTION OF ULTRAVIOLET RADIATION**
- **LABELING**

4. Ultraviolet

a. General

Personnel can be protected from the effects of ultraviolet radiation by shielding of sources of radiation, by goggles or face shields, by clothing, and, for special purposes, by absorbing or reflecting skin creams.

Principles and procedures in selecting suitable protection are summarized in this section, and studies of various protective measures are reviewed. Specific topics discussed are (1) sunscreens, (2) protective clothing, (3) barrier creams, (4) transparent material for skin and eye protection, (5) reflection of ultraviolet radiation and (6) labeling.

SUNSCREENS FOR UV PROTECTION

- CHEMICAL–ABSORB UV
- PHYSICAL–REFLECT UV

4. Ultraviolet (cont)

   b. Sunscreens

Sunscreening preparations are usually classified as chemical or physical. The former include para-aminobenzoic acid and its esters, cinnamates, and benzophenones, all of which act by absorbing radiation so that the energy can be dissipated as radiation of lower energy. The physical agents act as simple physical barriers, reflecting, blocking, or scattering light. They include titanium dioxide, talc, and zinc oxide. Largely because of cosmetic objections, the physical barriers are infrequently used in sunscreen formulations.

Sunscreen protection from absorbing chemicals depends on maintenance of film thickness. Robertson reported that a series of sunscreens of 0.01 mm thickness protected fair skin during four to five hours of sunshine if the protective layer was fully maintained for the whole period. When the thickness of the layer was halved, erythema occurred within a maximum of one hour.

For individuals with chronic photosensitivity diseases, it is desirable to add a light-scattering and reflecting agent (e.g., titanium dioxide, talc, and zinc oxide) in combination with a light absorber in a hydrophilic ointment.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	141

CLOTHING FOR UV PROTECTION

- LONG SLEEVE GARMENTS
- HELMETS
- CAPE
- GLOVES

4. Ultraviolet (cont)

c. Protective Clothing

Long sleeve garments of densely woven flannelette, poplin, or synthetic fabric will give sufficient protection for most ultraviolet radiation. A small cape on the back and sides of the helmets of welders may be necessary during some welding operations. This may also be necessary for other UV sources of similar intensity. When the ultraviolet radiation is severe enough to burn the skin through these materials, then leathers and/or asbestos should be used for protection.

Gloves of densely woven material as mentioned above are adequate for most ultraviolet sources where flame or arc flashes are not of concern. Asbestos gloves are recommended when working close to flame or high ultraviolet sources that can burn the skin.

CAUTION

Synthetic clothing fibers can melt or catch fire and thereby cause severe burns. Clothing of synthetic fibers should be flame resistant.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	142

ULTRAVIOLET TRANSMISSIVITY OF FABRICS

Material	Transmissivity, %
Batiste, white (Muslin)	50
Cotton voile	37–43
Kapron	31
* Crepe de Chine (1. grey)	22.5
Kapron and Nylon	26.6
Nylon	25–27
Silk stockings	25
Cotton stockings	18
Stockinet	14–16.5
Linen, white, coarse	12
Rayon stockings	10.5
Satin, beige	10
Linen cambric	8–8.5
Rayon (linen type)	3.8–5.3
Wool stockinet	1.4–2.8
Flannelette	0.3
Poplin	0

* Data based on Morikofer,[146] Pleiderer[147] and Voznesenskaia[148]

4. Ultraviolet

c. Protective Clothing (cont)

The ultraviolet transmission of various fabrics is shown in the above chart. These range from 50% transmission for ~~mulsin~~ muslin down to 0.3% for flannelette and 0% for poplin.

BARRIER CREAMS FOR UV PROTECTION

- **PARAFFIN**
- **BENZOPHENONES**
- ZINC OXIDE

4. Ultraviolet (cont)

   d. Protective Creams

   Where it is impossible to shield the skin by clothing, gloves, masks, shields or by redirecting the radiation by suitable reflectors, a barrier cream should be applied to the skin before irradiation. Ordinary soft paraffin is an excellent barrier, but its greasiness will often preclude its use on hands. Barrier creams contain ingredients which absorb ultraviolet radiation. The benzophenones are the best compounds for this purpose because of their great absorption capability throughout most of the near and far ultraviolet spectrum.

   Zinc oxide absorbe UV readily, and is used in many protective creams.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	144

TRANSPARENT MATERIAL FOR SKIN AND EYE UV PROTECTION

- **COMMON WINDOW GLASS**
- **PROTECTIVE GLASSES**

4. Ultraviolet (cont)

   e. Transparent Material

   Transparent material for skin and eye protection include common window glass (for low intensity UV sources) and protective glasses (high intensity UV sources).

COMMON WINDOW GLASS

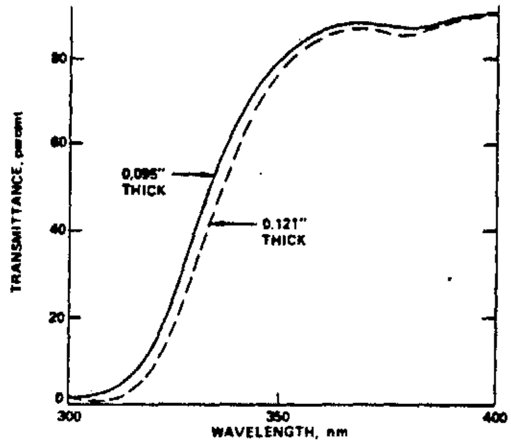
- THICKNESS OF 2 MM OR GREATER
- PRACTICALLY OPAQUE TO UV WAVELENGTHS SHORTER THAN 300 NM

4. Ultraviolet

e. Transparent Material (cont)

For protection of the eyes and skin from limited exposure to ordinary ultraviolet lamps, common window glass is usually adequate. Ordinary window glass in thickness of 2 mm or more is practically opaque to ultraviolet radiation of wavelengths shorter than 300 nm. Thus an ordinary window pane, although it emits much of the incident visible radiation, excludes practically all the ultraviolet wavelengths of the erythemal and therapeutic ranges.

TRANSMITTANCE OF WINDOW GLASS TO UV



TRANSMISSION FOR TWO THICKNESSES OF WINDOW GLASS

4. Ultraviolet

e. Transparent Material (cont)

The chart shows the percent transmission as a function of wavelength for two thicknesses of window glass. As can be seen from the curve, the transmission falls off rapidly with wavelength below 360 nm. Window glass 1/8 inch in thickness is adequate protection for the eyes and skin against ultraviolet radiation from ordinary ultraviolet sources. In the case of very intense sources of ultraviolet radiation, it may not be sufficient.

15	INFRARED RADIATION ULTRAVIOLET VISIBLE &	PROTECTION AND CONTROL	147

PROTECTIVE GLASSES FOR UV

- STRONG ABSORBERS OF UV
- MANY ARE ALSO STRONG ABSORBERS OF VISIBLE AND INFRARED RADIATION

4. Ultraviolet

e. Transparent Material (cont)

Protection of the eyes in industrial applications such as welding requires materials which are strong absorbers of ultraviolet radiation. A large number of protective glasses have been developed for this purpose. Many of them also absorb strongly in various portions of the visible and infrared regions. The earliest of these glasses was developed almost 60 years ago, and subsequently, many others have been developed. Their characteristics are described in "Spectral-Transmissive Properties and Use of Eye Protective Glasses" by R. Stair.

Glass workers, arc welders and people engaged in similar types of work may be exposed to infrared radiation as well as ultraviolet radiation, and may need eye protection from both types of radiation. Such people should wear goggles with an infrared absorbing glass and an infrared reflecting surface. Ordinary glass, plastics and other materials are usually transparent to infrared rays which can cause thermal damage to the eye. A glass that absorbs in both the ultraviolet and infrared regions of the spectrum will be needed in such cases. For listings of absorbing glasses refer to ANSI-Z 49.1. A chart showing the transmittances for various absorptive lenses, filter lenses and plates is presented in Section 7.

PROTECTION AGAINST 253.7 nm UV

- UV ABSORBING PLEXIGLASS
- ORDINARY (GLASS) SPECTACLES
- FLINT GLASS

4. Ultraviolet

e. Transparent Material (cont)

Full protection against 253.7 nm radiation is provided by shields of clear ultraviolet-absorbing plexiglass, ordinary (glass) spectacles, crookes glass, and similar ultraviolet-absorbing materials. Crown glass, an alkali-lime silicate glass, (2 mm-thick) will significantly reduce exposure hazards. Flint glass, a heavy glass containing lead oxide, (2 mm-thick) affords essentially complete protection at all wavelengths. Noviol glasses or Polaroid ultraviolet filters can be used where high intensity ultraviolet is anticipated, as in welding.

REFLECTANCE OF 253.7 nm RADIATION FROM VARIOUS SURFACES

Material	% Reflectance *
Aluminum, etched	88
Aluminum foil	73
Chromium	45
Nickel	38
Stainless steel	20–30
Silver	22
Tin—plated steel	28
White wall plaster	40–60
White paper	25
White cotton	30
White oil paints	5–10
White porcelain enamel	5
Glass	4
Water paints	10–30

* Values obtained at normal incidence. The percentage reflectance increases rapidly at angles greater than 75%.

4. Ultraviolet (cont)

f. Reflection of Ultraviolet Radiation

If an individual is working in a room with an ultraviolet source for any length of time, he should wear protective glasses or a face shield because many materials reflect 253.7 nm radiation as shown in the chart.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	150

REFLECTION OF ULTRAVIOLET RADIATION

- GLASS
- POLISHED METAL
- HIGH-GLOSS SURFACES

4. Ultraviolet

f. Reflection of Ultraviolet Radiation (cont)

When a number of ultraviolet generators are operating in one room, protection of personnel poses several problems. In many applications, little difficulty is encountered in properly shielding the source so that most, or all, of the output is restricted to the exposed material. Stray radiation can be reduced, but reflection from glass, polished metal, and high-gloss ceramic surfaces can be harmful to people working in the room. Absorption of ultraviolet radiation therefore becomes an important item to consider in planning a safe work environment.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	151

THE BASIC REQUIREMENTS WHICH DETERMINE THE REFLECTING POWER OF AN ULTRAVIOLET REFLECTING PAINT ARE:

- PIGMENT PARTICLES
- BINDER OR VEHICLE
- REFRACTIVE INDEX

4. Ultraviolet

f. Reflection of Ultraviolet Radiation (cont)

Since painted walls and ceilings can be a significant source of ultraviolet reflection, it is necessary to consider the ultraviolet reflective properties of the paint used.

The basic requirements which determine the reflecting power of an ultraviolet-reflecting paint are:

(1) Particles of the pigment must be low in absorption (except metallic pigments), so that a large portion of the incident radiation is returned by multiple reflection and refractions.

(2) The binder or vehicle must be transparent to the radiation to be reflected.

(3) The difference in refractive index between pigment and medium must be large so that reflection and refraction at pigment-medium interfaces will be appreciable.

The properties of a paint depend upon the nature and amount of the pigment and the state of its aggregation. The addition of a small amount of colored pigment to a white paint may result in a large decrease in the ultraviolet reflection. The reflectance decreases with increase in amount of added colored pigment.

REFLECTION OF WHITE PIGMENTS AND OTHER MATERIALS*

	2537Å in Percent	2967Å in Percent	3650Å in Percent	Visible Light in Percent
Pressed Zinc Oxide	2.5	2.5	4	88
Barytes	65	70	77	86
Titanium Oxide	6	6	31	94
Pressed Magnesium Oxide	77	88	87	93–95
Smoked Magnesium Oxide	93	83	94	95–97
Pressed Calcium Carbonate	78	83	86	96
White Wall Plaster	46	65	76	90
SW White Decotint Paint	33	41	58	79
Kalsomine White Water Paint	12	20	40	70
Albastine White Water Paint	10	14	45	78
White Porcelain Enamel	4.7	5.4	63	80
Flat Black Egyptian Lacquer	5	5	5	5
Five Samples of Wallpaper	18–31	21–40	33–50	55–75

* M. Luckiesh Applications of Germicidal, Erythemal and Infrared Energy, New York, D. Van Nostrand Company, 1946, page 383.

4. Ultraviolet

f. Reflection of Ultraviolet Radiation (cont)

The reflection of incident ultraviolet radiation from pigments can range from negligible to more than 90%. A given material's ability to reflect visible light is no indication of its ability to perform similarly with ultraviolet. The chart gives the reflection from a number of white pigments and other materials at several wavelengths in the ultraviolet. It also shows that ordinary white wall plaster has a reflection of 46% at 253.7 nm, whereas zinc and titanium oxides, which are equally good reflectors for visible light, reflect only 2.5% and 6%, respectively, at this wavelength.

Oil-vehicle paints usually have low reflectances because of the absorption by the oil. However, some paints using synthetic plastic vehicles with high ultraviolet transmission may have high reflectances. Walls surfaced with gypsum products tend to have high reflectances.

ULTRAVIOLET REFLECTANCE OF DRY WHITE PIGMENTS*

Pigment	Ultraviolet Reflectance Factor in Percent
Lead—free zinc oxide	3
35% leaded zinc oxide	4
Zinc sulfide	6
Titanox B	6
Titanium oxide	7
Titanox C	7
Lithopone	8
Antimony oxide	17
Zirconium oxide (commercial)	41
Diatomaceous silica (Celite 110)	46
Basic sulfate white lead	48
China clay	54
Aluminum oxide	56
Basic carbonate white lead (Dutch process)	62
Aluminum hydroxide	67
Zirconium oxide, C.P.	78
Magnesium carbonate (commercial)	81

* D. F. Wilcock and W. Soller: Ind. Eng. Chem. 32: 1446, 1940.

Note: Lead—based pigments must not be applied where their use might result in ingestion; lead—based pigments will be limited in paints for the home by Food and Drug Administration regulations.

4. Ultraviolet

f. Reflection of Ultraviolet Radiation (cont)

No assumptions regarding the reflections of white pigments should be made without investigating their composition. The reason for this is demonstrated by the difference between two white pigments, zinc oxide and white lead. Although both of the pigments are very good reflectors of visible radiation, zinc oxide reflects only 3% of the ultraviolet, whereas white lead reflects about 60%. Colored pigments are almost invariably poor reflectors of ultraviolet. Stutzl studied 38 colored pigments and found that only turquoise blue had a reflectance of as much as 25% at 331.1 nm. At 253.6 nm turquoise blue had a reflectance of 22%, whereas none of the others exceeded 7.5%.

The chart shows the ultraviolet reflectance of a number of dry white pigments in the region between 280 and 320 nm. These measurements were made with the unresolved radiation from a S-1 lamp as a source and a cadmium phototube as a detector. These measurements may be assumed to be predominantly at the wavelength 302.4 nm.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	154

ULTRAVIOLET PROTECTIVE MEASURES AGAINST SUNLIGHT

- PROTECTIVE CLOTHING
- FACE AND NECK PROTECTION

4. Ultraviolet (cont)

   g. Sunlight

   Susceptible persons working outside in strong sunlight should be protected. Protective clothing, such as long-sleeved shirts, trousers or skirt, and face and neck protection will normally be adequate. Face and neck protection can be afforded by a broad-brimmed hat, by a billed hat or cap, or by a neck shield (if the neck is not protected by hair). Hard hats may have bills or face shields to protect the face, and may have neck shields. Alternatively, face and eye protection can be achieved by barrier creams and goggles or spectacles.

ULTRAVIOLET PROTECTIVE MEASURES FOR LOW INTENSITY SOURCES

- SPECTACLES, GOGGLES OR SHIELDS
- LIGHT-WEIGHT CLOTHING
- ABSORBING CREAMS

4. Ultraviolet (cont)

h. Low-Intensity Ultraviolet Sources

Examples of sources of low-intensity ultraviolet radiation are low-pressure mercury vapor lamps, sunlamps, and black-light lamps.

Glass or plastic (1/8 inch thick or greater) spectacles, goggles or shields provide adequate eye protection. Skin can be protected by light-weight clothing, by absorbing skin creams containing benzophenones or p-aminobenzoic acid, or by barrier creams containing titanium dioxide or zinc oxide.

ULTRAVIOLET PROTECTIVE MEASURES FOR HIGH INTENSITY UV SOURCES

- GOGGLES, FACE SHIELDS, MASKS
- CLOTHING OF DENSELY WOVEN FIBERS
- BARRIER CREAMS
- LOW REFLECTIVE MATERIALS

4. Ultraviolet (cont)

i. High-Intensity Ultraviolet Sources

Examples of high-intensity ultraviolet sources are high-pressure mercury vapor lamps, high-pressure xenon arcs, xenon-mercury arcs, carbon arcs, plasma torches and welding arcs.

For eye protection, workers shall wear goggles, face shields or masks. For shade required for this eye protection, consult Section 7 of the American National Standards Institute Z49.1-1967 (ANSI Z49.1). However, in some welding operations such as gas-shielded arc welding, workers with inadequate visual acuity may have to wear a shade of less absorbence (greater transmission) to facilitate their locating the electrodes and prevent starting the arc before putting their masks or goggles in place; eye protection must be used at all times while the arc is operating, and, if necessary in order to see the operation, shade 8 may be used in place of a shade of greater absorbence.

Skin must also be protected. Clothing of densely woven flannelette, poplin, or synthetic fabric will give sufficient protection. Facial skin can be protected by face shields of shades specified in ANSI Z49.1 or by barrier creams containing titanium dioxide or zinc oxide.

Because many synthetic clothing fibers can melt or catch fire and thereby cause severe thermal burns, clothing of synthetic fibers should be flame-resistant if operations involve great heat, sparks, or flame.

Welder's helpers and others working nearby may also require protection and shielding, such as the welder's booth to guard against accidental exposure of other people. Reflection from lamp housings, walls, ceilings, and other possible reflective surfaces should be kept to a minimum by coating such surfaces with a pigment-based paint of low ultraviolet reflectance. Where such shielding and non-reflective surfaces are not used, welder's helpers and others near the welding operation should wear protective clothing, skin creams, gloves, goggles, or face shields.

RADIATION SOURCE	LAMP OR INSTRUMENT	HOUSING	WORK AREA	CONTAINER (SHIPPING OR STORAGE)
1. LOW PRESSURE MERCURY	YES	YES	NO	YES
2. SUNLAMP	YES	NO	NO	YES
3. BLACK LIGHT LAMP	NO	NO	NO	NO
4. PRESSURE TYPE ARC LAMPS*	NO	YES	YES	YES
5. OPEN AREAS* AND INCANDESCENT SOURCES	NO	YES	YES	YES
6. WELDING	YES	–	YES	YES
7. PLASMA TORCHES	YES	YES	YES	YES
8. OTHER ARTIFICIAL UV GENERATING SOURCES	YES	YES	YES	YES

* LAMPS CANNOT BE LABELED BECAUSE OF THEIR HIGH OPERATING TEMPERATURES.

4. Ultraviolet (cont)

j. Labeling

All sources, work areas, and housings specified in the above chart shall carry the following warning:

CAUTION

HIGH INTENSITY ULTRAVIOLET ENERGY

PROTECT EYES AND SKIN

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	158

VISIBLE PROTECTION AND CONTROL MEASURES

- NATURAL EYE RESPONSE
- EYE PROTECTION FILTERS

5. Visible

The visible light range presents little biological hazard except possibly to the eye. When considering eye protection measures, two items should be considered. First, the natural eye response to high intensity light and secondly, eye protection filters.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	159

NATURAL EYE RESPONSE

- CONSTRICTION OF THE PUPIL
- BLINK REFLEX

Normally, intense bright sunlight causes maximal constriction of the pupil, thus reducing the energy density on the retina. The bright sunlight, furthermore, causes painful photophobia which will not permit prolonged direct and fixed observation of the sun. The lid reflex (approximately 150 ms) is another mechanism to protect the eye. The continuous action of these measures would be adequate under normal conditions to avoid burn injuries to the retina.

EYE PROTECTION FOR INTENSE VISIBLE LIGHT

- **SHADE**
- **OPTICAL DENSITY**

5. Visible (cont)

Eye protection filters for glass workers, steel and foundry workers, and welders were developed empirically; however, optical transmission characteristics are now standardized as shades and specified for particular applications. Although maximum transmittances for ultraviolet and infrared radiation are specified for each shade, the visual transmittance or visual optical density D defines the shade number S.

(A chart showing the visible transmittance was presented earlier.)

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	161

INFRARED PROTECTION AND CONTROL MEASURES

- EYE PROTECTION
- SKIN PROTECTION

6. Infrared

Two areas of concern regarding exposure to infrared radiation, especially between the wavelengths of 700 to 1400 mm, are the eyes and skin.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	162

EYE PROTECTION FOR INFRARED RADIATION

- SHADE
- TRANSMITTANCE

Eye protection against certain infrared radiation can be provided by the use of protective filters and lenses. (A chart showing the shade number and transmittance of various lenses is presented.)

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	163

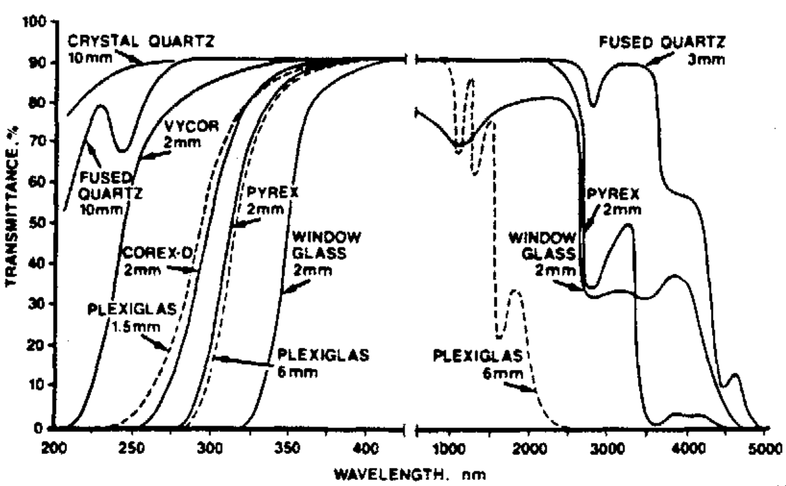
SKIN PROTECTION FOR INFRARED RADIATION

- **LIGHT WEIGHT CLOTHING**
- **SHIELDS**

6. Infrared (cont)

Skin exposure to infrared radiation is primarily thermal in nature. Personnel should: wear light-weight cotton clothing; prevent exposure to radiant heat sources with a shield placed close to, but not touching, the hot object; and use a highly reflective surface, such as unpainted aluminum.

15	ULTRAVIOLET VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	164



7. Summary of UV-VIS-IR Window Shields

Chart 164 shows the transmittance of a variety of commonly used protective window materials over the range 200 nm—5000 nm.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	165

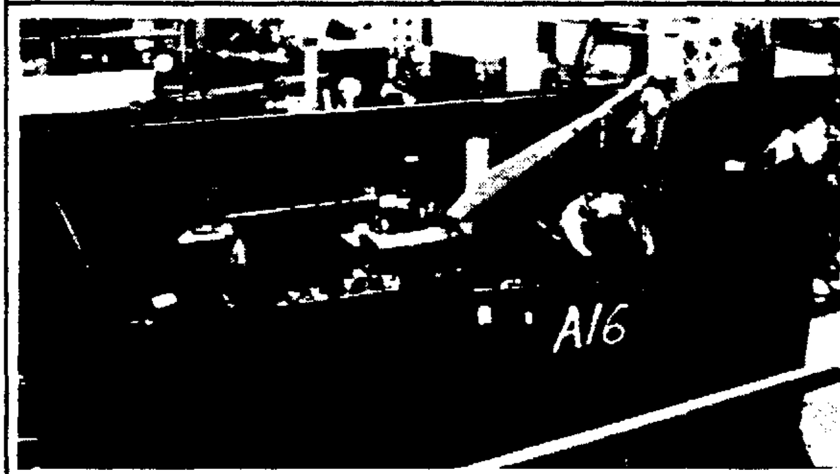
7. Facility Design

a. Weld Screens

This slide shows the use of protective weld screens around MIG operations.

NOTE: The perimeter wall in the background is painted black.

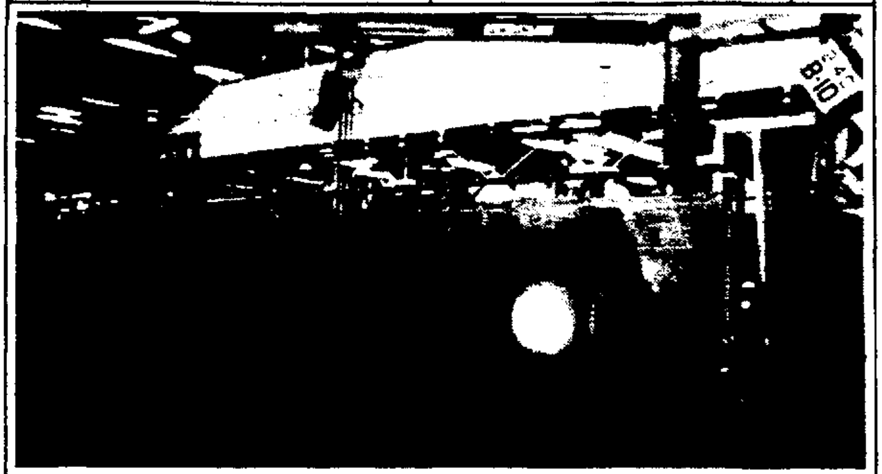
15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	166



b. Protective Weld Screen

In this slide we have men working in close proximity to each other. Notice the use of the weld screen in this situation.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	167

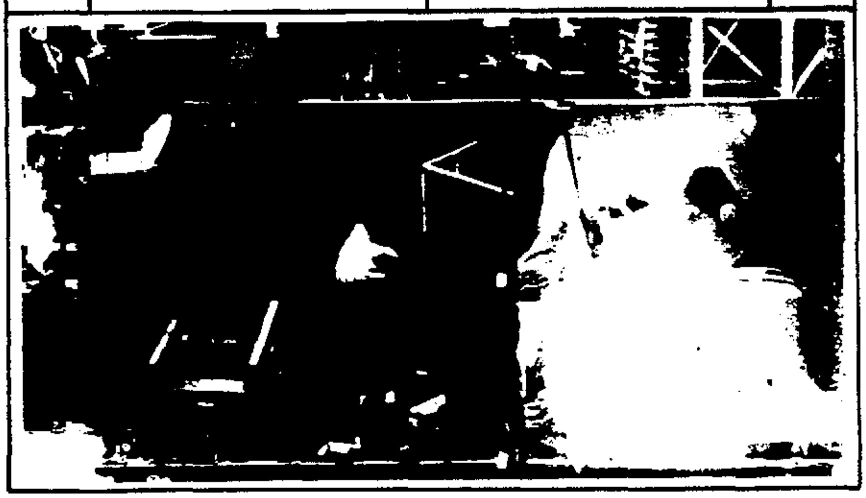


7. Facility Design (cont)

c. Welding Curtains

This slide shows yellow plastic weld protection curtains which are in limited use.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	168



d. Portable Weld Screen

Here we have table top operations where several men are working with the aid of portable screens.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	169

7. Facility Design (cont)

e. Head Cutting Torch

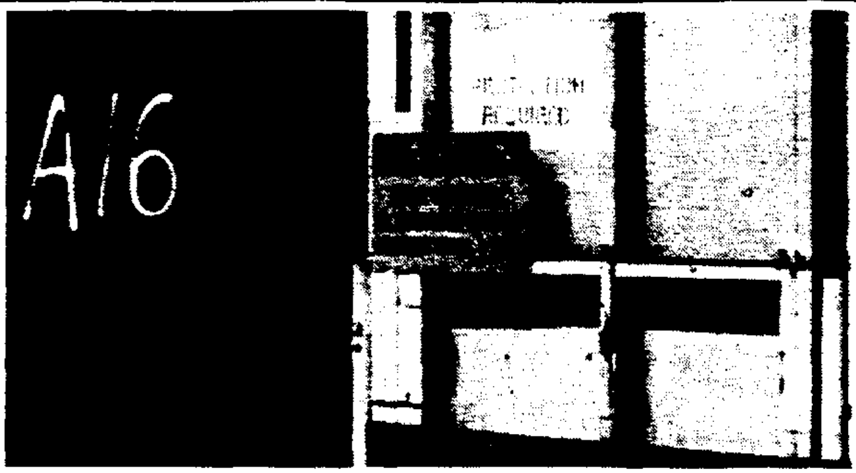
In this slide the operator is wearing tinted eye goggles and a long sleeved shirt.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	170

f. Single Cutting Torch

Here we have a single cutting torch where the operator is located closer to his work. Operator is wearing eye goggles, gloves, leather apron, and not showing through the sparks are leather covering his shoes.

15	ULTRAVIOLET, VISIBLE & INFRARED RADIATION	PROTECTION AND CONTROL	171



7. Facility Design (cont)

g. Caution Sign and Screening

This caution sign and weld screen at the entrance give ample warning and control of the potential hazard.

VIDEO DISPLAY TERMINALS

- LOW X-RAY LEVELS
- VERY LOW R.F. LEVELS (DETECTION LIMITS)
- VERY LOW UV, IR, VIS LEVELS
- MAGNETIC FIELDS?
- LOW CHEMICAL TOXICITY
- POOR ERGONOMICS
- HIGH STRESS

Make B+W insert

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3. Lewis R. Koller, Ph.D., *Ultraviolet Radiation, First and Second Editions*, John Wiley and Sons, Inc.

4. *A Review of Selected Bioeffects Thresholds for Various Spectral Ranges of Light*, U.S. Department of Health, Education, and Welfare, Public Health Service, Food and Drug Administration, Bureau of Radiological Health, Rockville, Maryland, 20852.

5. "Human Exposure to Non-Ionizing Radiant Energy — Potential Hazards and Safety Standards," S. M. Michaelson, Proc. IEEE, pp. 369—421, April 1972.

6. Non-Ionizing Radiation Guide Series — American Industrial Hygiene Association. (Several Concepts and Ultraviolet Radiation)

7. Carcinogenic Properties of Ionizing and Non-Ionizing Radiation, Vol. I, Light, IR, UV, NIOSH Report.

REFERENCES - A PARTIAL LIST

"A Radiation and Industrial Hygiene Survey of Video Display Terminal Operations", by William Murray, Eugene Moss, Wordie Parr and Clinton Cox (NIOSH), Human Facors, 1981, Vol 23(4), p 413. VDT operators are not being exposed to hazardous levels of radiation.

"Electromagnetic Emission from Visual Display Units: a Non-hazard", by M.L.Wolbarsht, et al., SPIE Vol. 229, Ocular Effects of Non-Ionizing Radiation (1980), p 187.

"Carcinogenic Properties of Ionizing and Non-Ionizing Radiation", Vol.I - Optical Radiation, NIOSH Publication 78-122.

"Determination of Ocular Threshold Levels for Infrared Radiation Cataractogenesis", NIOSH Publication #80-121, June 1980

29CFR1910.132-134, Subpart I - Personal Protective Equipment (for eyes, face extremities, etc of workers with non-ionizing radiation and other hazards).

"What Happens to the Human Lens in Cataract", Scientific American, Dec. 1975; still a good article on cataractogensis.

LESSON PLAN NO. 16
LASERS I

OBJECTIVES

16	LASERS I	OBJECTIVES	1

AT THE END OF THIS SESSION YOU WILL BE ABLE TO DEMONSTRATE YOUR KNOWLEDGE OF:

1. **THEORY OF LASER OPERATION**
2. **LASER CHARACTERISTICS**
3. **LASER HAZARDS**
4. **CONTROL OF LASER HAZARDS I (ANSI Z136.1 – 1976 ON THE SAFE USE OF LASERS)**

16 LASERS

At the end of this two hour presentation you will be able to demonstrate, in a problem session, your grasp of the following subjects.

1. Theory of laser operation

2. Characteristics of lasers

3. Laser Hazards

4. Control of Laser Hazards Using the ANSI Standard for Safe Use

   Session 17, Lasers II, will cover Industrial Uses of Lasers more on the Control of Laser Hazards and a Summary

Lasers are finding ever increasing application in our every day life and there is much concern over the rapidly growing number of people who are subject to the hazards of laser radiation. Lasers are already being used in communications, precision measurements, radar systems (lidar), guidance systems, range finding, metal working, photography, holography, and medicine.

Although high-powered laser systems are capable of causing serious and permanent injury, the hazards associated with their operation can be avoided by a basic understanding of their operation and the exercise of proper precautions.

16	LASERS I	THEORY OF OPERATION	2

ELECTROMAGNETIC ENERGY

WAVE CONCEPT

PARTICLE CONCEPT

1. Basic Principles

   a. Review

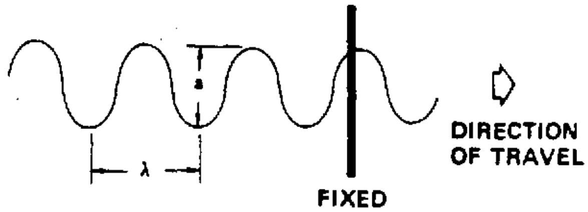
Earlier in this course we discussed the two modes of description of light, the photon and the wave concepts. In considering laser operation and hazards we shall use both of these concepts. Recall that each description of electromagnetic radiation explained certain phenomena most readily: (1) The wave nature of light is most apparent in explaining how light propagates through space, moves through apertures, or reflects from surfaces; (2) The photon nature of light is involved in explaining how the light is generated and absorbed in atoms or molecules.

Both explanations are a part of a more comprehensive view of nature, including the Quantum Theory of Radiation. The two concepts are neither equivalent nor contradictory but rather conplementary.

A. THEORY OF LASER OPERATION

16	LASERS I	THEORY OF OPERATION	3

WAVE CONCEPT



WAVELENGTH, λ
FREQUENCY, f
VELOCITY, v
AMPLITUDE, a

1. Basic Principles

   a. Review

   The wave nature of light is seen in the observable fact that light travels as oscillatory, or vibrating, electric and magnetic fields, having wavelength velocity and frequency. The velocity of the wave in free space is 3×10^8 m/sec; velocity in any medium is determined by the magnetic and electrical properties of the medium.

   Frequency is the number of vibrations, or wave cycles, passing a fixed point per second. Wavelength is the distance between corresponding points on two successive cycles. The amplitude of an electromagnetic wave is a measure of the electric field strength. It is the force that a charge such as an electron would feel from the field.

16	LASERS I	THEORY OF OPERATION	4

PHOTON CONCEPT

ELECTROMAGNETIC RADIATION AS PHOTONS
TRAVELING AT SPEED OF LIGHT

$$E = hf$$

E = ENERGY OF PHOTON
h = PLANCK'S CONSTANT
f = FREQUENCY

1. Basic Principles

   a. Review

   The photon concept views light as bundles of energy, consistent with observations on how light is generated and absorbed in atoms. The relationship between the energy of a photon and the wavelength of the associated light wave is

   $$E = hc/\lambda = hf,$$

   where:

   E = photon energy
   h = Planck's constant (6.0×10^{-33} joule-sec)
   f = frequency
   λ = wavelength
   c = velocity of light (3×10^{8} m/sec)

   In understanding how lasers operate we shall use the concept of transitions between atomic or molecular states in which the energy emitted as photons.

16	LASERS I	THEORY OF OPERATION	5

ELECTROMAGNETIC SPECTRUM

UV:	UVC.	100 - 280 nm	200 - VACUUM
	UVB.	280 - 315 nm	ACTINIC
	UVA.	315 - 400 nm	BLACK LIGHT
VISIBLE:			
	400 - 700 nm		VISIBLE LIGHT
INFRARED:			
	IRA.	700 - 1400 nm	NEAR I. R.
	IRB.	1400 - 3000 nm	FAR I. R.
	IRC.	3000 - 10^6 nm	FAR I. R.

1. Basic Principles

a. Review (contd.)

Laser radiation falls in the ultraviolet (UV), visible, and infrared (IR) regions of the electromagnetic spectrum. The UV and IR regions are further divided for convenience; the wavelength ranges are somewhat arbitrary.

For the purpose of this course the word "laser" refers to coherent optical sources emitting visible (400 to 700 nm) infrared (700 mm to 1 mm) and/or ultraviolet 200–400 nm) radiation. Although very high intensities from lasers have been known to produce ionization in air and other materials, laser radiation should not be confused with ionizing radiation (i.e. X-rays and gamma rays).

16	LASERS I	THEORY OF OPERATION	6

DEFINITIONS

LASER	LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION
MASER	MICROWAVE AMPLIFICATION BY STIMULATED EMISSION OF RADIATION
COHERENT:	WAVES IN PHASE IN SPACE AND TIME

1. Basic Principles (contd.)

b. Definitions

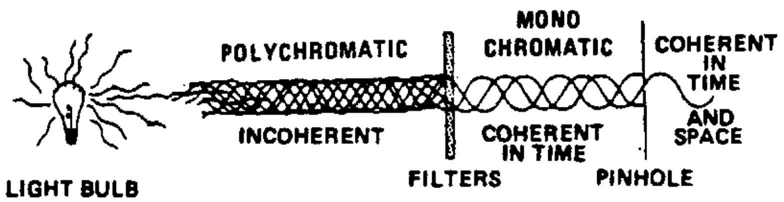
The term "laser" is an acronym standing for "Light Amplification by Stimulated Emission of Radiation." Thus the laser is a device which produces and amplifies light. The mechanism by which this is accomplished, stimulated emission, was postulated by Einstein in 1916 but has only recently been applied. The light which a laser produces is unique, for it is characterized by properties which are very desirable but almost impossible to obtain by any other means.

Likewise the term "maser" stands for "Microwave Amplification by Stimulated Emission of Radiation." The operation of a maser is analogous to that of a laser except that radiation from a different portion of the electromagnetic spectrum is used. Masers were the predecessors of lasers.

The unique characteristic of laser light is that the waves emitted are "coherent," i.e.. they are in phase in space and time. Thus they are intense, since the electric and magnetic fields of the waves add; and they are monochromatic, or are composed of waves of a single wavelength. (Lasers with several monochromatic lines, of course, also exist. The point is that laser light consists of very narrow bands of wavelenths, usually with one such line prominent.

16	LASERS I	THEORY OF OPERATION	7

INCOHERENCE - COHERENCE



1. Basic Principles (contd.)

   e. Incoherent and Coherent Radiation

   We defined "coherence," a characteristic of laser light, as the condition where the light waves are in phase in both space and time. Most commonly observed light is incoherent.

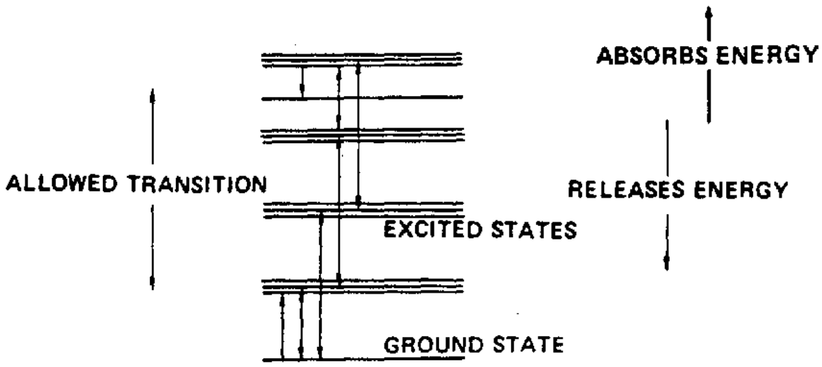
   An ordinary electric light bulb is an example of the atomic emission of radiation. An electric current passing through the tungsten filament heats the tungsten atoms, causing them to vibrate violently and collide with one another. Many of the atoms absorb the collision energy, and are raised in energy to any of the allowed excited states. When the electrons de-excite back to a lower energy level, electromagnetic radiation in the form of light is emitted. As might be expected from the disordered way the light was created and the number of excited states, the radiated light is a mixture of frequencies, directions, and phases. It is incoherent.

   Most light sources are incoherent. If an ideal filter is placed in the incoherent light, only one frequency emerges from the filter, the other frequencies are absorbed or reflected. The light from the filter is monochromatic, or of only one color. Monochromatic light is coherent in time. The light is all of the same frequency, but not in phase.

   Monochromatic light passed through a single hole of the appropriate size is all of one phase. The light is now coherent in both time and space. True coherence requires both temporal and spatial coherence. In the example, however, to obtain coherent light from the incandescant bulb involved filtering and absorbing most of the light energy from the beam, leaving only a very small intensity coherent beam.

16	LASERS I	THEORY OF OPERATION	8

ALLOWED TRANSITIONS BETWEEN STATES



NOT ALL TRANSITIONS ARE ALLOWED

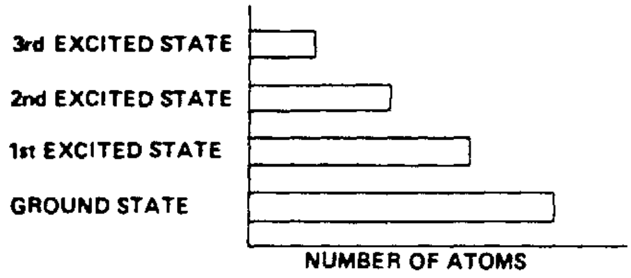
1. Basic Principles (contd.)

   c. Distribution of Energy States in Atoms

   Typically an atom or molecule has a number of possible energy states, although it can be in only one state at a time. Transitions may occur between various states; if energy is absorbed by the molecule, it jumps to a higher energy state; when energy is lost or emitted by a photon, it jumps to a lower, or less excited, state. The lowest energy state a molecule can have is called the ground state. Generally each electronic orbital state has a number of closely spaced substates that represent different vibrational and/or rotational energies. Not all transitions are allowed to occur by photon processes. These "forbidden" transitions between states can occur only rarely, or may occur as a result of collisions.

16	LASERS I	THEORY OF OPERATION	9

POPULATION DISTRIBUTION AS
A RESULT OF THERMAL MOTION



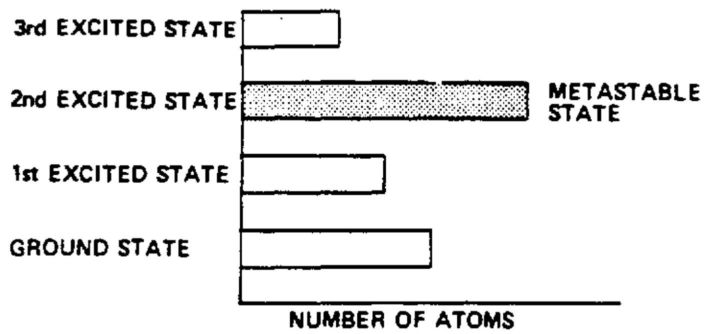
1. Basic Principles

   c. Population Inversion (contd.) (2) Normal Energy State Distribution

      Atoms normally occupy the lowest available, or ground, state. However, due to thermal motions and random collisions with other atoms and molecules, some atoms/molecules exist in exicted states. As temperatures increase a larger fraction of the atoms/molecules will be found in various higher states. The number in any particular level decreases as the energy of the level increases, as shown.

16	LASERS I.	THEORY OF OPERATION	10

POPULATION INVERSION AS A RESULT OF PUMPING



1. Basic Principles

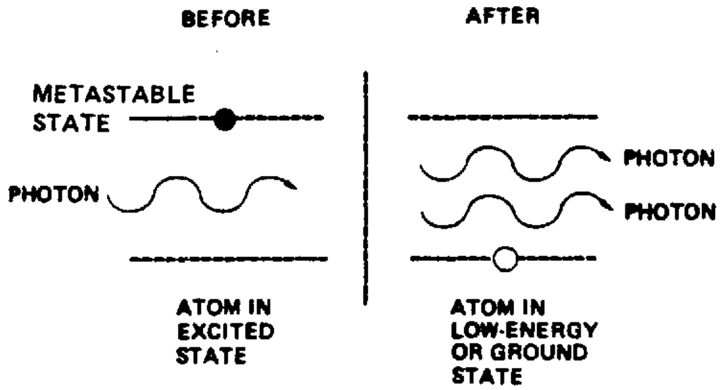
   c. Population Inversion (contd.) (3) Inversion by Pumping

      If, due to energy being added to a collection of atoms/molecules, a significantly larger number of them are able to get into an excited state than exist in some lower energy level, then there is a "population inversion." Usually the only way this can happen is for the higher level state to be "metastable," i.e., have no allowed transitions to lower states. It is this characteristic of some atoms that makes these materials suitable for lasers. The metastable state is crucial for laser operation.

      The means of injecting energy into the laser material is called "pumping." In general the pumping energy may be supplied by an intense light source, an electron beam, or by a chemical reaction. Then this energy is, in essence, stored briefly by the material in its higher energy level metastable state. In this condition, the population is said to be inverted because there are more atoms in the higher state than there would normally be at that temperature, and there may even be more than in the ground state population.

16	LASERS I	THEORY OF OPERATION	11

STIMULATED EMISSION



1. Basic Principles (contd.)

   d. Stimulated Emission

   Electrons transfer from one energy level to another by absorption or emission of energy. When electomagnetic energy is involved, this transfer is called radiative transition.

   There are three types of radiative transitions. Two of these, absorption and spontaneous emission, are quite familiar, but the third, stimulated emission, is relatively unfamiliar.

- Absorption – an electron absorbs energy from a photon of the requisit energy.
- Spontaneous Emission – an excited electron in a high energy level de-excites by radiating a photon and transferring to a lower energy level.
- Stimulated Emission — an incident photon of the correct energy triggers the de-excitation of an excited atom.

STIMULATED EMISSION – II

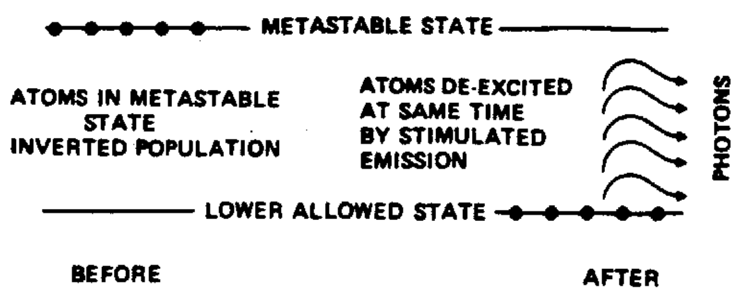
- INCIDENT PHOTON HAS PRECISE (RESONANT) ENERGY REQUIRED TO DE-EXCITE ATOM
- INCIDENT PHOTON IS NOT ABSORBED; IT SIMPLY TRIGGERS DE-EXCITATION OF ATOM
- PHOTON FROM DE-EXCITATION OF ATOM HAS SAME ENERGY AS INCIDENT PHOTON (SAME WAVELENGTH)

In 1916 Einstein postulated that photons released from an excited atom would, upon interaction with a second, similarily excited atom, trigger the second atom into de-exciting itself with the release of a photon.

The photon released by the second atom would be identical in frequency, energy, direction and phase with the triggering photon. The triggering photon would continue on its way, unchanged. Accompanied by the second identical photon, these two photons could go on and trigger more excited atoms through the same process.

16	LASERS I	THEORY OF OPERATION	13

PRODUCTION OF COHERENT RADIATION BY LASER



1. Basic Principles

In the case of laser operation there is a population inversion in the material. That is, there are many atoms in metastable excited states, unable easily to return to lower energy or ground states because the transition is not allowed. This population inversion was produced by the pumping. A photon of the correct energy then can trigger the de-excitation of many of these atoms, with the release of more photons. The stimulated emissions have the same wavelength, because they come from the same atomic transition of the lasing medium. In the process the new photons are emitted in phase and in the same direction also as the triggering photon.

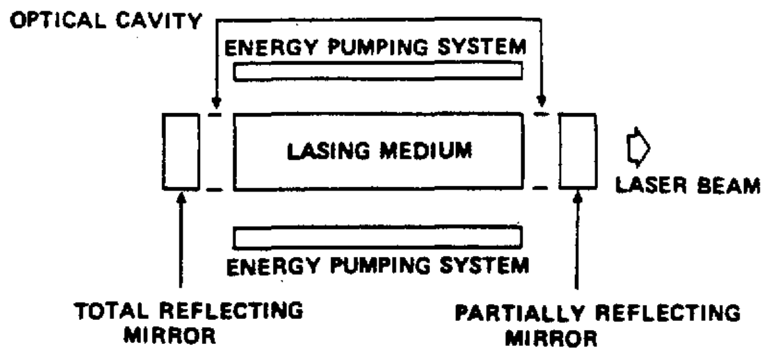
LASER RADIATION

- LASERS EMIT COHERENT LIGHT
- THE ENERGY IS CONCENTRATED (IN PHASE) AT ONE FREQUENCY
- IT CAN BE PROJECTED IN NARROW BEAMS OVER LONG DISTANCES

It is the coherence of laser light that makes it applicable to many industrial, medical and scientific problems. Coherence allows the lgiht energy to be intense and to have narrow beams with small divergence that can project the energy over large distances.

16	LASERS I	THEORY OF OPERATION	15

LASER



2. Laser Components

a. General

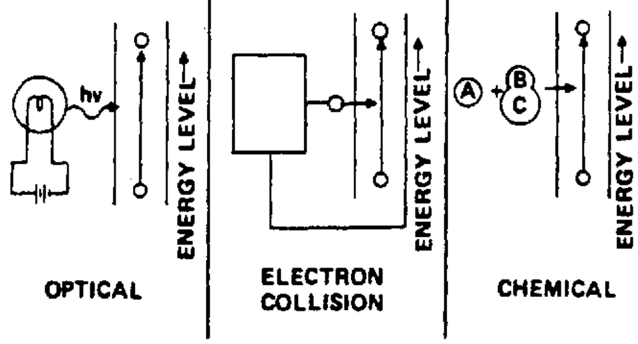
A generalized laser consists of a lasing medium, a pumping system and an optical cavity.

The lasing material must have a metastable state in which the atoms or molecules can be trapped after receiving energy from the pumping system.

We will consider each of these laser components.

16	LASERS I	THEORY OF OPERATION	16

PUMPING SYSTEMS



2. Laser Components

   a. Pumping Systems (Cont'd.)

The pumping system imparts energy to the atoms or molecules of the lasing medium enabling them to be raised to the metastable state, creating a population inversion.

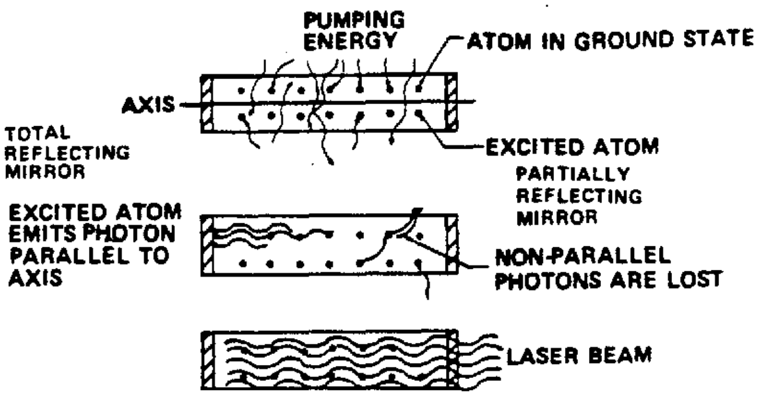
Optical pumping uses photons provided by a source such as a Xenon flash tube or another laser to transfer energy to the lasing material. The optical source must provide photons which correspond to the allowed transition levels of the lasing material.

Electron collision pumping relies on the transfer of energy to the lasing material by collision with electrons passed through the lasing material. Again energies which correspond to the allowed transitions must be provided.

Chemical pumping systems use the binding energy released in chemical reactions to raise the lasing material to the metastable state.

16	LASERS I	THEORY OF OPERATION	17

OPTICAL CAVITY



2. Laser Components (Cont'd.)

   b. Optical Cavity

An optical cavity is required to provide the amplification desired in the laser and to select the photons which are traveling in the desired direction. As the first atom or molecule in the metastable state of the inverted population decays, it triggers, via stimulated emission, the decay of another atom or molecule in the metastable state. If the photons are traveling in a direction which leads to the walls of the lasing material, which is usually in the form of a rod or tube, they are absorbed and the amplification process terminates. They may actually be reflected, but sooner or later are absorbed.

If, on the other hand, the first decaying atom or molecule releases a photon parallel to the axis of the lasing material, it may trigger the emission of another photon and both may be reflected by the mirror on the end of the lasing rod or tube. These photons then pass back through the material triggering further emissions which are reflected by the mirrors on the ends of the lasing material. This amplification process continues until the radiation is capable of escaping through the partially silvered mirror. In this way a narrow concentrated beam of coherent light is formed.

The mirrors on the laser optical cavity must be precisely aligned for light beams parallel to the axis. The optical cavity itself, i.e., the lasing medium material must not be a strong absorber of the light energy.

16	LASERS	THEORY OF OPERATION	18

LASING MEDIA

1. SOLID STATE
2. GAS
3. LIQUID
4. SEMI-CONDUCTOR

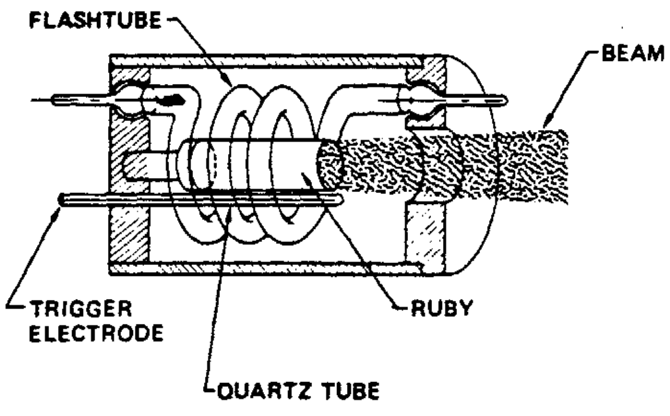
2. Laser Components (contd.)

c. Lasing Media

Lasers are commonly classified by the type of lasing material employed. There are four types which are: solid state, gas, liquid and semi-conductor. The characteristics of each type will be described.

16	LASERS I	THEORY OF OPERATION	19

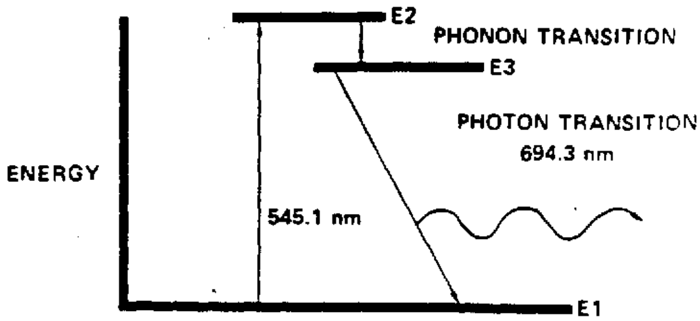
RUBY LASER



Solid State Lasers – Solid state lasers employ a lasing material distributed in a solid matrix. One example is the ruby laser, using a precise amount of chromium impurity distributed uniformly in a rod of crystalline aluminum oxide. The output is primarily at a wavelength of 694.3 nm, which is deep red in color.

16	LASERS I	THEORY OF OPERATION	20

ENERGY LEVELS OF CHROMIUM

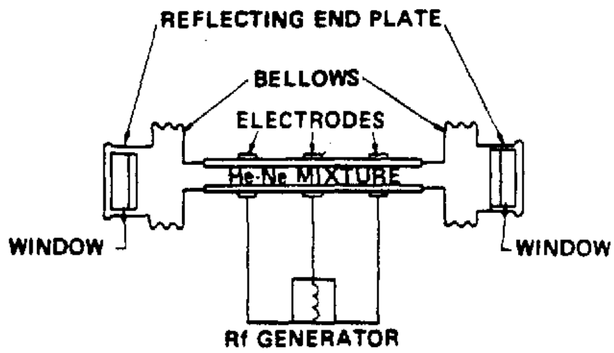


2. Laser Components

   c. Lasing Media (contd.)

   The chromium gives the ruby its red color and is responsible for the lasing. Chromium exhibits a three-level energy system, as represented above. In a ruby laser. the electrons of the chromium atoms are pumped to an excited energy level by means of a xenon flashtube placed beside or around the ruby rod. The chromium electrons absorb photons in a band centered around 545.1 nm and are raised from their ground level to excited level E2. From here they drop almost immediately to level E3 by means of a phonon (radiationless) transition. The small amount of energy lost here is through heat and vibration. The electrons will reside in level E3 for a considerable length of time,much less than a second, but for an electron, a relatively long time. Thus, since the flashlamp operates on a period of microseconds, a population inversion can be obtained. The excited atoms begin to de-excite spontaneously, dropping from level E3 to E1, and since a population inversion is in effect, stimulated emission may begin. In any lasing medium, stimulated emission may occur in all directions and no particular direction of propagation is favored. As stated earlier, to gain control of the emission direction and increase the amount of energy within the pulse, the lasing medium is placed within an optical cavity. Photons not emitted along the axis of the cavity will pass out of the system and be lost. If, however, a photon cascade is aligned with the cavity axis, it will encounter one of the mirrors and be reflected back upon itself, pass once more through the lasing medium and trigger more excited atoms to undergo stimulated emissions. The pulse thus grows in size and on each encounter with the less reflective mirror, part of it emerges from the laser as high intensity coherent light.

He-Ne LASER



2. Laser Components

   c. Lasing Media (contd.)

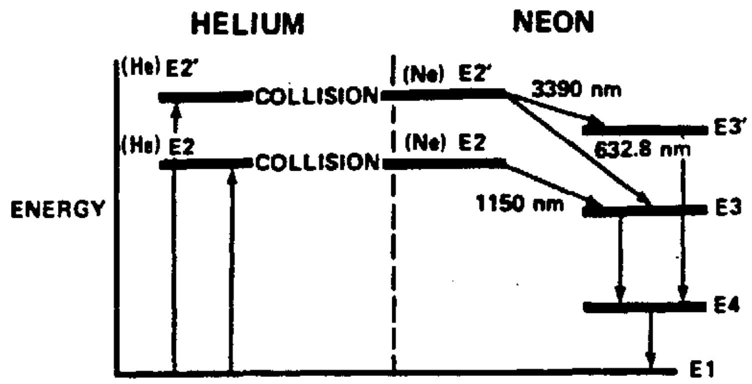
      Gas Lasers - Gas lasers use a gas or a mixture of gasses within a glass tube. Common gas lasers include the He-Ne laser, with a primary output of 632.8 nm in the visible range of the electromagnetic spectrum, and the CO_2 laser, which radiates at 10,600 nm in the infrared. Argon and krypton lasers, with output in the blue and green regions, are becoming quite common. Water vapor can be made to lase in the infrared.

      The most common laser used today in both industry and education is the He-Ne laser. It was first operated in 1961 and has proved to be the forerunner of a whole family of gas lasers. Gas lasers are quite similar in construction and behavior.

      The lasing medium in the He-Ne laser is a mixture of about 90 percent helium and 10 percent neon, with neon providing the lasing action, i.e., emitting the photons.

      The He-Ne gas mixture is contained in a sealed tube. Excitation of the helium is accomplished by a radio frequency current or a direct discharge of electricity throughout the tube, similar to a neon sign. The mirrors may be enclosed within the tube or may form the end caps of the tube containing the He-Ne mixture. This is a rather solid geometrical configuration and results in a stable light output.

16	LASERS I	THEORY OF OPERATION	22



2. Laser Components

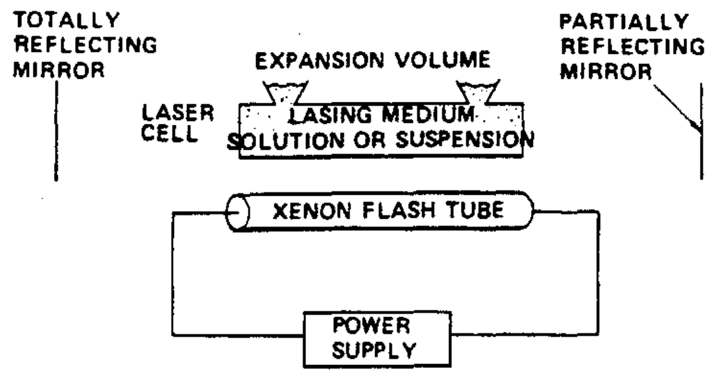
c. Lasing Media (contd.)

The pumping of neon to an excited state is not done directly by the enrgy source. Rather, indirect pumping is accomplished by exciting atoms of helium which then transfer energy to the neon atoms by way of atomic collisions. These two gases are chosen because they have electron excitation levels which are almost identical, thus facilitating the necessary energy transfer. Additionally, one does not need to effect a population inversion in helium in order to obtain a population inversion in neon. A more complete energy level scheme for He-Ne is shown above. The primary emission is at 632.8 nm with secondary emissions at 1150 nm and 3390 nm.

The four-level system of the neon laser differs from the three-level system of chromium in that the emission of a photon does not return the atom to a ground state. Transitions from level E3 to E4 to E1 are accomplished through non-coherent photon transitions in which energy is transfereed mainly in the form of heat.

16	LASERS I	THEORY OF OPERATION	23

LIQUID LASER



2. Laser Components

   c. Lasing Media (contd.)

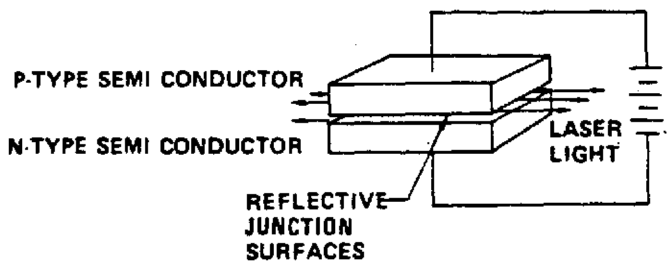
      In liquid lasers the lasing medium is usually a complex organic dyd in liquid solution or suspension.

      The most striking feature of liquid lasers is their "tunability." Proper choice of the dye and its concentration allows light production at almost any wavelength in or near the visible spectrum.

      Liquid lasers commonly employ optical pumping although some types have used chemical reaction pumping.

16	LASERS I	THEORY OF OPERATION	24

SEMI CONDUCTOR LASER



2. Laser Components

   c. Lasing Media (contd.)

Semiconductor Laser – Semiconductor lasers are not to be confused with solid state lasers. Semiconductor devices consist of two layers of semiconductor material sandwiched together.

In a p-n junction laser, lasing is produced by forcing electrons from the n region into the junction, while, in counterbalancing action, "holes" are forced in from the p region. In the junction, electrons combine with lower-energy holes, releasing energy in the form of photons which in turn impinge on other higher energy electrons and stimulate them to release additional photons. The lasing is intensified by making the opposite sides of the junction parallel and reflective.

Semiconductor lasers may be optically pumped by another laser or electron collision pumped by an electron beam or an electric current.

Semiconductor lasers are generally very small physically, and individually of low power. However, they may be made into larger arrays.

MODES OF LASER OPERATION

- CONTINUOUS WAVE
- LONG PULSED
- RAPID PULSED
- Q-SWITCHED
- MODE LOCKED
- TEM MODE

3. Modes of Operation

The different modes of operation of a laser are distinguished by the rate at which energy is delivered.

a. Continuous Wave

In a continuously radiating laser the beam power density is constant with time.

b. Long Pulsed or Pulsed

In general, lasers operating in a normal pulse modes have pulse durations of a few microseconds to a few miliseconds. This mode of operation is sometimes referred to as long pulse or pulsed. The beam power density varies with time and the average power output is dependent on the pulse rate, the pulse width, and the power density of each pulse. This is true for any laser that operates intermittently.

c. Rapid Pulsed

This is the same general operational mode as long pulsed but it is capable of higher pulse rates.

16	LASERS I	THEORY OF OPERATION	25

MODES OF LASER OPERATION

- CONTINUOUS WAVE
- LONG PULSED
- RAPID PULSED
- Q-SWITCHED
- MODE LOCKED
- TEM MODE

3. Modes of Operation

   d. Q-Switched

   Q-switched lasers produce very short, intense pulses by enhancing the storage and dumping of energy in and out of the lasing medium.

   Q pertains to the "Quality" of the optical cacity. A high Q encourages reflection; a low Q indicates a poor reflector or strong absorber. Somewhere in the optical cavity, a device is inserted which will permit rapid changing of the Q of the cavity. When a optical cavity is Q-spoiled, the light reflections between mirrors do not occur. In this condition, a much larger population inversion results. When the Q-switching device finally permits reflection to occur, the resulting output is of large power.

   A laser operating in the Q-switched mode delivers less total energy than the same laser operating in the normal pulse mode, but the energy is delivered in a much shorter time period. Thus, Q-switched lasers are capable of delivering very high peak power of several megawatts or even gigawatts.

16	LASERS I	THEORY OF OPERATION	25

MODES OF LASER OPERATION

- CONTINUOUS WAVE
- LONG PULSED
- RAPID PULSED
- Q-SWITCHED
- MODE LOCKED
- TEM MODE

3. Modes of Operation (contd.)

e. Mode Locked

The resonant modes of the optical cavity affect the characteristics of the output beam. The effect can vary from small transient effects to large fluctuations in the beam intensity with time.

When the phases of different frequency modes are synchronized, i.e., "locked together," the different modes will interfere with one another to generate a beat effect. The result will be a laser output which is observed as regularly spaced pulsations. Lasers operating in this fashion, mode-locked, usually produce trains of pulses, each having a duration of a few picoseconds to a few nanoseconds. A mode-locked laser can deliver higher peak powers than the same laser operating in the Q-switched mode.

f. Transverse Electromagnetic Wave (TEM) Mode

Some laser beams have wave patterns across the direction of travel. The patterns are regular and identified by an indexing system which originated in microwave terminology. A laser operated in this mode would require measurement across the beam to determine total power.

B. CHARACTERISTICS OF LASERS

16	LASERS	CHARACTERISTICS OF LASERS	26

GENERAL CHARACTERISTICS OF LASERS

- SMALL DIVERGENCE
- MONOCHROMATIC
- COHERENT
- HIGH INTENSITY

1. General Characteristics

Lasers are not limited to the frequency of visible light. Laser units can be designed to operate over a wide range of frequencies. One of the most powerful laser beams uses a carbon dioxide laser and emits a continuous beam of photons in the infra-red region. Lasers also operate in the ultra-violet or visible region.

The light output of visible, as well as UV and IR, lasers differ from the output of ordinary light sources. Four properties characterize the laser's output: small divergence, monochromaticity, coherence, and high intensity. These four properties are responsible for the ever-lengthening list of laser application.

Small Divergence – Photons emerge from the lasing rod or tube in essentially parallel directions of travel. The degree to which this is true depends on how well the selection of parallel photons is done in the optical cavity. Some designs are capable of better selection than others, which results in less divergence of the beam as it travels away from the laser itself. Thus the energy density of the beam is not diffused greatly as the beam propagates.

16	LASERS	CHARACTERISTICS OF LASERS	26

GENERAL CHARACTERISTICS OF LASERS

- SMALL DIVERGENCE
- MONOCHROMATIC
- COHERENT
- HIGH INTENSITY

1. General Characteristics (Cont'd.)

Monochromaticity – Laser light is very close to being monochromatic since one transition is primarily responsible for the production of photons. Actually, very few lasers produce only one wavelength of light. For example a He-Ne laser emits light at 632.8 nm, and at 1,150 nm and 3,390 nm as was shown in the energy level diagram. However, the 632.8 nm wavelength predominates. The He-Ne laser is usually designed to emit only this wavelength.

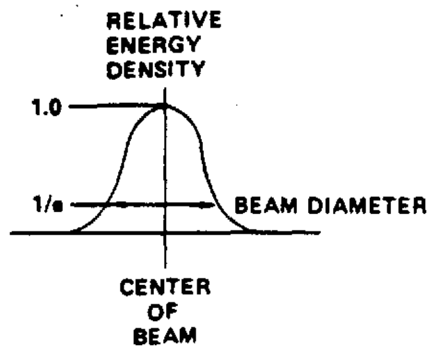
Coherence – Coherence, as discussed earlier, is a particular characteristic of laser radiation. Two waves with the same frequency, phase, and direction are termed spatially and temporally coherent.

High Intensity – Laser light can be very intense. The sun emits about 637 $W/cm^2/Sr$ at its surface. Lasers are presently capable of producing more than $10^{10} W/cm^2/Sr$ in a single pulse, but not in continuous operation. Lasers are thus capable of delivering large amounts of power to a target.

The following characteristics of lasers are important to understand for their applications to laser hazards and control.

16	LASERS	CHARACTERISTICS OF LASERS	27

BEAM DIAMETER



2. Beam Characteristics

   a. Diameter

      The diameter of a laser beam is usually defined as the distance between diametrically opposed points in the cross-section of a beam where the power per unit area is 1/e times that of the peak power per unit area.

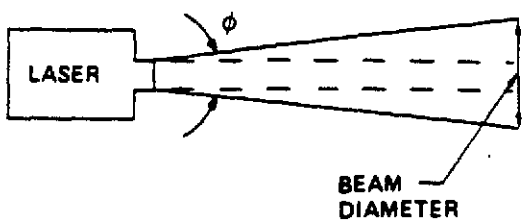
      Beam diameters are usually given at the laser aperture in centimeters.

      Beam diameter measurements are an important factor in determining the irradiance, (W/cm^2) and the radiant exposure, (J/cm^2), that a laser delivers.

      For lasers operated in various TEM modes, the different modes may be treated as parallel beams.

16	LASERS	CHARACTERISTICS OF LASERS	28

DIVERGENCE ANGLE



ϕ = BEAM DIVERGENCE ANGLE

2. Beam Characteristics (Contd.)

   b. Divergence Angle

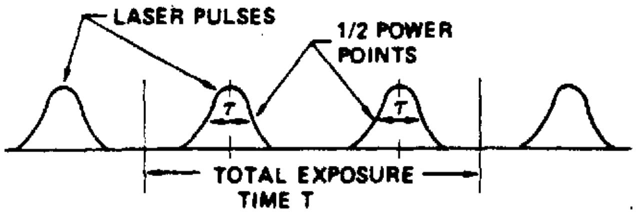
   Lasers are unable to produce perfectly collimated beams due to the wave nature of light and the limitations of the optical cavity. However, the divergence can be made much smaller than with other sources of radiant energy. The beam divergence angle is the angle of increase of the beam with increase in distance.

   The beam divergence angle is measured in radians of milliradians (1 milliradian = 10^{-3} radian) and is usually denoted by α.

   The reason for a part of the divergence of a laser beam is the diffraction of the light by the laser aperture itself. If the aperture is a circle of diameter a, then the diffraction angle, i.e., the angle from the centerline to the first minimum, is approximately $1.2\ \lambda/a$, where λ is the light wavelength. For a one centimeter exit beam diameter and λ = 633 nm (= 6.33×10^{-5} cm) the diffraction effect contributes about 0.08 milliradian to the divergence. This angle is the "diffraction limit," since the laser divergence angle cannot be less than this value.

16	LASERS	CHARACTERISTICS OF LASERS	29

PULSE DURATION, PULSE RATE, DUTY CYCLE



PULSE DURATION (τ) = TIME WIDTH OF PULSE AT ½ POWER POINTS

PULSE RATE = PULSES/UNIT TIME = F

DUTY CYCLE = PULSE DURATION x PULSE RATE

2. Beam Characteristics (Cont'd.)

   c. Pulse Duration

   For a pulsed laser a measure of the time of each pulse is required to calculate the total exposure from such a laser. Pulse duration is the time width of the individual pulse at the half-power points on the leading and trailing edges of the pulse.

   d. Pulse Rate

   For total exposure calculations, the pulse duration is not sufficient. A measure of the number of pulses arriving at the target is also necessary. he pulse rate is the number of pulses per unit time arriving at the target. The number of pulses during exposure time, T, is thus: n = TF.

   e. Duty Cycle

   Total dose may also be calculated using a quantity called the duty cycle which is defined as the fraction of the total exposure time that pulses are actually impinging on the target.

   Total dose is thus calculated (Dose/pulse) x (Duty Cycle) x (Total Exposure Time). It may also be seen that (Duty Cycle) = (Pulse Rate) x (Pulse Duration).

   f. Total Pulse On-Time is the time during which radiation is emitted; it is n τ, the number of pulses times the length of each pulse.

16	LASERS	CHARACTERISTICS OF LASERS	30

RATED SIZE OF LASERS

- RATED BY MANUFACTURER
- CONTINUOUS WAVE LASERS RATED IN POWER, P.
- PULSE MODE LASERS RATED IN ENERGY PER PULSE, Q.

3. Rated Size

The rated size of a laser is usually supplied by the manufacturer. The specifications are commonly minimal guarantee levels for that particular laser and actual outputs for any particular unit may exceed these specifications. A nominal 2 mW laser may have an output larger than 2 mW; a nominal divergence of 1.0 milliradians may in actuality be 0.8 milliradians.

Continuous wave lasers are generally rated in output power rather than energy, since the energy delivered per unit time remains relatively constant.

The power output level of CW lasers is usually expressed in milliwatts or watts. In contrast, pulse lasers deliver their energy in pulses and their effects may best be categorized by energy output per pulse. Pulse energy output is usually expressed in joules or millijoules per pulse.

EXAMPLES OF

COMMON LASERS

SEE TEXT

EXAMPLES OF COMMON LASERS

MATERIAL	WAVELENGTH	MODE OF OPERATION	COMMENTS
RUBY	694 NM (RED)	PULSED Q-SWITCHED OR OCCASIONALLY OPERATED CONTINUOUSLY (CW)	CAPABLE OF HIGH PULSED POWER.
NEODYMIUM-DOPED GLASS	1,060 NM (INFRARED)	PULSED, Q-SWITCHED OR MODE-LOCKED	CAPABLE OF VERY HIGH PULSED ENERGY IN LARGE SIZES
NEODYMIUM-CRYSTAL	1,060 NM (INFRARED)	PULSED, Q-SWITCHED CW OR MODE-LOCKED	OFTEN USED CW RANGE OF SIZES LESS THAN GLASS, USUALLY 1 TO 3 INCHES IN LENGTH
GALLIUM AR-SENIDE AND OTHER DIODE LASERS	ONE WAVELENGTH FROM 700 TO 1,000 NM (INFRARED) (DEPENDING ON MATERIAL AND TEMPERATURE)	RAPIDLY PULSED OR CW	SMALL, LOW-POWER BUT EFFICIENT. POTENTIAL USE IN COMMUNICATIONS AND ELECTRONICS.
HELIUM-NEON (GAS)	633 NM (RED)	CW	RELATIVELY LOW-POWERED BUT AN ECONOMICAL UNIT HAS VERY WIDE APPEAL AND USE.
ARGON ION (GAS)	SEVERAL SIMUL-TANEOUS WAVE-LENGTHS BETWEEN 455 AND 529 NM (BLUE AND GREEN)	PULSED, CW, OR RAPIDLY PULSED.	POWER UP TO TENS OF WATTS WHICH IS MODERATE WHEN KRYPTON IS ADDED, MANY WAVELENGTHS FROM BLUE TO RED. MODERATE CW POWER.
CARBON DIOXIDE	10,600 NM (10.6 μm) (INFRARED)	CW, PULSED, OR Q-SWITCHED	CAPABLE OF ENORMOUS CW POWERS OF MORE THAN 1,000 WATTS. CAN BURN MOST SUBSTANCES VERY QUICKLY.
DYE (LIQUID)	VISIBLE 340-700 NM	CW OR PULSED	SEVERAL DYES AVAILABLE EACH OF WHICH CAN BE "TUNED" TO OPERATE AT ANY WAVELENGTH WITHIN A BROAD RANGE.

4. Examples

There are many types of lasers in common use, some examples are shown above.

C. LASER HAZARDS

16	LASERS	LASER HAZARDS	32

HOW DANGEROUS ARE LASERS?

SOME LASERS CAN BE DANGEROUS
IF THEY ARE NOT PROPERLY USED OR
CONTROLLED

1. Biological Effects of Laser Light

Because of the narrow divergence, the coherence of the radiation, and possibility of high peak power, lasers are considered a dangerous type of equipment. For this reason it is important that they be used in a safe manner, and that their use be controlled. Later we shall consider ways of using and controlling them safely.

The danger from lasers comes from the potential biological effects. Basically the effects are due to interactions of UV, Visible and IR energy similar to those studied earlier in the course. However, the high power density and short pulse characteristics can lead to somewhat different, more catastrophic, effects in tissue due to intense localized heating.

16	LASERS	LASER HAZARDS	33

CONTROLLED LASERS ARE USED IN MEDICINE

TO IRRADIATE TUMORS

TO TREAT EYE CONDITIONS

AS THERAPY FOR CERTAIN TYPES OF SKIN CONDITIONS

1. Biological Effects (Cont'd.)

Lasers are being used in many research and industrial applications. In medicine, this energy is used to irradiate tumors, to supplement x-ray treatment of various tumors, to treat some types of eye conditions, such as vascular lesions and detached retinas, and as therapy for certain types of chronic skin lesions.

CAUTION!

BIOLOGICAL DAMAGE CAN BE PRODUCED BY LASER LIGHT

1. Biological Effects (contd.)

Human exposure to laser light emission can have damaging biological effects. Such effects can result, however, only if the light energy interacts with biological material. The damage that results from absorption of light energy can arise from excitation of cellular molecular species with a subsequent conversion of this excited state energy to heat within cells. When laser light impinges on tissue, the absorbed energy produces heat. The resultant rapid rise in temperature can easily denature the protein material of tissue, much as an egg white is coagulated when cooked. Since tissue is not homogenous, light absorption is not uniform and the thermal stress is greatest around those portions of tissue that are the most efficient absorbers. Rapid and localized absorption produces high temperatures, steam, or results in explosive destruction of the absorber. Steam production, readily evident only at high exposure levels, can be quite dangerous if it occurs in an enclosed and completely filled volume such as the cranial cavity or the eye.

A second interaction mechanism is an elastic or acoustic transient or pressure wave. As the light pulse impinges on tissue, a portion of the energy is transduced to a mechanical compression wave (acoustic energy), and a sonic transient wave is built up. This sonic wave can rip and tear tissue and if near the surface, can send out a plume of debris from the impact.

16	LASERS I	LASER HAZARDS	35

THREE DAMAGE MECHANISMS AT THE CELL LEVEL

1. HEAT
2. PHOTOCHEMICAL CHANGE
3. TORN TISSUE

1. Biological Effects (Continued)

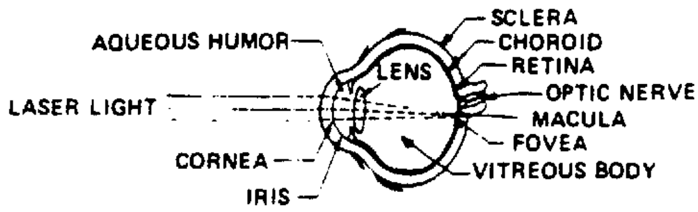
There are three mechanisms by which laser light can cause biological damage at the cell level. In one, damaging effects can be the direct result of molecular absorption of given wavelengths of light. This process produces heat which may damage specific cells and tissue in general.

In the second the energy is absorbed but not released as heat. Rather than releasing the energy, the molecular species undergoes a chemical reaction unique to its excited state. This reaction has some probability of affecting cellular structure and/or function. The latter mechanism is believed to be responsible for damage at low levels of exposure. This is called a photochemical effect.

The third mechanism involves the physical disruption or tearing of tissue by a sonic compression wave resulting from the mechanical response to an intense short duration exposure. This "thermoacoustic" effect occurs for pulses of light shorter than about a microsecond.

16	LASERS	LASER HAZARDS	36

THE ORGAN MOST SENSITIVE TO LASER RADIATION



THE EYE

2. Critical Organs

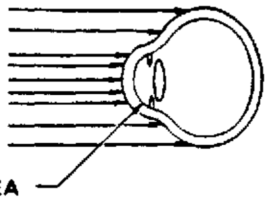
   a. Eyes

The organ most sensitive to laser radiation is the eye. Two broad wavelength classes may be distinguished in terms of their effects on the eye. (1) Those wavelengths that the eye can focus on the retina, and (2) those wavelengths that do not penetrate to the lens and so are not focussed. The ability of the eye to refract the near ultra-violet, visible, and near infrared radiation is the most important physiological characteristic contributing to the laser hazard. The irradiance at the retina may be 10^4 to 10^6 times greater than the irradiance at the cornea because of the focusing effects of the eye.

The fovea is the region of most distinct vision in light. The ability of the eye to see detail, distinguish colors, and perceive depth is most highly developed in the fovea. When we speak of 20/20 vision we are quantitating visual acuity in the fovea. The remainder of the retina is involved principally with peripheral vision and visual acuity decreases rapidly away from the fovea.

The far IR and middle-far UV are absorbed in the outer layers of the eye, and may produce damage there, in the cornea, conjunctiva, epithelium or anterior lens.

16	LASERS	LASER HAZARDS	37



CORNEAL DAMAGE

MIDDLE ULTRAVIOLET, FAR IR
ABSORPTION INJURY IS LOCALIZED AT THE CORNEA

2. Critical Organs

a. Eyes (contd.)

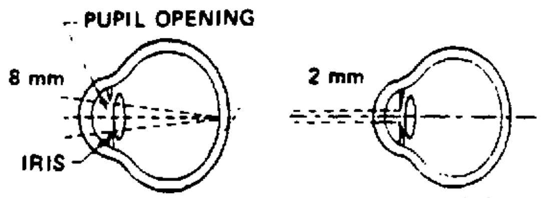
(1) IR — Excessive infrared exposure causes a loss of transparency or produces a surface irregularity in the cornea. A minimal corneal lesion is a white area whose surface is not elevated or swollen. It appears within ten minutes after the exposure. A minimal lesion will heal within 48 hours without visible scarring. These observations are based on experiments with CO_2 lasers therefore extrapolation to other wavelengths must be made with care.

To a large extent damage results from the heating of the cornea subsequent to absorption of the incident energy by water in the cornea. The absorption is diffuse and simple heat flow models appear to be valid. The nature of the sensitive material or protein in the cornea is not known. Although the critical temperature threshold is not known, it does not appear to be much above normal body temperature and there are indications that it is a function of exposure time.

Damage to the epithelium by absorption of ultraviolet light probably results from photochemical denaturation of protein or other molecules in the cells. The absorption is probably by selective sensitive portions of single cells. Thus the action of the ultraviolet radiation is photochemical rather than thermal, since the temperature rises calculated for the experimental exposures are negligible.

16	LASERS	LASER HAZARDS	38

PUPIL EFFECT



LARGER PUPIL

MORE DAMAGE
TO RETINA

SMALLER PUPIL

LESS DAMAGE
TO RETINA

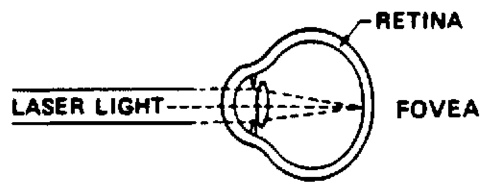
2. Critical Organs

a. Eyes (Cont'd.)

The pupil of the eye dilates when exposed to low levels of visible illumination and constricts when exposed to bright fields. The variation in pupil size extends over a wide range of lighting intensities. When viewing a bright sunny snow field, the pupil diameter may be as small as 2 millimeters. In a very dark room or with the use of drugs it is possible to have a pupil diameter of 8 millimeters. A large pupil will let in more energy flux of the laser beam and therefore cause greater damage to the eye, because more energy can be absorbed.

16	LASERS	LASER HAZARDS	39

BURN ON THE RETINA



CAN RESULT IN SERIOUS IMPAIRMENT OF VISION

2. Critical Organs

   a. Eyes (Cont'd.)

Burns in the peripheral retina, if small, may not be noticed by the victim, whereas any damage to the fovea, which is only about 1 mm in diameter, can result in serious impairment of vision. When one fixes his gaze on an object, the visual axis extends from the fovea through the nodal point of the eye to the object. Thus, if one looks directly into a laser beam the energy is concentrated onto the fovea, which is very susceptible to damage from laser light. Needless exposure of the retina should be avoided regardless of the power or energy level.

A minimal retinal lesion is the smallest visible change in the retina that can be seen with an ophthalmoscope. This change is a small white patch (apparently edema) which occurs within 24 hours of the time of exposure. At threshold, the lesion is probably the result of local heating of the retina. Injuries from energies markedly above threshold may cause physical disruption of the retina by steam formation or by the projectile-like motion of the pigment granules. Disruptive acoustical phenomena may also be present for short pulsed laser radiation.

16	LASERS I	LASER HAZARDS	40

THRESHOLD VALUES FOR DETECTABLE LESION PRODUCTION

Q-SWITCHED RUBY LASER – 0.07 J/cm^2 ON RETINA

PULSED RUBY LASER – 0.8 J/cm^2 ON RETINA

CONTINUOUS WHITE LIGHT – 6.0 W/cm^2 ON RETINA

CO_2 LASER – 0.2 W/cm^2 AT CORNEA

2. Critical Organs

a. Eyes (Cont'd.)

Power density at the retina cannot be experimentally measured but must be calculated on the basis of transmission and focusing of the beam. The power density which can be measured is that incident on the cornea. On the basis of measurements at the cornea, lesions can be caused by as little as 10^{-6} J/cm^2 from a pulsed ruby laser.

At present, threshold values for visible lesion production are approximately as follows:

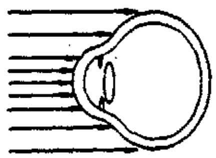
Q-switched ruby laser	@ 0.07 J/cm^2 on the retina
Pulsed ruby laser	@ 0.8 J/cm^2 on the retina
Continuous white light	@ 6.0 W/cm^2 on the retina
CO_2 laser	@ 0.2 W/cm^2 at the cornea

Since the lens can focus incident light upon the retina by factors of up to a million in the visible and near IR, one should multiply these values of retinal damage threshold by 10^6 to obtain corresponding incident light irradiance values. It is from such studies as these that the protection standards are determined, by multiplying further factors for conservatism. The Maximum Permissible Exposure (MPE) Standards are well below the exposure values that will produce minimal lesions.

Light levels below those producing visible lesions may also produce some permanent damage such as partial "bleaching" of the pigment for one particular light color. Research is under way to detect such damage by histochemical means as well as by electroretinography.

16	LASERS I	LASER HAZARDS	41

FAR INFRARED



ABSORPTION IS LOCALIZED AT THE CORNEA.

2. Critical Organs

   a. Eyes (contd.)

This slide and the next three to follow illustrate the sites of energy absorption in the eye as a function of wavelength throughout the electromagnetic spectrum. The longer wavelengths of the middle and far infrared. 1.4 to approximately 100 micrometers are absorbed at the cornea or in the intraocular media before reaching the retina.

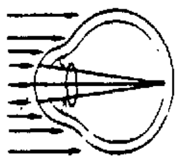
Two commercially available lasers emit in this portion of the spectrum: the carbon dioxide (CO_2) laser which emits at 10,600 nanometers and the recently developed erbium laser which emits at 1,650 nanometers.

Threshold damage in the far infrared is essentially thermal in nature. Eye damage thresholds were studied extensively by Fine and associates who exposed the eye of rabbits to the 5-nm-diameter beam from a CO_2 laser in a continuously emitting mode for time periods of up to 30 minutes. Such long exposure times, they believe, are well beyond those of any accidental situation for the CO_2 laser direct beam. Their examination for damage included slit lamp and ophthalmoscopic procedures as well as histological examinations and the criterion for damage was any observable corneal change by any examination procedure.

Lesions were formed by exposures to 0.5 W/cm^2 and 1.0 W/cm^2 for 5 minutes or less. Exposures of 15 minutes were capable of producing corneal lesions at an irradiance of 0.24 W/cm^2. The lesions in this case were observable with an ophthalmoscope, and histological changes were easily visible. As the irradiance levels were decreased from 0.2 to 0.1 W/cm^2, the authors reported a variability in the production of corneal change. No change was detected by any method following exposure to 0.1 W/cm^2 for 30 minutes.

16	LASERS	LASER HAZARDS	42

VISIBLE AND
NEAR INFRARED



ENERGY IS ABSORBED IN THE OCULAR MEDIA AND AT THE RETINA; NEAR INFRARED RAYS ARE REFRACTED, AND SO ARE FOCUSSED ON RETINA

2. Critical Organs

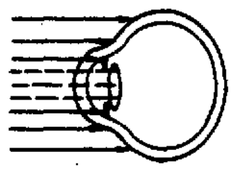
a. Eyes (Cont'd.)

That portion of the spectrum between 700 nm and 1400 nm can be termed the near infrared for purposes of biological effects discussions. Transmission of radiation to the retina is quite high over most of this spectral range but perception of that radiation is negligible. Common lasers that emit in this spectral range are the gallium arsenide (GaAs) lasers which emit at 850-950 nm and lasers of the neodymium (Nd) family which emit at about 1060 nm. Transmission of light to the lens (as opposed to the retina) extends past 1500 nm. and many common incandescent sources emit heavily in this portion of the spectrum.

The threshold levels for visible retinal lesion by the 1060 nm radiation from neodymium (Nd) lasers has been studied by Vassiliadis and associates. They exposed both Rhesus monkeys and a human to pulses of 30 nanosecond duration and noted a difference in the lowest levels at which lesions were produced, with the human requiring 25 times as much energy input. The retinal damage criteria for both species was a visible retinal lesion which appeared within 1 hour of exposure. Rhesus subjects were also exposed to Nd laser radiation of 600-microsecond duration. The lowest energy for damage was 3×10^{-3} J into a 100 micron diameter retinal spot. The short-pulsed Nd laser experiment can be compared with short-pulsed ruby laser experiments performed under similar conditions by the same author and reported in the same paper. For short pulse time domains, the Nd laser required about 10 times as much incident corneal energy to produce damage as did the ruby laser.

16	LASERS	LASER HAZARDS	43

NEAR ULTRAVIOLET



NEAR ULTRAVIOLET IS ABSORBED ON THE CORNEA AND IN THE LENS.

2. Critical Organs

   a. Eyes (Cont'd.)

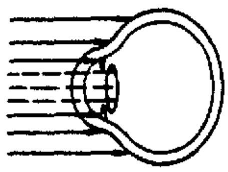
That portion of the electromagnetic spectrum from about 200 nanometers to 400 nanometers is usually termed ultraviolet (UV). While wavelengths shorter than 200 nm are readily produced, they are heavily absorbed in the air and generally need only be considered under vacuum conditions. The transmission of UV radiation through the ocular media to the retina decreases rapidly at wavelengths shorter than about 400 nm, and insufficient amounts reach the retina to elicit a visual response. The critical organs are skin and especially the anterior portion of the eye.

The most marked reaction to ultraviolet radiation by the eye takes place in the cornea, corneal epithelium, and the mucous membrane that lines the inside of the eye or the conjunctiva, since they receive all of the incident energy and absorb most of it in the spectral range less than 320 nm.

Recent work by Vassiliadis and associates has demonstrated the usefulness of the laser in eliciting damage information. Using a frequency doubled ruby laser of 347 nm wavelength and 3.0 ns emission duration, they exposed the eyes of Rhesus monkeys. The primary damage site was found to be the lens with the appearance of lenticular opacities. No damage was found at the retina, nor was any mentioned at the cornea. There is an absorption line in certain lens glucosides at 368 nm, in humans.

16	LASERS	LASER HAZARDS	43

NEAR ULTRAVIOLET



NEAR ULTRAVIOLET IS ABSORBED ON THE CORNEA AND IN THE LENS.

2. Critical Organs (Cont'd.)

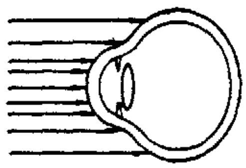
a. Eyes (contd.)

MacLeen and associates have studied the effect of 325 nm laser light from a helium-cadmium laser on the eyes of rabbits. Cataract production was noted, but no lenticular changes or alteration deeper within the eye were seen. No inference can yet be made on the choice of dose rate versus dose for threshold values. The development of a tunable laser source in the ultraviolet region will hopefully give much more definitive data on the spectrum between 315 nm and 400 nm, a region which is not well known today in terms of biological effects.

The evaluation of threshold damage cannot be done immediately, since some finite time must elapse after exposure before the damage is manifest as a visible lesion. Evalution times range from about 5 minutes after exposure up to 24-48 hours after exposure. Davis indicates that the minimum power levels for visible lesions assessed at 1 hour after exposure are about 80 percent of the levels required for immediate detection. Ham states "... irreversible lesions appear at a lower irradiance when observation time post exposure is extended to a day or so" Campbell found that waiting at least 16 hours, rather than 5 minutes after exposure decreased the energy required on the human retina for visible lesion production from $1\ 10^{-2}$ J to $3.4\ 10^{-3}$ J in one subject and from 6.4×10^{-3} J to 2.7×10^{-3} J in another.

16	LASERS	LASER HAZARDS	44

FAR ULTRAVIOLET



ABSORPTION OCCURS PRINCIPALLY AT THE CORNEA

2. Critical Organs

   a. Eyes (Cont'd.)

The ultraviolet radiation below 310 nanometers wavelength is absorbed principally at the cornea of the eye. Considerably less energy is transmitted on to the retina. Widmark used a carbon arc lamp to obtain typical photophthalic reactions in rabbits, such as acute conjunctivitis with swelling, and a shedding of the corneal epithelium. Larger doses resulted in corneal opacities and discoloration of the iris. Verhoff and Bell showed that these characteristic effects of ultraviolet exposure were caused by light of wavelength shorter than 305 nm. They demonstrated corneal changes, widespread effects on the lens capsule and with intense exposure, superficial damage to the lens, but were unable to produce any retinal damage.

16	LASERS	LASER HAZARDS	45

LASER LIGHT IMPINGING ON SKIN WILL BE

1. REFLECTED
2. ABSORBED
3. TRANSMITTED

DEPENDING ON WAVELENGTH
AND PIGMENTATION

2. Critical Organs (contd.)

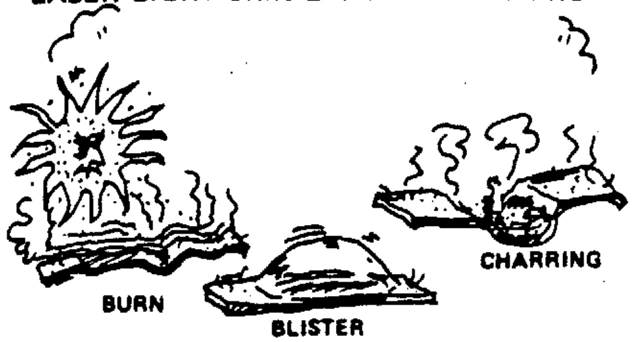
b. Skin

The other body organ susceptible to laser light damage is the skin. Naturally, it is not as sensitive as is the eye, and if damaged, most injuries are more easily repaired. However the skin is subject to great damage from laser impact when energy densities approach several J/cm^2.

Electromagnetic radiation impinging upon tissue will be reflected, absorbed, and transmitted; the percentage of each is dependent on the wavelength and the tissue involved. The darker the pigment of the tissue the more heavily it will absorb in the visible region of the spectrum. The property of selective absorption has led to the use of lasers to remove skin blemishes such as birthmarks and tattoos. This obviously should be done only by a qualified physician.

16	LASERS	LASER HAZARDS	46

LASER LIGHT SKIN EFFECTS VARY FROM



ALL EXPOSURE SHOULD BE AVOIDED

2. Critical Organs

   b. Skin (contd.)

   Skin effects may vary from mild reddening or sunburn (first degree burns) to blisters (second-degree) or charring of skin (third degree), depending on the amount of energy absorbed. Other effects, such as damage to an organ lying close beneath the skin, and depigmentation have been reported in the literature for experimental animals exposed to extremely high powered laser radiation. Needless exposure of the skin to laser radiation should be avoided regardless of the level of irradiance.

LONG-TERM LOW-LEVEL EXPOSURE

UV	–	POSSIBILITY OF SKIN CANCER
VISIBLE	–	THIRD DEGREE AND POSSIBLY SECOND DEGREE BURNS
IR	–	FIRST, SECOND OR THIRD DEGREE DEPENDING ON POWER LEVEL AND EXPOSED AREA

2. Critical Organs

b. Skin (contd.)

Long-term, low-level exposure to ultraviolet radiation is associated with an increase in the occurrence of skin cancer. While no definitive studies have yet been done to ascertain the threshold for the effect, the cause and effect relationship is accepted by most researchers.

Skin damage from visible light can be essentially thermal in nature. Some individuals do however, exhibit unusual sensitivity even to visible light, and some chemicals do cause photosensitization. Threshold damage levels for thermal damage are similar to those of near and far infrared radiation.

Far infrared skin damage was studied by Fine and associated as an adjunct to their work on corneal injury thresholds. They reported "thermofax paper readily blackens upon exposure to $1 W/cm^2$ and accidental exposure at this level resulted in cutaneous burns on the fingers and hands of several of the investigators." They further stated "Deliberate exposure of the finger of one of the investigators to $0.3 W/cm^2$ for several minutes resulted in considerable pain and a burn that persisted for several days, whereas there was no pain or marked thermal sensation on prolonged exposure to $0.1 W/cm^2$."

It should be noted that the levels reported for skin damage thresholds are valid only for irradiated areas equal or close in diameter to those used in the experiment; that is, diameter of 14 to 16 millimeters. Larger irradiated areas would probably required lower irradiances to produce damage, while smaller areas with a greater rate of heat loss would require a greater irradiance. A good discussion of this subject is provided by Sliney who states, for a CO_2 laser "the beam size incident upon human skin must be nearly 1 centimeter or greater in diameter for $0.1 W/cm^2$ to produce a definite sensation of warmth, and at least 2-3 mm diameter for $1 W/cm^2$ to produce this sensation, while $0.01 W/cm^2$ would probably be sensed for whole body exposure."

16	LASERS	LASER HAZARDS	48

ABSORBED ENERGY FROM A LASER DEPENDS ON:

1. INCIDENT { RADIANT EXPOSURE, H, J/cm^2 ; IRRADIANCE, E, W/cm^2 }
2. WAVELENGTH, λ (ABSORPTION COEFFICIENT)
3. EXPOSURE DURATION
   a) ON-TIME, T (CW)
   b) PULSE LENGTH AND REPETITION RATE (PULSED)

3. Absorbed Energy

a. Radiant Exposure and Irradiance

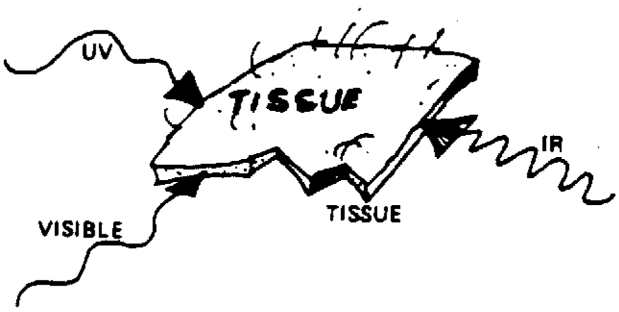
The magnitude of the irradiance (energy flux) from a laser is closely related to the degree of hazard. Radiant exposure is the quantity of energy per unit area in the beam and is usually expressed in $joules/cm^2$. Irradiance is the rate at which the energy per unit area is delivered and is usually expressed in $watts/cm^2$ (i.e., $joules/sec \cdot cm^2$). As the energy content of the beam increases so does the associated hazard. Longer exposure time at a given E increases H, since

$$H\ (J/cm^2) = E\ (W/cm^2) \times T$$

The absorbed energy from a laser beam depends also upon dependent absorption coefficients of the tissue or other medium involved.

16	LASERS	LASER HAZARDS	49

DEGREE OF HAZARD DEPENDS ON WAVELENGTH – PENETRATION CHARACTERISTICS



3. Absorbed Energy (Cont'd.)

   b. Spectrum

      From qualitative observations of the behavior of electromagnetic energy, we deduce that certain wavelengths penetrate deeper into tissue than other wavelengths. For instance, some wavelengths in the infrared region penetrate deeper into the tissue than certain wavelengths in the ultraviolet region. Theoretically, every wavelength has its own penetration characteristics. However, there are other considerations such as the percentage of water in the organ, the reflectivity or focusing characteristics at the surface of the biologic tissue, etc., which also influence the depth of penetration.

      The laser is usually a hazard to only those tissues through which the light beam can penetrate and those which will absorb the wavelength involved. With potential hazard evaluation and safety in mind, the concern is primarily with two organs–the eye and the skin.

16	LASERS	LASER HAZARDS	50

TIME DEPENDENT EFFECTS RESULT FROM:

1. **PULSE DURATION**
2. **PULSE REPETITION RATE**

FOR THE SAME TOTAL ENERGY DELIVERED

3. Absorbed Energy (Cont'd.)

c. Time Dependence

There are certain time dependent characteristics of the laser beam that influence the probability of biological damage. These are:

1) Pulse duration. If a certain quantity of energy is delivered over a short period of time, say nanoseconds, instead of milliseconds, the potential for tissue damage is greater.

2) Pulse repetition rate. Here we have the additive effect of several pulses of the laser, rather than a single pulse, over a certain period of time. The time for tissue recovery between pulses is obviously less.

16	LASERS	LASER HAZARDS	51

TO SUMMARIZE: THE TYPE AND EXTENT OF BIOLOGICAL DAMAGE FROM LASERS IS A FUNCTION OF:

1. **ENERGY ABSORBED**
2. **WAVELENGTH OF RADIATION**
3. **TIME HISTORY OF EXPOSURE**
4. **SPECIFIC BODY ORGAN EXPOSURE**

3. Absorbed Energy (Cont'd.)

   d. Absorption Review

   High energy densities of electromagnetic radiation are capable of causing damage to living tissue. The type and extent of damage is a function of:

   1) Energy absorbed
   2) Wavelength of the radiation
   3) Time history of the exposure
   4) Specific body organ exposed
   5) Ability of the exposed organ to lose heat to surrounding tissue (at low rates).

   The damaging effects of CW and pulsed laser radiation to the eye appear to be mostly thermal and very similar in effect to damage from other radiation sources in the same region of the spectrum. However, because of the high degree of collimation, a laser beam entering the eye can be focused onto an extremely small spot at the retina. This results in higher radiant exposures and requires less total energy into the eye to cause damage than is the case for light from other sources. The retinal irradiance resulting from the focusing of a Q-switched laser beam, or any very high power laser, may be so high that non-thermal effects such as shock waves and electrical field effects can occur.

16	LASERS	LASER HAZARDS	52

ASSOCIATED (NON-LIGHT) HAZARDS

1. HIGH VOLTAGE SHOCK
2. GAS HAZARDS
3. FIRE
4. X-RADIATION
5. HIGH VELOCITY DEBRIS
6. LASER MEDIUM TOXICITY

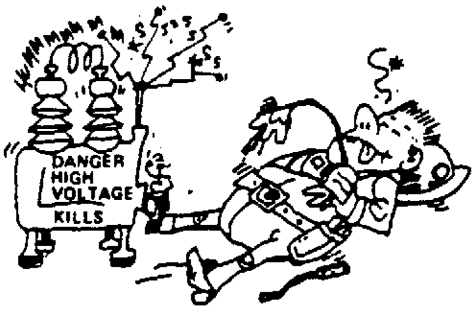
4. Associated (non-light) Hazards

The associated hazards can sometimes be more dangerous than the light given by the laser itself. One should always be conscious of these possible hazards to personnel. They include: gas pressure tanks, cryogenic gases, high voltage, toxic gases and fumes, fire, x-radiation, and high velocity projectiles from a system failure. Most of these hazards are obvious and will only be pointed out and discussed briefly.

The laser medium may be toxic, as is the case of fluorine, used in Kv – F or HF gas lasers.

16	LASERS	LASER HAZARDS	53

HIGH VOLTAGE



GONE TO R.I.P.

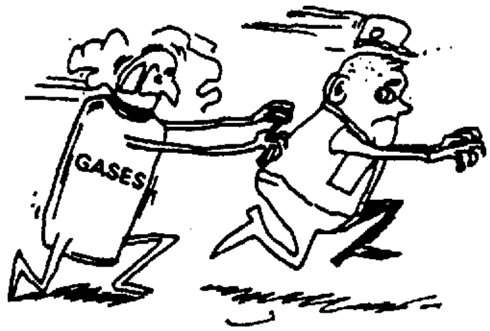
4. Associated (Non-Light) Hazards (Cont'd.)

a. High Voltage Shock

The power supplies for lasers are essentially all high voltage equipment and should be treated with a great deal of caution. Death from electrocution is a very real possibility in many laser installations. Unlike developmental laboratory lasers, most commercial lasers are designed to be operated by personnel with little if any training in the repair of electronics equipment. Dangerous or fatal shocks to operators can most easily be avoided by leaving service and repair work to qualified service personnel.

16	LASERS	LASER HAZARDS I	54

GASES UNDER PRESSURE ARE HAZARDOUS



4. Associated (Non-Light) Hazards (Cont'd.)

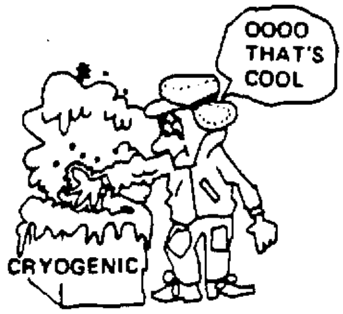
   b. Gas Hazards

      1) Pressure Failures

      Gases contained in pressure vessels are generally found in the near vicinity of most experimental laser operations. Improper procedures may result in overpressurization and rupture of a plumbing system utilizing compressed gas cylinders. These pressure bottles can become high velocity missiles when the container is punctured or a valve is broken.

16	LASERS	LASER HAZARDS	55

CRYOGENIC
GASES
AND LIQUIDS
FREEZE TISSUE

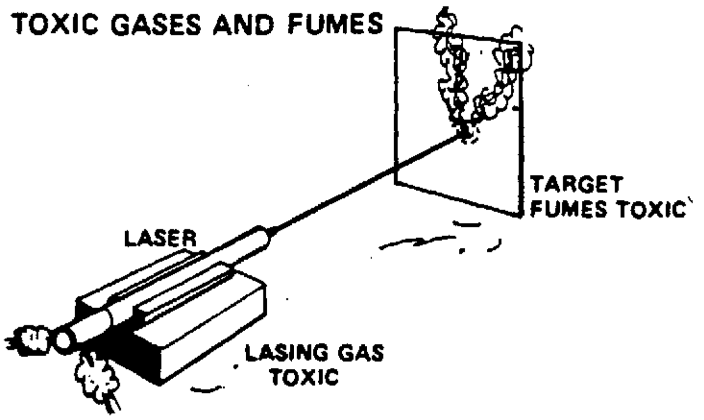


4. Associated (Non-Light) Hazards

   b. Gas Hazards (Cont'd.)

      2) Cryogenic Gas Escape

      Cryogenic gases are used in cooling laser systems and are an auxiliary part of most experimental lasers. Frozen tissue can result from mishandling of these gases. Cryogenic system failures can injure personnel (or damage property) by impact of fragments and shock waves, by suffocation, and by contact with intensely cold materials.



4. Associated (Non-Light) Hazards

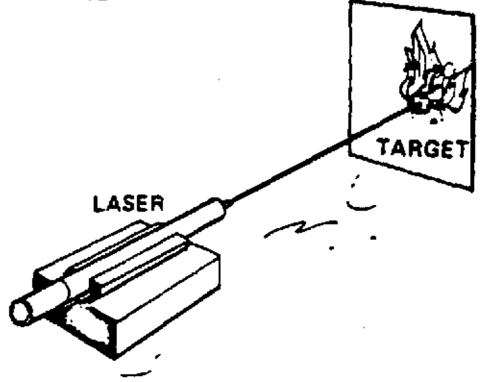
   b. Gas Hazards (contd.)

      3) Toxic Fumes

Toxic gases and fumes may be encountered in the operation of most lasers. Many different gases are used to operate lasers and each gas has its own toxic characteristics. Some of the gases which are toxic are: Mercury-Krypton, Mercury-Zinc, Hydrogen-Cyanide, and Fluorine. Toxic gases such as Ozone and Oxides of Nitrogen may be formed when a laser is operated in the ultraviolet region. Toxic fumes can be generated during cutting, drilling, and machining operations or whenever laser target material is vaporized.

16	LASERS I	LASER HAZARDS	57

FIRE IS ALWAYS A POSSIBLE HAZARD



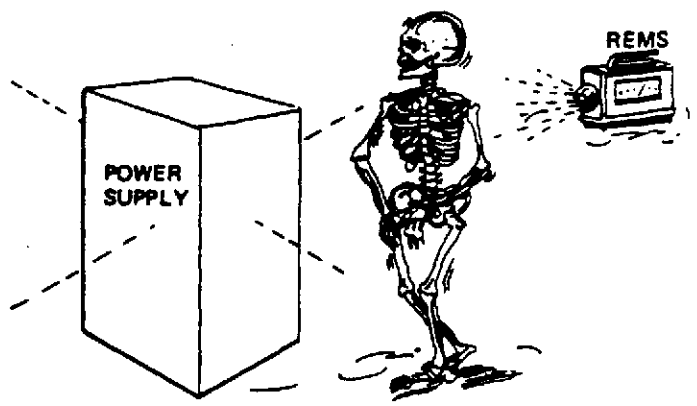
4.. Associated (Non-Light) Hazards (Cont'd.)

c. Fire

Fire and explosion hazards are possible if the beam is misdirected in the presence of flammable or combustible materials. These materials may be present in the form of gases associated with the equipment, or in the form of material in the path of the beam. Experimental lasers have demonstrated potential fire hazard by igniting paper at distances of several miles. An obvious but important precaution to be taken in the vicinity of lasers is the strict routine observance of simple "good housekeeping". Flammable materials should be removed from the premises if possible, and if not, they should be stored in cabinets or drawers.

16	LASERS	LASER HAZARDS	58

X-RAYS ARE HAZARDOUS TO HEALTH



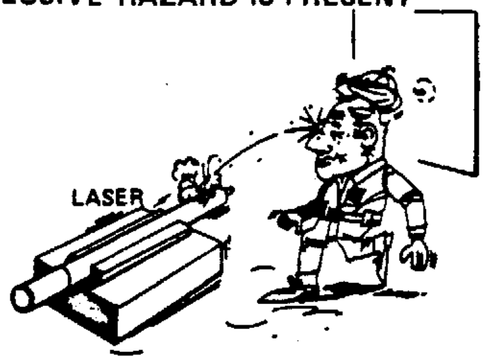
4. Associated (Non-Light) Hazards (Cont'd.)

   d. X-Radiation

   Any time that high voltage equipment is operated in the kilovolt region there is a possibility of having an x-radiation hazard. Any tube, electron gun, or power supply operating at these voltages should be checked with standard radiation protection survey instruments. X-ray exposure levels in the vicinity should be clearly marked with suitable radiation hazards signs indicating the exposure rate to be expected when the laser is operating. Excessive, x-radiation levels should be corrected by the installation of additional shielding where necessary.

16	LASERS	LASER HAZARDS	59

AN EXPLOSIVE HAZARD IS PRESENT



4. Associated (Non-Light) Hazards (Cont'd.)

e. Projectiles

Failure of part of the laser system could cause an explosive hazard. High velocity projectiles or shrapnel from a system failure can be extremely hazardous to both personnel and the facility.

D. CONTROL OF LASER HAZARDS I

16	LASERS L	CONTROL OF LASER HAZARDS L	60

SCOPE

- ANSI AND ACGIH STANDARDS
- HAZARD CLASSIFICATION
- CRITERIA FOR EXPOSURE OF EYE AND SKIN
- CONTROL FACTORS

THE PRESENTATION CONTROL OF LASER HAZARDS II WILL COVER HAZARD EVALUATION, PROTECTIVE FACILITIES AND DEVICES, OPERATING PROCEDURES, TRAINING PROGRAMS, MEDICAL SURVEILLANCE AND LAWS AND REGULATIONS PERTAINING TO LASERS.

1. Introduction

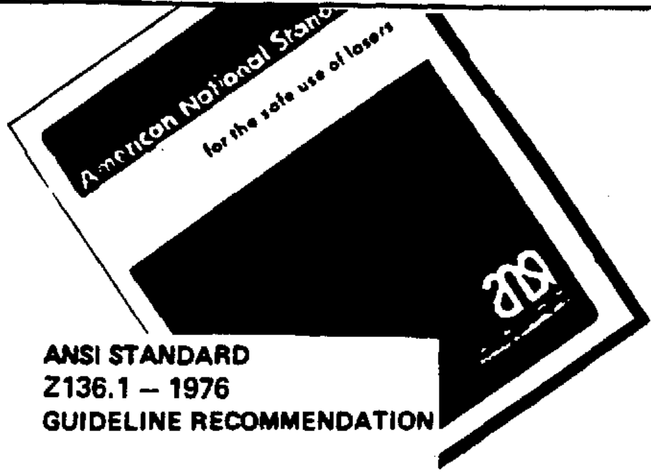
   a. Scope.

This section covers the Laser Hazard Controls recommended by the ACGIH and ANSI Standards. The O.S.H.A. regulations for safe use of lasers in the occupational setting will follow the ACGIH and ANSI recommendations. The FDA regulations for performance standards of manufactured laser equipment incorporate the ANSI recommendations.

Hazard classification of lasers will be described. Threshold Limit Values and Extended Threshold Limit Values for eye and skin exposure will be given.

Control factors of limiting apertures, wavelength corrections, effects of multiple exposures and associated hazards will be discussed.

The next lecture will cover Hazard Evaluation, Protective Facilities and Devices Operating Procedures, Training Programs, Medical Surveillance and Laws and Regulations pertaining to lasers.



1. Introduction (contd.)

b. Standards

In 1973 the American Standards Institute, Inc. released a standard, "Safe Use of Lasers," which was updated in 1976 (Z136.1-1976), covering lasers in use at nearly all power levels. The guidelines also provide for both the construction and the use of lasers in laboratories and classrooms.

et seq., current standard 1986.

with output wavelengths between 0.2 μm and 1 millimeter (mm)." Thus, Maximum Permissible Exposure (MPE) values for these operating conditions are provided in detail.

The ANSI standard spells out the rules for operating lasers at essentially any wavelength of pulse duration. It defines control measures for each of four laser classifications, and it provides technical information on measurements, calculations, and biological effects.

Topics covered in detail include definitions, hazard evaluation and control, administration of laser safety programs, medical surveillance, special considerations such as electrical and explosion hazards, measurements, and criteria for exposure of the eye and skin.

A GUIDE FOR CONTROL OF LASER HAZARDS

ACGIH: AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS

GUIDE FOR USERS

1. Introduction

   b. Standards (contd.)

The American Conference of Governmental Industrial Hygienist (ACGIH) recommended standards patterned after the American National Standards Institute (ANSI). The scope and purpose of the ACGIH is as follows:

> This guide is intended to identify certain health hazards common to all types of lasers and to provide minimum guidelines to ensure the safety and health of personnel operating lasers and of other persons likely to be exposed to their radiations and associated hazards. Those recommendations containing the word "shall" identify requirements necessary to meet the standards of protection of this guide. Those using the word "should" indicate advisory recommendations, which should be applied when practicable.
>
> A classification scheme for analyzing the degree of potential of optical radiation hazards from a specific laser can simplify the hazard evaluation procedure and the determination of control measures. A laser or laser system can usually be classified from knowledge of the laser specifications; and optical measurements and calculations become unnecessary.
>
> This guide does not limit the intentional use of laser radiation for the purpose of performing medical, surgical, and dental procedures but some of the hazard control practices should be incorporated as in all laser installations.
>
> For the purpose of this guide the word "laser" refers to coherent optical sources emitting visible (400 to 700 nm) infrared (700 nm to 1 mm) and/or ultraviolet (200-400 nm) radiation. Although very high intensities from lasers have been known to produce ionization in air and other materials, laser radiation should not be confused with ionizing (i.e., x-rays and gamma rays).

16	LASERS I	CONTROL OF LASER HAZARDS I.	63

STANDARDS AND REGULATIONS

OSHA:	REQUIRED REGULATIONS BY USER
ANSI ACGIH	STANDARDS VOLUNTARY BY USER
FDA/BRH	PROPOSED STANDARDS FOR MANUFACTURERS

1. Introduction

b. Standards (contd.)

O.S.H.A. is still (1979) formulating laser usage regulations. Currently 21CFR 1526 controls construction laser usage. ANSI and ACGIH are recommending bodies for laser users, and OSHA is the agency that regulates use, by means of inspection and enforcement of rules.

The F.D.A., Food and Drug Administration (Department of Health, Education and Welfare) has published performance standards to be followed by manufacturers of laser products. This was published on July 31, 1975 in Volume 40 of the Federal Register, and is entitled "Laser Products."

16	LASERS I.	CONTROL OF LASER HAZARDS I.	64

ANSI & ACGIH

SCOPE

REASONABLE AND ADEQUATE
GUIDES FOR SAFE USE OF LASERS
WITH OUTPUT WAVELENGTH
BETWEEN 0.2μm AND 1mm

1. Introduction

b. Standards (contd.)

The scopes of the ANSI and ACGIH recommended standards are to provide reasonable and adequate guides for the safe use of lasers and laser systems with output wavelengths between 0.2 μm and 1 mm.

The objectives of standards are to provide reasonable and adequate guidelines for the safe use of lasers and laser systems. A practical means for accomplishing this is to first classify lasers and laser systems according to their relative hazards and then to specify appropriate controls for each classification.

In what follows here we will primarily use and reference the ANSI Standard (Z136.1–1976).

ANSI LASER CLASSIFICATION

- FOUR CLASSES OF LASERS
- CLASSIFIED BY HAZARD POTENTIAL

  CLASS I ⟶ CLASS IV

  LEAST HAZARDOUS ⟶ MOST HAZARDOUS
- HAZARD DEFINED IN TERMS OF ACCESSIBLE RADIATION

The ANSI Standard (Section 3 and Table 1) describes the classification scheme. There are four basic hazard classes, defined in terms of accessible radiation, power or energy output in various wavelength ranges.

The classification designation I, II, II or IV, should appear on laser products manufactured subsequent to the standard, and should be used unless the laser is modified to change its output power or energy significantly.

16	LASERS I	CONTROL OF LASER HAZARDS I	66

PARAMETERS REQUIRED FOR HAZARD CLASSIFICATION

- WAVELENGTH(S) OR WAVELENGTH RANGE
- FOR CW OR REPETITIVELY PULSED LASER
  AVERAGE POWER OUTPUT (Φ) AND
  LIMITING EXPOSURE DURATION (T_{max})
- FOR PULSED LASERS:
  TOTAL ENERGY PER PULSE (Q)
  PULSE DURATION (t),
  PULSE REPETITION FREQUENCY (F),
  EMERGENT BEAM RADIANT EXPOSURE (H).

2. Hazards Classifications

   a. Parameters. The laser output parameters necessary for laser hazard classification are:

      1) Classification of essentially all lasers requires a knowledge of: the wavelength(s) or wavelength range, and a determination of the classification duration.

         Classification of Multi-Wavelength Lasers

         The classification of laser devices which can potentially emit at numerous wavelengths shall be based on the most hazardous possible operation.

      2) Classification of CW or repetitively pulsed lasers also requires knowledge of average power output.

      3) Classification of pulsed lasers also requires knowledge of total energy/pulse (or peak power), pulse duration, PRF, and emergent beam radiant exposure.

      4) Classification of extended-source laser devices such as injection laser diodes and those lasers having a permanent diffuser within the output optics, requires two additional parameters beside (1) through (3) and listed: the laser source radiance or integrated radiance and the maximum viewing angular subtended.

16	LASERS I.	CONTROL OF LASER HAZARDS I.	67

CLASS I LASER — A SYSTEM WHICH IS INCAPABLE OF PRODUCING A HAZARDOUS EXPOSURE CONDITION

$< P_{EXEMPT}$ OR Q_{EXEMPT}

2. Hazards Classification (contd.)

b. Class I

Class I lasers cannot emit radiation in excess of exempt power (P_{exempt}) or energy (Q_{exempt}) levels for their maximum system on-time. Values of P_{exempt} and Q_{exempt} are given in Table 1 of the ANSI Standard, as follows:

UV	VIS	VIS-NEAR IR	NEAR IR	FAR IR	SUBMILLIMETER
200–400	400–550	550–1060	1060–1400	1400–	10^5–10^6 nm
$\leq 0.8 \times 10^{-9}$ to $\leq 8 \times 10^{-6}$	$\leq 0.4 \times 10^{-6}$	$\leq 0.4 \times 10^{-6}$ to $\leq 20 \times 10^{-6}$	$\leq 200 \times 10^{-6}$	$\leq 0.8 \times 10^{-3}$	≤ 0.1 watts

Thus, Class I lasers are exempt from radiation controls. However, note that there may be non-light-related hazards.

CLASS II LASERS

- VISIBLE LIGHT (400–700 NM)
- CW OR REPETIVELY PULSED
- RADIANT POWER > P_{EXEMPT} (= 0.4 μW
- RADIANT POWER $\leq 10^{-3}$ WATT

2. Hazard Classification

c. Class II

Class II designation applies only to visible light lasers, either continuous wave (cw) or repetitively pulsed. If the radiant power of the laser exceeds the exempt level in the visible (0.4 microwatts) and is less than or equal to one milliwat, the laser is classified Class II.

CLASS III LASERS - MEDIUM POWER SYSTEMS WHICH PRESENT AN OCULAR HAZARD FROM INTRABEAM VIEWING OF THE DIRECT OR SPECULARLY REFLECTED BEAM.

2. Hazards Classification (contd.)

d. Class III

A Class III laser system is a medium power system requiring control measures to prevent viewing of the direct beam. Control measures emphasize preventing direct access to the primary or specularly reflected beam. Safety eyewear is necessary with this class.

The conditions for this class are as follows:

1) Infrared (1400 nm – 10^6 nm) and ultraviolet (200 nm to 400 nm) laser devices which can emit a radiant power in excess of P_{exempt} for the classification duration, but cannot emit:

   a) An average radiant power in excess of 0.5W, for T_{max} greater than 0.25 s, or

   b) A radiant exposure of 10 J/cm^2 within an exposure duration of 0.25 s or less.

2) Visible (400 nm to 700 nm) CW or Repetively-Pulsed Laser Device producing a radiant power in excess of P_{exempt} for a 0.25 s exposure (1 mW for a CW laser): but cannot emit an average radiant power of 0.5W for T_{max} greater than 0.25 s.

3) Visible and Near-infrared (400 nm - 1400 nm) Pulsed Laser Devices which can emit a radiant energy in excess of Q_{exempt} but which cannot emit a radiant exposure that exceeds either 10 J/cm^2 or that required to produce a hazardous diffuse reflection as given in Table B-1, of the ANSI Standard.

4) Near-infrared (700 nm - 1400 nm) CW Laser Devices or Repetively-Pulsed Laser Devices which can emit power in excess of P_{exempt} for the classification duration but cannot emit an average power of 0.5 W or greater for periods in excess of 0.25 s.

CLASS III LASERS

- **POWER > CLASS I OR CLASS II**
- **FOR ALL WAVELENGTHS CLASS III LASER POWER DOES NOT EXCEED 0.5 W**
- **CLASS III a, III b**

2. Hazards Classification

   d. Class III (contd.)

   In general, Class III lasers exceed the exempt or Class II power levels, but do not exceed 0.5 Watt average radiant power.

   A laser or laser system (1) whose accessible power output is less than five times the lower Class III limit for its wavelength range and exposure duration; and (2) whose output does not exceed the MPE value as measured over the appropriate limiting aperture, is classed as IIIa.

16	LASERS I.	CONTROL OF LASER HAZARDS I.	71

CLASS IV LASERS

HIGH POWER SYSTEMS
OCULAR HAZARD FROM DIFFUSE REFLECTION
SKIN HAZARD
FIRE HAZARD

2. Hazards Classification (contd.)

e. Class IV

High-power systems requiring control measures to prevent exposure of the eye and skin to the direct and diffusely reflected beam.

16	LASERS I.	CONTROL OF LASER HAZARDS I.	72

CLASS IV

ALL LASERS WITH:

- OUTPUT POWER EXCEEDING 0.5W,
- ENERGY OF $10 J{\cdot}cm^{-2}$ OR
- PRODUCING HAZARDOUS DIFFUSE REFLECTIONS FOR PERIODS > 0.25 SEC.

2. Hazards Classification

   e. Class IV (contd.)

   The following are the conditions for this class:

   1) Ultraviolet (200 nm - 400 nm) and Infrared (1.4 μm - 1 mm) Laser Devices which emit an average power in excess of 0.5 W for periods greater than 0.25 s or a radiant exposure of 10 J/cm^2 within an exposure duration of 0.25 s.

   2) Visible (400 nm - 700 nm) and Near Infrared (700 nm - 1400 nm) Laser Devices which emit an average power of 0.5 W or greater for periods greater than 0.25 s, or a radiant exposure in excess of either 10 $J\ cm^{-2}$ or that required to produce a hazardous diffuse reflection as given in Table B-1, ANSI Standard.

16 72 A

1980 book
1976 Std.

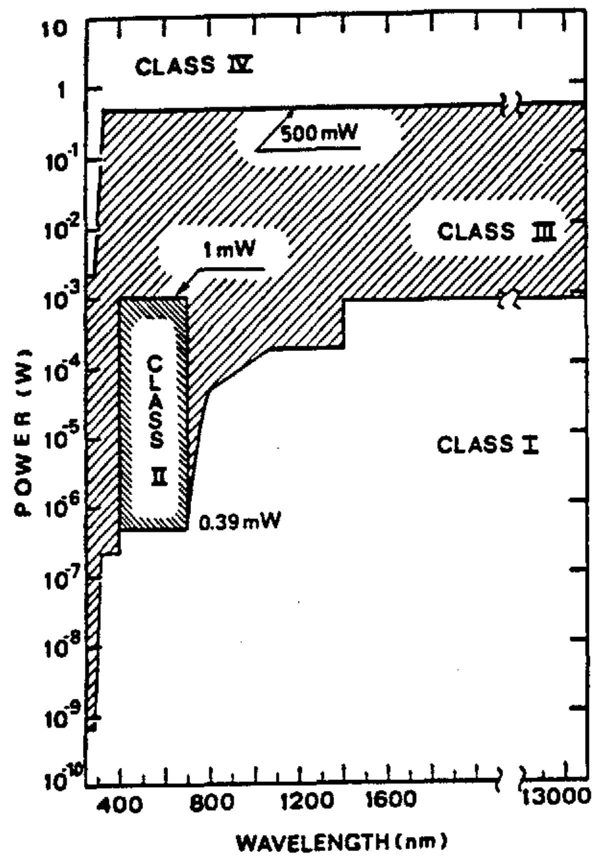


Figure 9-1. Emission Limits in Perspective. The 1978 BRH limits for CW laser emission by class. The ANSI Z-136.1, 1976 limits are the same except for slight differences for upper limits of Class I CW lasers at wavelengths between 550 nm and 1400 nm, and ANSI limits exist between 200 and 250 nm and 13 μm and 1 mm.

ANSI STANDARD FOR SAFE USE OF LASERS

- EXPOSURE CRITERIA FOR EYE AND SKIN
- CRITERIA FOR DIFFERENT VIEWING CONDITIONS
- MAXIMUM PERMISSIBLE EXPOSURE (MPE), OR THRESHOLD LIMIT VALUES (TLV) ARE BELOW KNOWN HAZARD LEVELS
    - IRRADIANCE, E, W/cm^2
    - RADIANT EXPOSURE, H, J/cm^2

3. Exposure Criteria

The American National Standards Institute (ANSI) Standard Z136.1-1976 contains a number of tables and charts that provide the exposure criteria, or maximum permissible exposure (MPE) values for eyes and skin, for intrabeam and extended source viewing conditions, and for cw, single pulsed and repetitively pulsed lasers. The MPE values, called also "Threshold Limit Values" (TLV's), are exposure levels well below known hazard levels, based on observable human and animal experimental data.

16	LASERS I.	CONTROL OF LASER HAZARDS I.	74

- TLV FOR OCULAR EXPOSURE
  SAFE BUT MAY BE
  UNCOMFORTABLE TO VIEW

- NEVER ALLOW MORE
  EXPOSURE THAN NECESSARY

3. Criteria for Exposure of Eye and Skin (contd.)

   b. Eyes

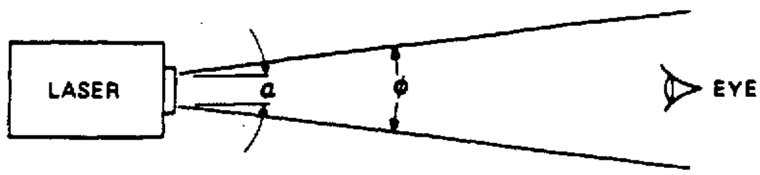
   The threshold limit values given for the eye are safe but may be uncomfortable to view. Thus, it is good practice to maintain exposure levels as far below TLV values as is practicable.

   When a laser emits radiation at several widely different wavelengths, or when pulses are superimposed upon a CW background, computation of the TLV is complex. Exposures for several wavelengths in the same time domain are additive on a proportional basis of spectral effectiveness with due allowance for all correction factors. The simultaneous exposure to pulses and CW radiation is not strictly additive. Caution should be used in these situations until more data is available.

   An appropriate aperture must be used for measurements and calculations with all TLV values. This is the limiting aperture and is the maximum circular area over which irradiance and radiant exposure can be averaged.

16	LASERS I	CONTROL OF LASER HAZARDS I	75

INTRABEAM VIEWING - DIRECT BEAM (PRIMARY BEAM)



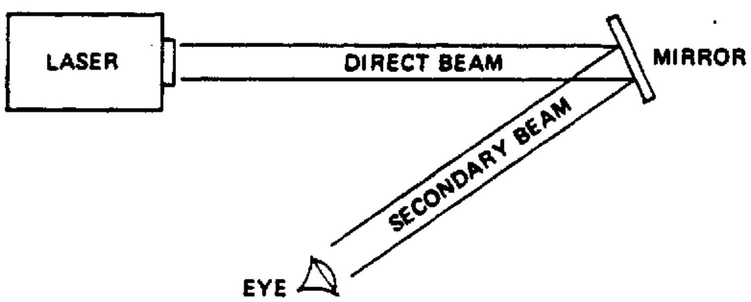
3. Criteria for Exposure of Eye and Skin

   b. Eyes (contd.)

      Two types of viewing are addressed in the ANSI Standard. The chart shows the Intra-Beam Viewing (IBV) situation, where the eye (or skin) is in the direct or primary laser beam.

16	LASERS I	CONTROL OF LASER HAZARDS I	76

VIEWING - SPECULARLY REFLECTED BEAM FROM FLAT SURFACE (SECONDARY BEAM)



A specularly reflected beam from a shiny flat surface should also be considered IBV, and the MPE values for this viewing condition used in hazard assessment.

16	LASERS I	CONTROL OF LASER HAZARDS I.	77

EXTENDED - SOURCE VIEWING TLV

DIFFUSE REFLECTION

DIODES ARRAYS

SOURCE ANGULAR SUBTENSE,

$a \geqslant a_m$

3. Criteria for Exposure of Eye and Skin (contd.)

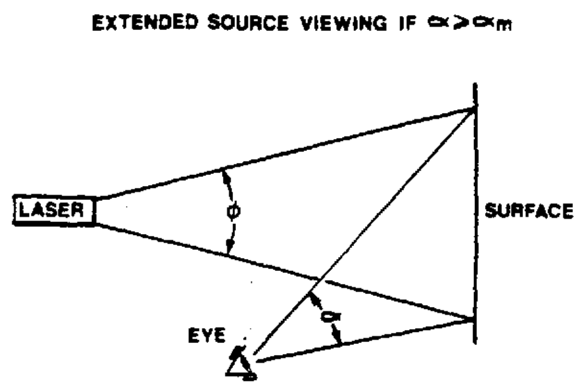
c. Extended Source Threshold Limit Values Application

The extended source TLV's are applied only in the spectral region of 400-1400nm where the source size is significantly larger than a "point" and where the corresponding retinal image in the viewer's eye is definitely not a "minimal spot".

Extended source viewing (ESV) is the second viewing situation addressed in the ANSI Standard. As the name indicates, ESV involves large source areas as viewed, so that the retinal image is not a minimal spot. Diffuse reflections or arrays of diode lasers are examples of ESV sources. The criterion for ESV is that the source should not subtend an angle a greater than a_m shown in Figure 3 of the Standard.

Class I and II lasers are not capable of producing hazardous diffuse reflections and only the intrabeam TLV's are applied except for intrabeam viewing of semiconductor-diode laser arrays. Class IV, visible and near-infrared lasers, are always capable of producing hazardous diffuse reflections at close viewing distances. Class III lasers do not produce hazardous diffuse reflections unless focused, and intrabeam TLV's would normally be used except for some laser diode arrays.

16	LASERS	CONTROL OF LASER HAZARDS	78



3. Criteria

   c. ESV TLV's

   The chart shows the geometric situation typical of ESV and defines some terms. Note the difference between divergence angle, ϕ, and angular subtense angle of viewing, α. The ANSI standard, Appendix B discusses ESV further.

THRESHOLD LIMIT VALUES (TLV) FOR OCULAR EXPOSURE TO EXTENDED SOURCES FOR SINGLE PULSES OR EXPOSURES

WAVELENGTH, λ (μm)	EXPOSURE TIME, t (s)	THRESHOLD LIMIT VALUE (TLV)
VISIBLE AND NEAR-INFRARED		
0.4 - 1.4	10^{-9} - 10	$10t^{1/3}\ J\cdot cm^{-2}\cdot sr^{-1}$
	10 - 10^4	$20\ J\cdot cm^{-2}\cdot sr^{-1}$
	10^4 - 3×10^4	$1.0 \times 10^{-3}\ W\cdot cm^{-2}\cdot sr^{-1}$

3. Criteria for Exposure of Eye and Skin

   c. Extended Source Threshold Limit Values Application (contd.)

      Some of the threshold limit values (TLV) for ocular exposure to extended visible-near IR sources for single pulses or exposures are given above, for use in problems.

16	LASERS I	CONTROL OF LASER HAZARDS I	80

TERMINOLOGY FOR ESV SOURCES

L = RADIANCE ($W{\cdot}cm^{-2}{\cdot}sr^{-1}$)

L_p = INTEGRATED RADIANCE ($J{\cdot}cm^{-2}{\cdot}sr^{-1}$)

THESE ARE SOURCE-RELATED TERMS.

3. Criteria for Exposure of Eye and Skin

   c. Extended Source Threshold Limit Values Application (contd.)

In considering exposure to extended sources you must familiarize yourself with the associated terminology. Radiance (L) refers to radiant power output (per unit area of source)(per unit solid angle)($W \cdot cm^{2} sr^{-1}$).

The radiometric quantities of "radiance" ($W \cdot cm^{-2} \cdot sr^{-1}$) and "integrated radiance" ($J \cdot cm^{-2} \cdot sr^{-1}$) are used for extended sources since these quantities, which describe the source directly, determine the irradiance.

DETERMINATION OF MPE USING ANSI STANDARD

- EYE (OCULAR) OR SKIN
- VIEWING CONDITION: IBV OR ESV
- EXPOSURE CONDITION: CW/SINGLE PULSE OR REPETITIVELY PULSED
- LASER WAVELENGTH

UV	200–400 NM
VIS	400–550–700 NM
NEAR IR	700–1400 NM
FAR IR	1400–1,000,000 NM

3. Criteria for Exposure

a. Use of the ANSI Standard

The chart shows the parameters one needs to have in order to determine MPE or TLV levels for safe exposure to lasers using the ANSI Standard. There are charts for both eye and skin exposure, for IBV and ESV conditions, for various wavelengths; also the MPE's depend upon exposure time durations for CW or single pulses, and upon pulse length and pulse repetition rates (i.e., upon average power and total pulse-on time) for repetitively pulsed lasers.

Examples of the IBV skin and eye MPE's given by the Standard for several visible lasers and an IR laser are shown in the next two charts.

INTRABEAM TLV'S WHICH ARE APPLICABLE TO MANY COMMON CW LASERS FOR EYE AND SKIN EXPOSURE TO LASER RADIATION

LASER TYPE	PRIMARY WAVELENGTH(S) (nm)	THRESHOLD LIMIT VALUE EYE	SKIN
HELIUM-CADMIUM	441.6	(a) 2.5mW·cm^{-2} FOR 0.25s	0.2W·cm^{-2}
HELIUM-NEON	632.8	b) 10mJ·cm^{-2} FOR 10-10,000s	0.2W·cm^{-2}
ARGON	488,514.5		
KRYPTON	647.1	c) 1μW·cm^{-2} FOR > 10,000s	0.2W·cm^{-2}
FRQ. DOUBLED ND:YAG	532		
CARBON-DIOXIDE (AND OTHER LASERS 1.4μm TO 1000 μm)	10.6μm (10,600 nm)	0.1W·cm^{-2} FOR t > 10s	0.1W·cm^{-2} FOR t > 10s

INDICATES a), b), AND c) APPLY TO EACH LASER TYPE IN THE GROUPING.

The above chart shows the intrabeam TLV's which are applicable to many common (CW) lasers for skin exposure.

Notice the popular He-Ne laser TLV for 0.25 seconds is 0.2 W$\cdot$ cm^{-2} (200 milliwatts $\cdot$ cm^{-2}). The TLV is the same for the He-Ne, He-Cd, Ar, Kr, and the frequency double Neodynium (YAG), but differs from the Carbon Dioxide (CO_2).

INTRABEAM TLV'S WHICH ARE APPLICABLE TO MANY PULSED LASERS FOR EYE AND SKIN EXPOSURE TO LASER RADIATION

LASER TYPE	PRIMARY WAVELENGTH(S) (nm)	PULSE DURATION	THRESHOLD LIMIT VALUE	
			EYE	SKIN
NORMAL-PULSED RUBY	694.3	~ 1ms	10^{-6} J-cm^{-2}	0.2J-cm^{-2}
Q-SWITCHED RUBY	694.3	5-100ns	5 x 10^{-7} J-cm^{-2}	0.02J-cm^{-2}
RHODAMINE 6G DYE LASER	~ [illegible]-700	0.5-20µs	5 x 10^{-7} J-cm^{-2}	[illegible] J-cm^{-2}
NORMAL PULSED NEODYMIUM	1064	~ 1ms	5 x 10^{-6} J-cm^{-2}	0.2J-cm^{-2}
Q-SWITCHED NEODYMIUM	1064	5-100ns	5 x 10^{-6} J-cm^{-2}	0.02J-cm^{-2}

3. Criteria for Exposure of Eye and Skin

   d. TLV for Skin Exposure (contd.)

      The above chart shows the intrabeam TLV's for many pulsed lasers. Notice the popular Q-switched Ruby laser eye and skin TLV's which are, respectively, 5 x 10^{-7} and 0.02 J -cm^{-2} for 5-100 nanoseconds.

DETERMINATION OF CW MPE USING ANSI STANDARD

- FIRST DETERMINE IF IBV OR ESV
- USE TABLES AND MAKE CORRECTIONS (C_a, C_b, T_1)

OR

- USE FIGURES WITH SOME CORRECTIONS INCLUDED

3. Criteria for Exposure (contd.)

e. Use of the ANSI Standard (contd.)

The first step in determining the MPE or CW or single pulses is to decide if IBV or ESV conditions apply. Do this by considering the angle a subtended by the source at the eye. If a is less than a_m then one has the IBV situation; if $a \geq a_m$ then one has ESV.

Next, one may either use the Tables or Figures to obtain the appropriate MPE. If one uses the tables, there may be correction factors to apply as specified. The figures have already included most of these correction factors.

Generally, for an arbitrary wavelength, it is more accurate to use the tabulated values and formulas, applying the specified wavelength- or time-dependent corrections. However, where applicable, the MPE figures are easier to use if the wavelength is close to that appropriate to one of the plotted curves. Remember, there are some possible corrections to be made even if the charts are used. We shall discuss these shortly.

DETERMINATION OF CW MPE USING ANSI STANDARD

		MPE TABLE NO.	MPE FIG. NO.	MPE FIG. NO. WITH SOME CORR. FACTORS	FURTHER CORR. NEEDED AS INDICATED
EYE	IBV $a < a_m$	5	4	5, 6, 10	x100 FOR 1540 NM AND $\tau \leq 1\ \mu s$
	ESV $a > a_m$	6	7	11	" "
SKIN		7	–	–	X C_A FOR 700–1400 NM

3. Criteria for Exposure (contd.)

e. Use of the ANSI Standard (contd.)

The chart indicates the Tables and Figures, by number in the ANSI Standard, that provide CW MPE values for specific viewing conditions.

For IBV ($a < a_m$) Figure 4 has the same data as Table 5, except that the Table calls out certain wavelength-dependent correction factors, C_A and C_B; and a wavelength-time exposure dependency via the parameter T_1. To use Table 5 one may need to obtain C_A, C_B and T_A from other indicated figures in the Standard. In Figure 4 these corrections have been applied.

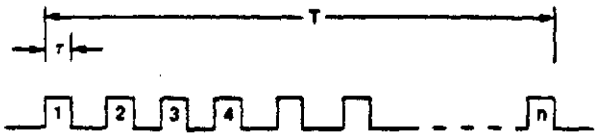
All correction factors except one have been already included in the CW MPE values plotted in Figures 5, 6 and 10, for UV, far IR, and visible-near IR, respectively. That one correction factor applies at wavelength 1540 nm for pulse lengths less than one microsecond; for this situation the MPE given in Figure 6 is to be multiplied by 100.

Similar considerations apply to ocular ESV ($a \geq a_m$): the Table 6 MPE values are plotted in Figure 7; the same set of correction factors are called out, to be obtained from other figures in the Standard. Figure 11 plots MPE values for ESV that include all these corrections (except for the factor of 100 at 1.54 microns for one microsecond or shorter pulses).

For skin MPE's, the ANSI Standard provides only Table 7, without a corresponding figure. According to paragraph 8.4 the wavelength-dependent correction factor, C_A, given in Figure 8, is to be applied. (Note that this correction is not called out directly in Table 7.) C_A increases from 1.0 to 5.0 over the range 0.7 to 1.06 microns, and is 5.0 at longer wavelengths.

The student should practice determining skin and eye CW MPE values for various wavelengths, exposure conditions and pulse lengths. A few example problems are given in the ANSI Standard.

DEFINITION of TERMS USED
in EVALUATING REPETITIVELY PULSED LASER MPE'S



F = frequency, pulses/sec
T = duration of exposure
n = number of pulses = Ft
τ = individual pulse length
nτ = total pulse on time (or "TOTP")

3. Criteria for Exposure (contd.)

   e. Use of the ANSI Standard (contd.)

      In determining the MPE values for repetitively pulsed lasers, one needs to know the pulse length of each pulse, τ, the frequency F or pulse repetition rate, prf, and the duration of the exposure, T,. From these parameters, one can calculate the number of pulses, n = FT, and the total pulse on time, TOTP - $n\tau$. The chart shows a train of pulses and defines these terms.

      If T is not known, use 0.25 seconds (the blink time) for visible and near IR lasers, and 10 seconds (the time assumed for some eye/head movement) for UV and far IR lasers.

16	LASERS	CONTROL OF LASER HAZARDS	87

DETERMINATION OF REPETITIVELY PULSED LASER MPE's

- DETERMINE CW MPE's

  (1) INDIVIDUAL PULSE LIMITATION
  (CW MPE FOR "COMPARABLE" PULSE)

  (2) AVERAGE POWER DURING PULSE TRAIN
  (CW MPE FOR TRAIN DURATION)

- REPETITIVELY PULSED LASER MPE IS THE MORE RESTRICTIVE (SMALLER VALUE OF (1) OR (2).

The procedure indicated in the chart applies if the pulse repetition frequency (F or prf) is greater than one Hertz (one pulse per second). The repetitively pulsed laser MPE is the lesser value of two CW MPE's, one determined from a consideration of individual pulses, the other from the average power.

compare: ① CWMPE $(t = n\tau)$

↑ TOT (Time on Target)

• for $\tau > 10\ \mu s$

or

CWMPE $(t = \tau) \times n \times$ Fig 12 CF

• for $\tau \leq 10\ \mu s$

} "comparable single pulse"

and

② CWMPE $(t = T)$ } Avg pwr

use smaller, limiting value

16	LASERS	CONTROL OF LASER HAZARDS	88

REPETITIVELY PULSED LASER MPE

Pulsed	CWMPE (Additive for 24-hr)	1. MPE = CWMPE ($t = \tau$) x C.F. (Fig. 12) x n 2. MPE = CWMPE (t = T) 3. COMPARE (choose smaller)	1. MPE = CWMPE ($t = n\tau$) 2. MPE = CWMPE (t = T) 3. COMPARE (choose smaller)
IBV $\alpha < \alpha_m$	F < 1 Hz	$\tau < 10\ \mu sec$	$\tau \geq 10\ \mu sec$
ESV $\alpha \geq \alpha_m$	F < 1 Hz	$\tau < 10\ \mu sec$	$\tau \geq 10\ \mu sec$
SKIN	F < 1 Hz	$\tau < 10\ \mu sec$	$\tau \geq 10\ \mu sec$

NOTES

α – angular subtense (Fig. 3)	F – frequency	if T not known:
T – exposure time	n – FT (no. pulses)	T = 0.25 sec VIS
τ – pulse width	$n\tau$ – on time	T = 10 sec UV, IR

Consider first the individual pulse limitation. In this case the "comparable" single pulse is determined in either of two ways depending upon the pulse length.

(a) For $\tau < 10\ \mu s$, the MPE os a comparable pulse is found by multiplying the CW MPE for an exposure length τ by n, the number of pulses in the train, and also by the prf correction factor given in Figure 12.

(b) For $\tau \geq 10\ \mu s$, the MPE of a comparable single pulse is the CW MPE for an exposure duration equal to the total pulse on time, $n\tau$. (The correction factor of Figure 12 does *not* apply).

Second, consider the average power limitation. The repetitively pulsed MPE must be less than the CW MPE value for an exposure of duration T.

Third, choose the smaller of the CW MPE's determined in the first two steps, i.e., the smaller of the individual comparable pulse limitation and the average power limitation. This is the repetitively pulsed laser MPE.

The chart above lays out the procedure just described for easy reference.

FOR REPETITIVELY-PULSED LASERS;
THE TLV FOR EXPOSURE SHALL
NOT EXCEED:

- THE TLV BASED ON A SINGLE PULSE
- THE TLV BASED ON THE TOTAL EXPOSURE TIME

In summary, for repetitive-pulsed lasers, the TLV is determined as follows. (1) Exposure shall not exceed the TLV based upon a single comparable pulse exposure; and (2) the average irradiance of the pulse train shall not exceed the TLV application for the total pulse-on time (TOTP) of the pulse train.

In effect, the formulas given earlier provides the TLV or MPE.

16	LASERS I	CONTROL OF LASER HAZARDS I	90

SPECIAL QUALIFICATIONS - VISIBLE AND NEAR INFRARED

- NO ALLOWANCE FOR PUPIL SIZE DIFFERENT FROM 7mm
- **WAVELENGTH CORRECTION TO TLV IF NOT MADE**
- MULTIPLE EXPOSURES

4. Control Factors

a. Limiting Aperture

In the ANSI Standard language there are special qualifications for limiting aperture, wavelength correction factors, and multiple pulsing for laser exposures to the eye and skin.

The TLVs expressed as radiant exposure or irradiance in this section may be averaged over an aperture of 1 mm except for the eye in the spectral range 400—1400 nm, which should be averaged over a 7 mm limiting aperture (pupil). No modification of the TLVs is permitted for pupil sizes less than 7 mm.

If the corrections are not already made, i.e., in using Tables 5, 6, 7 of the ANSI Standard, then make the indicated corrections. If using the Figures, 5, 6, 7, 10 or 11, note that all corrections are already made, except for 1.54 μm lasers.

16	LASERS I.	CONTROL OF LASER HAZARDS I.	91

MULTIPLE EXPOSURES

EXPOSURES AT SEVERAL
WAVELENGTHS ARE ADDITIVE
ON A PROPORTIONAL BASIS

4. Control Factors (contd.)

   c. Multiple Exposures

   Multiple exposures at different wavelengths are additives on a proportional basis. Each should be calculated separately and added.

16	LASERS I.	CONTROL OF LASER HAZARDS I.	92

MULTIPLE EXPOSURES

MULTIPLE EXPOSURES FROM REPETITIVELY
PULSED LASERS (F < 1 Hz)
PULSES SHOULD BE CONSIDERED ADDITIVE
OVER A TWENTY-FOUR HOUR PERIOD

4. Control Factors

   c. Multiple Exposures (contd.)

      For multiple pulse exposure from repetitive pulsed lasers where the frequency is less than 1 Hertz (Hz) the pulses should be added over a twenty-four period. This has to do with recovery time for damage.

      The daily occupational exposure limits for various wavelengths may be used for determining these limits. (See Lesson 15.)

16	LASERS I.	CONTROL OF LASER HAZARDS I.	93

ASSOCIATED HAZARDS

- COMPRESSED GASES
- CRYOGENIC MATERIAL
- TOXIC MATERIAL
- FIRE
- NOISE
- IONIZING RADIATION

4. Control Factors (contd.)

d. Associated Hazards

Some laser applications, particularly in the research laboratories present associated hazards. These shall be evaluated and appropriate control measures shall be taken. Examples of associated hazards associated are: compressed gas, cryogenic material, toxic material, fire noise and ionizing radiation. These have been discussed in section C4 of this document

The control of associated hazards shall receive the same degree of attention given to the control of lazer hazards. The procedures controls and personnel described in the introduction to lazer hazards. (section D1 of this document). Also apply to associated hazards. The laser control officer shall use standards and guidelines for control of these hazards.

REFERENCES

1. ANSI Standard, *American National Standard for Safe Use of Lserrs*, Z136.1-1976, American National Standards Institute, New York, New York 10018, April, 1976.

2. ACGIH Standard, *A Guide for Control of Laser Hazards*, The American Conference of Governmental Industrial Hygienist, ACGIH, P.O. Box 1937, Cincinnati, Ohio 45201, 1973.

3. *Laser Health Hazards Control*, Air Force Manual, AFM 161—8, Department of Air Force, Headquarters, USAF, Washington, D.C., 20330, April 1969.

4. "Control of Hazards to Health from Laser Radiations," TB MED 229, U.S. Army, 1975.

5. "Non-Ionizing Radiation: Lasers, Microwaves, Light," Chap. 7 in Fundamentals of Industrial Hygiene, Olishevsky and McElroy, Ed., National Safety Council.

6. "Optical Radiation, With Particular Reference to Lasers," by Dr. L. Goldman, *et al.* World Health Organization, 1977, Document ICP/CE p. 803.

LESSON PLAN NO. 17
LASERS II

17	LASERS II	OBJECTIVES	1

AT THE END OF THIS SESSION YOU WILL BE ABLE TO DEMONSTRATE YOUR KNOWLEDGE OF THE FOLLOWING LASER HAZARD CONTROLS:

1. HAZARD EVALUATION
2. PROTECTIVE FACILITIES AND DEVICES
3. OPERATING PROCEDURES
4. TRAINING PROGRAM
5. MEDICAL SURVEILLANCE
6. LASER LAWS AND REGULATIONS

17. LASERS II

At the end of this four hour presentation you will be able to demonstrate your knowledge of the following laser hazard controls.

1. Hazard Evaluation
2. Protective Facilities and Devices
3. Operating Procedures
4. Training Program
5. Medical Surveillance
6. Laser Laws and Regulations

In this lesson we will cover the second part of Control of Laser Hazards. The recommendations for Laser Hazard Controls from the ACGIH and ANSI Standards are reviewed. The OSHA regulations follow the ACGIH and ANSI recommendations.

This lesson includes motion picture, Laser Safety (Univ. of California).

A. HAZARD EVALUATION

17	LASERS II	HAZARD EVALUATION	2

PROTECTION PROGRAM

- LASER SAFETY COMMITTEE
- LASER SAFETY OFFICER

1. Protection Program

Laser safety committees may be warranted by the magnitude of potential hazards of laser operations within the organization. Membership should be skilled in laser technology and have experience in laser hazards.

The Laser Safety Officer is to have authority for supervision and control of laser hazards. His duties are as follows:

Consultative Services. He is to provide consultative services in laser hazard evaluation and control.

Regulations. If a committee does not exist, the Laser Safety Officer will establish and maintain adequate regulations for the control of laser hazards.

Authority. The Laser Safety Officer has the authority to suspend, restrict, or terminate the operation of a laser system if he deems that laser hazard controls are inadequate.

Maintain Records. He will maintain the necessary records required by applicable governmental regulations.

Protective Equipment. If protective equipment is necessary, only that protective equipment approved by the Laser Safety Officer is to be used for control of laser hazards.

17	LASERS II	HAZARD EVALUATION	3

LASER SAFETY OFFICER

- REGULATIONS - PROCEDURES
- ENFORCEMENT
- RECORDS - PERSONNEL AND EQUIPMENT
- PROTECTIVE EQUIPMENT
- SURVEYS
- INSTALLATION/MODIFICATION
- ACCIDENT INVESTIGATION

I. Protection Program (cont)

Personnel Records. He will submit to the appropriate medical officer the persons' names that are obtained in accordance with D4.3, D4.4, and D5.3 of the ACGIH Appendix. He will maintain appropriate records that scheduled medical examinations have been performed.

Surveys. He will survey all areas using laser equipment as frequently as he considers necessary.

Review of Planned Installation or Modification. When submitted, he will review the planned installation or modification of laser equipment relative to laser hazards and their control, approving of the installation or modification only if he is satisfied that laser hazard controls are adequate.

Accidents. On notification of a real or suspected accident resulting from laser operation, he is to investigate said accident and initiate appropriate action.

Approval of Laser System Operation. He will approve a laser system for operation only if he is satisfied that laser hazard controls are adequate.

Warning Systems and Signs. He is to make certain that adequate warning systems and signs are installed in the appropriate locations.

THREE ASPECTS INFLUENCE THE APPLICATION OF CONTROL MEASURES

1. **LASER SYSTEM'S CAPACITY TO INJURE PEOPLE**
2. **ENVIRONMENT IN WHICH LASER IS USED**
3. **PERSONNEL WHO MAY USE THE LASER OR BE EXPOSED.**

2. Classification Scheme

There are three aspects of laser application that influence the total hazard evaluation and thereby influence the application ofcontrol measures, namely:

(a) The laser or laser system's capability of injuring personnel

(b) The environment in which the laser is used

(c) The personnel who may use or be exposed to laser radiation

The laser classification scheme is based on aspect (a). Laser and laser systems classified in accordance with the ANSI standard shall be labeled with the appropriate hazard classification. This hazard classification should be used unless the laser is modified to significantly change its output power or energy, or is enclosed.

Aspects (b) and (c) vary with each laser application and cannot be readily standardized. The total hazard evaluation procedure must consider all three aspects, although in most cases only aspect (a) influences the control measures which are applicable.

17	LASERS II	HAZARD EVALUATION	5

THREE ASPECTS INFLUENCE THE APPLICATION OF CONTROL MEASURES

1. LASER SYSTEM'S CAPACITY TO INJURE PEOPLE
2. ENVIRONMENT IN WHICH LASER IS USED
3. PERSONNEL WHO MAY USE THE LASER OR BE EXPOSED.

2. Classification Scheme (cont)

Effective controls at the laser itself generally mean locating the entire laser system within an opaque enclosure, as is done in most laser microwelding and drilling units used in industry today. This approach is always the most desirable, if practical. In some applications, it is possible to reduce the output intensity of the laser to a safe level without interfering with the operation. This approach may become more widespread in many applications as advances in detector technology make such efforts feasible. The ulitization of less-hazardous infrared wavelengths is also limited by detector technology.

Environmental controls may differ widely, depending on whether the laser is used in a laboratory or out-of-doors. Backstops and shields to exclude the beam from occupied areas are commonly used in both locations. Well-illuminated laboratories and limited-access rooms are important environmental controls. The prevention of unsafe acts by personnel may be achieved by the use of physical barriers, by the application of administrative procedures (education and training), and through careful supervision. The use of protective eyewear is a major control often made mandatory when any risk of injury to the eye exists.

Many specific control measures employed fall into the category of common-sense procedures aimed at limiting laser exposure.

ENVIRONMENTAL FACTORS

EXPOSURE OF UNPROTECTED PERSONNEL TO PRIMARY OR SPECULARLY REFLECTED BEAM REQUIRES:

CALCULATED EXPOSURE

AND/OR

MEASURED EXPOSURE

3. Environmental Factors

Following laser-device classification, environmental factors require consideration. Their importance in the total hazard evaluation depends upon the laser classification. The decision to employ additional hazard controls not specifically required in Section 5 of the ANSI Guide for Class III and Class IV laser devices may depend largely on environmental considerations. The probability of personnel exposure to hazardous laser radiation must be considered as it is influenced by whether the laser is used indoors, such as; in a machine shop, in a classroom, in a research laboratory, or a factory production line; or outdoors, such as: in a mine, at a highway construction site, on the open sea, on a military laser range, in the atmosphere above occupied areas, or in a pipeline construction trench. Other environmental hazards shall be considered. If exposure of unprotected personnel to the primary or specularly reflected beam is expected, calculations or measurements of either irradiance or radiant exposure of the primary or specularly reflected beam, or radiance of an extended source, at that specific location are required. These are discussed in the ANSI Standard.

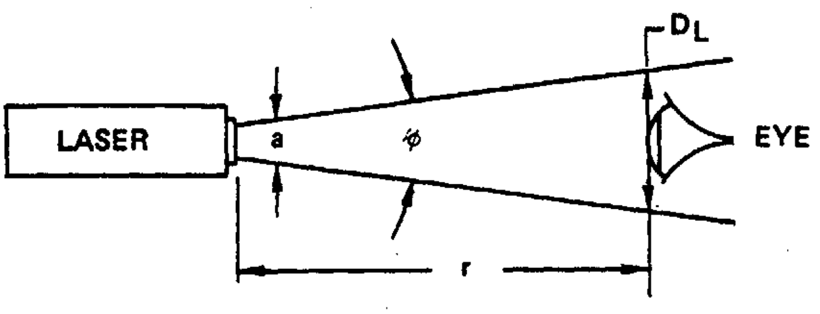
Indoor Laser Operations.

In general only the laser is considered in evaluating an indoor laser operation if the beam is enclosed or is operated in a controlled area. The following step-by-step procedure is recommended for evaluation of Class III laser devices indoors when this is necessary (since there is a potential exposure of unprotected personnel with this particular Class of laser).

Step 1. Determine the hazardous beam path(s).
Step 2. Determine extent of hazardous specular reflection (as from lens surfaces). (See figure 1)*
Step 3. Determine the extent of hazardous diffuse reflections if the emergent laser beam is focused.
Step 4. Determine if other (non-laser) hazards exist .*

*ANSI Standard

BEAM DIVERGENCE



4. Hazard Evaluation Calculations

Permissible viewing for different conditions can be obtained by considering each of the items discussed below:

a. Beam Divergence

The beam divergence is an important consideration in determining beam diameter at far distances from the laser.

In calculating the beam divergence use the following formula:

The relation of beam divergence and beam diameters for small angles is

$$D_L = a + \phi r, \text{ or } \quad \phi = \frac{D_L - a}{r}$$

where:

a = Diameter of beam in cm

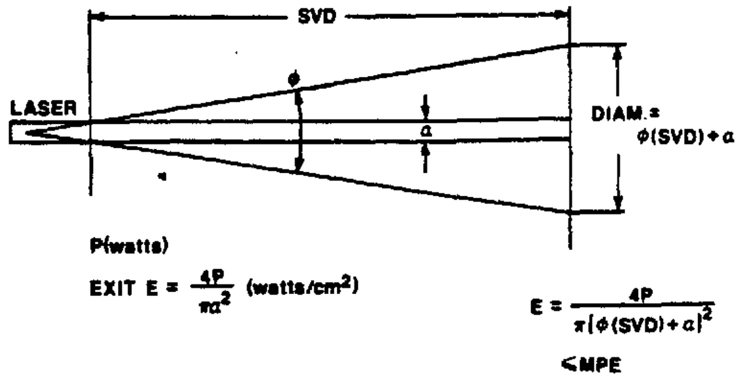
r = Distance from the aperture to laser viewer in cm

ϕ = Beam divergence in radians

D_L = Diameter of beam at r

Since all the energy leaving the laser aperture is spread over the area of the circle with diameter D_L, the radiant exposure and radiance decrease as r increases.

DEFINING DIAGRAM for SAFE VIEWING DISTANCE



4. Hazard Evaluation Calculations (Contd.)

a. Beam Divergence

The beam divergence enters the hazard evaluation because the laser exit irradiance or radiant exposure becomes spread out over a larger beam area at larger distances. Thus the irradiance at some distance r is less than that at the aperture. At some distance, called the "safe viewing distance," SVD, the irradiance, E, in W/cm^2, or the radiant exposure, H, in J/cm^2 will be equal to the MPE E or H, and at greater distances it will be less than the MPE.

17	LASERS II	HAZARD EVALUATION	9

LASER SAFE VIEWING DISTANCE

- EXIT IRRADIANCE $= \dfrac{\text{LASER POWER}}{\text{APERTURE AREA}} = \dfrac{\Phi}{\pi a^2/4} = \dfrac{4\,\Phi\,(\text{WATTS})}{\pi a^2\ (\text{cm}^2)}$

  $$= \frac{1.27\,\Phi}{a^2}\ \text{WATTS/cm}^2$$

- IRRADIANCE AT DISTANCE r (NEGLECTING ABSORPTION)

  $$E = \frac{1.27\,\Phi}{D_L^2} = \frac{1.27\,\Phi}{(a + r\,\phi)^2}\ \text{WATTS/cm}^2$$

- SAFE VIEWING DISTANCE $\approx \dfrac{1}{\phi}\sqrt{\dfrac{1.27\,\Phi\,(\text{WATTS})}{\text{TLV: } E(\text{W/cm}^2)}} - \dfrac{a}{\phi}$

4. Hazard Evaluation Calculations (Contd.)

   b. Safe Viewing Distance

   Safe Viewing Distance, SVD, or permissible Viewing Distance, may be calculated by setting the MPE equal to the irradiance when the distance equals SVD, in the formula for irradiance as a function of distance. The irradiance at any distance r is equal to the radiant power divided by the beam area at that distance. (Here we assume beam uniformity and neglect attenuation in the air.)

   We solve the equation of E as a function of r for the distance r, and set r = SVD with E = MPE. A little algebra gives the approximate formula given on the chart for SVD. To compute SVD one needs to know beam divergence, laser power (i.e., radiant power), aperture size, and the MPE for the particular viewing conditions, wavelength and exposure conditions involved.

THRESHOLD LIMIT VALUE (TLV) FOR DIRECT OCULAR INTRABEAM VIEWING FOR SINGLE PULSES OR EXPOSURES

WAVELENGTH, λ (μm)	EXPOSURE TIME, t (s)	TLV·
VISIBLE AND NEAR-INFRARED		
0.4 - 1.4	10^{-9} to 2×10^{-5}	5×10^{-7} J · cm^{-2}
	2×10^{-5} to 10	$1.8 \times 10^{-3} t^{3/4}$ J · cm^{-2}
0.4 – 0.55	10 to 10^4	10^{-2} J · cm^{-2}
0.4 – 0.7	10^4 to 3×10^4	10^{-6} W · cm^{-2} x C_B
FAR-INFRARED	10^{-9} to 10^{-7}	10^{-2} J · cm^{-2}
1.4-10^3	10^{-7} to 10	$0.56 t^{1/4}$ J · cm^{-2}
	>10	0.1 W · cm^{-2}

4. Hazard Evaluation Calculations (contd.)

c. TLV for Intrabeam Viewing

The next two charts give some MPE values from the ANSI Standard tables and figures. The student should be able to use these tables and figures to determine MPE's for specific cases. As an example, determine the IBV ocular MPE for a ruby laser (693.4 nm) having a 100 ns pulse duration.

Solution:

(1) Find the 400—700 nm range on the IBV ocular exposure table.
(2) Find the exposure duration within which 100 ns lies.
(3) Read the basic MPE value: 5×10^{-7} J/cm^2.
(4) Determine if there are any corrections to be applied. (None in this case.)

The personnel exposure limit is 5×10^{-7} J/cm^2.

17	LASERS II	HAZARD EVALUATION	11

EXPOSURE DURATION FACTOR

$$\text{TLV: } H = \left[\frac{1.8t}{\sqrt[4]{t}}\right] \text{mJ} \cdot \text{cm}^{-2}$$

$$\text{TLV: } H = 1.8 \times 10^{-3}\, t^{3/4}\ \text{J} \cdot \text{cm}^{-2}$$

$$\text{TLV: } H = \frac{1.8 \times 10^{-3}\, t}{\sqrt[4]{t}} = \frac{(1.8 \times 10^{-3})(8 \times 10^{-4})}{\sqrt[4]{8 \times 10^{-4}}}$$

$$= \frac{1.44 \times 10^{-6}}{1.68 \times 10^{-1}} = 8.6 \times 10^{-6}\ \text{J} \cdot \text{cm}^{-2}$$

Since $E \cdot t = H$, we could also express the TLV as:

$$\text{TLV: } E = \frac{H}{t} = \frac{8.6 \times 10^{-6}\ \text{J} \cdot \text{cm}^{-2}}{8 \times 10^{-4}\ \text{s}} = 1.1 \times 10^{-2}\ \text{W} \cdot \text{cm}^{-2}$$

4. Hazard Evaluation Calculations (contd.)

   c. TLV for Intrabeam Viewing

      If the time of exposure in the above ruby laser problem is changed to, say, 0.8 ms, or 8×10^{-4} seconds, then one must use the formula given in Table 5 (see Chart 17-10 here) to determine the MPE. The computation is done on the chart above.

      If the time of exposure were between 10 and 10^4 seconds, then one must use a parameter T_1 (since 693 nm is in the 550—700 nm range) as shown in ANSI Table 5. Alternatively, and a more convenient method, one could use Figure 10 of the ANSI Standard, where the correction is included in the plotted values. For example, if T = 20 seconds, the MPE is 0.8×10^{-4} Watt/cm^2.

TABLE 1(a) *

Intrabeam TLV's which are applicable to many common CW lasers for eye and skin exposure to laser radiation.

Laser Type	Primary Wavelength(s) (nm)	Threshold Limit Value: Eye	Threshold Limit Value: Skin
Helium-Cadmium	441.6	a) $2.5 mW\text{-}cm^{-2}$ for 0.25s	$0.2W\text{-}cm^{-2}$
Helium-Neon	632.8		
Argon	488.514.5	b) $10 mJ\text{-}cm^{-2}$ for 10-10.000s	
Krypton	647.1		
Frq. Doubled ND:YAG	532	c) $1 \mu W\text{-}cm^{-2}$ for > 10,000s	$0.2W\text{-}cm^{-2}$

* ACGIH

4. Hazard Evaluation Calculations (contd.)

   d. Skin Exposure

   For skin exposure TLV use Table 7 of the ANSI Standard or above. You will see that the allowable TLV is 0.2 watts · cm^{-2} (200 mw · cm^{-2}) for all time periods.

17	LASERS II	HAZARD EVALUATION	13

REPETITIVELY PULSED LASER

- NO ALLOWANCE FOR PUPIL SIZE DIFFERENT FROM 7 mm (VISIBLE – NEAR IR)
- IF τ < 10 μSEC, USE FIG. 12 P.R.F. CORRECTION FACTOR
- USE "3-STEP" METHOD TO DETERMINE MPE (SEE CHART 87)

4. Hazard Evaluation Calculations (contd.)

e. Repetitively Pulsed Lasers

Use the methods of Chart 16–87 and 88 for evaluating repetitively pulsed lasers. An example is given in the next few charts.

17	LASERS II	HAZARD EVALUATION	14

MULTIPLE EXPOSURES

FROM REPETITIVELY PULSED LASERS (F > 1 Hz) - CORRECTIONS FACTOR MADE TO TLV

FROM REPETITIVELY PULSED LASERS (F < 1 HZ) PULSES ADDITIVE OVER A 24 HOUR PERIOD.

For multiple exposures from repetitive pulsed lasers, with frequencies greater than 1 Hz, a correction factor is applied to the TLV. For frequencies less than 1 Hz, the pulses are additive over a 24 hour period.

17	LASERS II	HAZARD EVALUATION	15

VERY HIGH PULSE REPETITION RATES

DETERMINE THE INTRABEAM TLV

FOR AN ARGON LASER OPERATING

AT F = 10MHz, t = 10ns.

FOR AN EXPOSURE DURATION OF 0.25s.

4. Hazard Evaluation Calculations (contd.)

   e. Repetively Pulsed Lasers (contd.)

      Consider another problem that provides practice in using the ANSI Standard to find MPE's. We will use the so-called "Three-Step" procedure (See Chart 16–87). This involves (1) determining the "comparable" individual pulse MPE, (2) determining the average power CWMPE for the pulse train, and (3) choosing the smaller of the two values as the repetitively pulsed MPE.

      Problem

      Determine the direct intrabeam threshold limit value of a 514.5 nm (argon) laser for a 0.25 s total exposure, operating at F = 10 MHz and t = 10 ns (i.e., 10^{-8} s).

17	LASERS II	HAZARD EVALUATION	16

PROBLEM:

FIND IBV MPE FOR 514.5 nm LASER, T = 0.25 SEC,

F = 10 MHz, τ = 10 ns

SOLUTION:

(1) CWMPE ($t = \tau$) x n x PRF CORRECTION FACTOR

Class: Work the problem.

PROBLEM:

FIND IBV MPE FOR 514.5 nm LASER, T = 0.25 SEC,
F = 10 MHz, τ = 10 ns

SOLUTION:

(1) CWMPE ($t = \tau$) x n x PRF CORRECTION FACTOR
5×10^{-7} J/cm^2 x 10 x 10^7/SEC x 0.25 SEC x 0.06 = 7.5×10^{-2} J/cm^2

Class continue to work problem.

17	LASERS II	HAZARD EVALUATION	18

PROBLEM:

FIND IBV MPE FOR 514.5 nm LASER, T = 0.25 SEC, F = 10 MHz, τ = 10 ns

SOLUTION:

(1) CWMPE ($t = \tau$) x n x PRF CORRECTION FACTOR =
5×10^{-7} J/cm^2 x 10×10^7/SEC x 0.25 SEC x 0.06 = 7.5×10^{-2} J/cm^2

(2) CWMPE (t = T) = 6.3×10^{-4} J/cm^2

(3) COMPARE AND CHOOSE SMALLER VALUE
REPETITIVELY PULSED MPE = 6.3×10^{-4} J/cm^2
= 2.5 mW/cm^2.

The answer is worked out to this problem on the two previous charts, and shown above. We have also converted the radiant power MPE to an irradiance value, using the fact that T = 0.25 seconds, for a visible laser.

MAXIMUM PERMISSIBLE EXPOSURE
SUMMARY

- VALUES OF E(W/cm^2) OR H(J/cm^2) ON SKIN OR EYE THAT ARE CONSIDERED "SAFE" (FAR BELOW OBSERVED DAMAGE THRESHOLDS)
- VALUES NOT TO BE EXCEEDED BY PERSONS EXPOSED TO LASER LIGHT
- VALUES MAY BE DETERMINED FROM ANSI Z136.1-1976 STANDARD USING METHODS DESCRIBED HERE OR IN THAT DOCUMENT

4. Hazard Evaluation Calculations (contd.)

f. Summary

The previous charts were intended to show how to determine MPE's for different situations. Recall what the MPE's are:

(1) Values of E or H that are considered "safe," i.e., are well below the observed damage thresholds.

(2) Maximum values for personnel exposure to laser light. These values may be obtained from the ANSI Standard using methods described there or here.

SUMMARY – ANSI STANDARD APPLICATION GUIDE

	CWMPE		ADDITIONAL CORRECTIONS NEEDED	
CW	MPE Table	MPE Figure	MPE X CA	MPE X100
IBV $a < a_m$	5	4, 5, 6, 10	....	1.54 μm < 1 μsec
ESV $a > a_m$	6	7, 11	....	1.54 μm < 1 μsec
SKIN	7	....	.7–1.4 μm	....

Pulsed	CWMPE (Additive for 24-hr)	1. MPE = CWMPE ($t = \tau$) x C.F. (Fig. 12) x n 2. MPE = CWMPE ($t = T$) 3. COMPARE (choose smaller)	1. MPE = CWMPE ($t = n\tau$) 2. MPE = CWMPE ($t = T$) 3. COMPARE (choose smaller)
IBV $a < a_m$	$F < 1$ Hz	$\tau < 10\ \mu$sec	$\tau \geq 10\ \mu$sec
ESV $a \geq a_m$	$F < 1$ Hz	$\tau < 10\ \mu$sec	$\tau \geq 10\ \mu$sec
SKIN	$F < 1$ Hz	$\tau < 10\ \mu$sec	$\tau \geq 10\ \mu$sec

NOTES

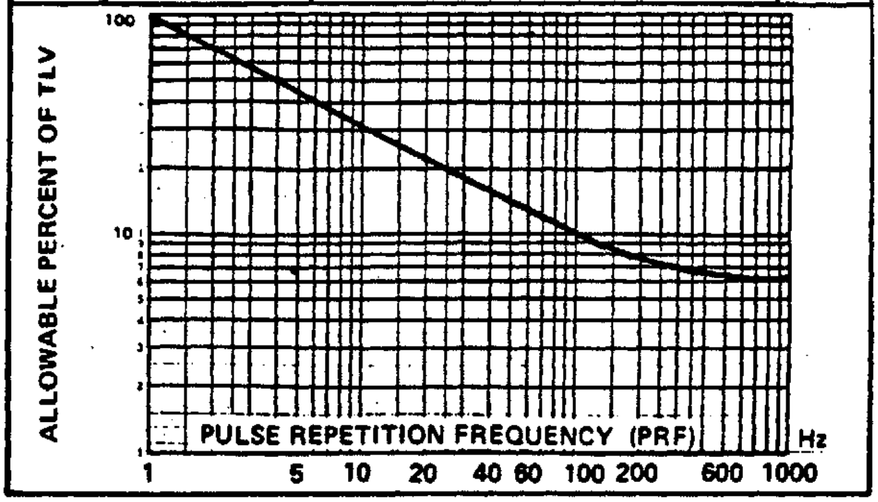
a – angular subtense (Fig. 3)	F – frequency	if T not known:
T – exposure time	n – FT (no. pulses)	T = 0.25 sec VIS
τ – pulse width	$n\tau$ – on time	T = 10 sec UV, IR

4. Hazard Evaluation Calculations (contd.)

f. Summary

An applications guide chart is shown, to assist the user of the ANSI standard in finding the proper tables or figures and making the appropriate corrections in determining MPE values.

17	LASERS II	HAZARD EVALUATION	21



4. Hazard Evaluation Calculations (contd.)

   f. Summary

   This chart shows the pulse repetition frequency (PRF) correction factor for use in the problems.

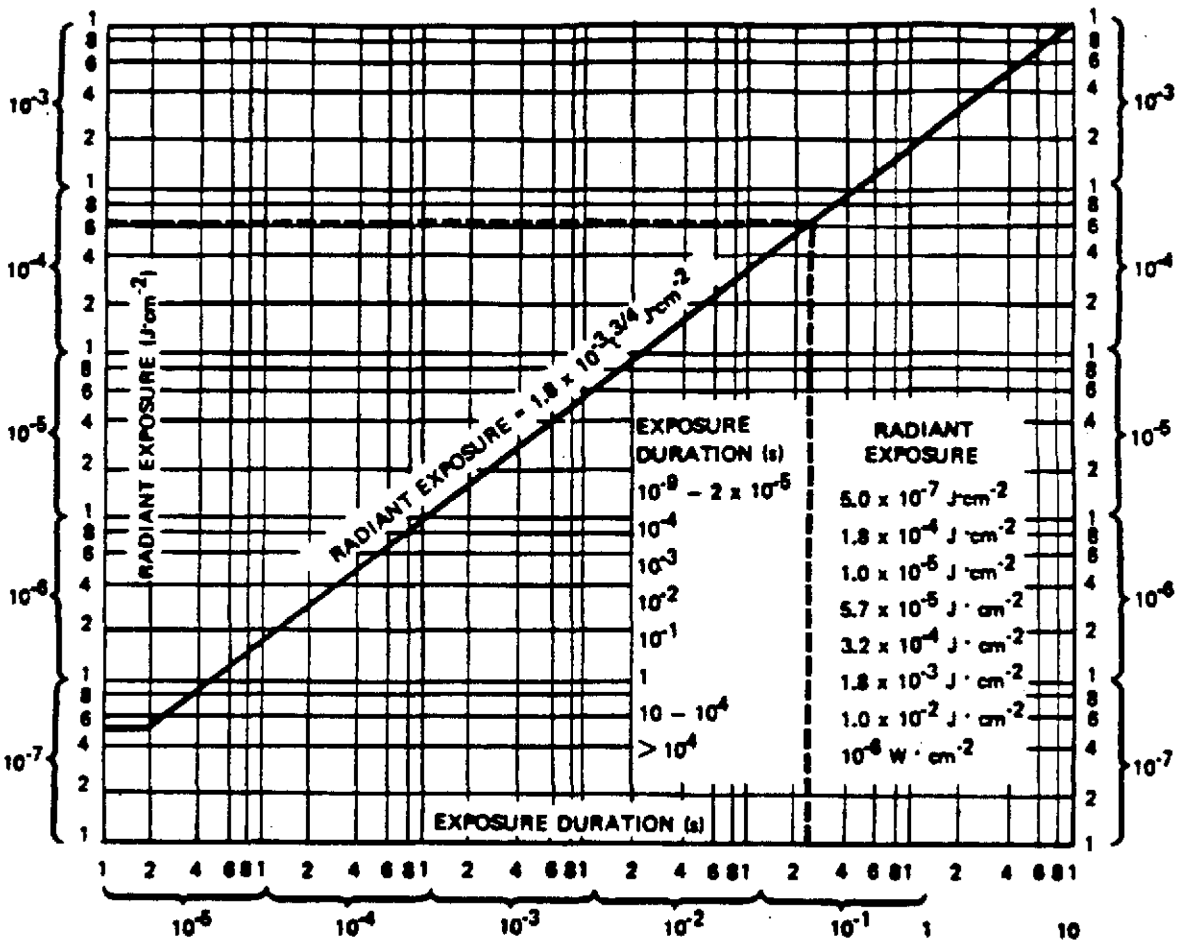
17	LASERS II	HAZARD EVALUATION	22

THRESHOLD LIMIT VALUE (TLV) FOR DIRECT OCULAR INTRABEAM VIEWING FOR SINGLE PULSES OR EXPOSURES

WAVELENGTH, λ (μm)	EXPOSURE TIME, t (s)	TLV
VISIBLE AND NEAR-INFRARED		
0.4 - 1.4	10^{-9} to 2×10^{-5}	5×10^{-7} J · cm^{-2}
	2×10^{-5} to 10	$1.8 \times 10^{-3} t^{3/4}$ J · cm^{-2}
FAR-INFRARED	10^{-9} to 10^{-7}	10^{-2} J · cm^{-2}
1.4-10^3	10^{-7} to 10	$0.56 t^{1/4}$ J · cm^{-2}
	> 10	0.1 W · cm^{-2}

Some MPE values are given for use in the problems.

TLV for Direct Ocular Exposure to Visible Radiation (λ = 0.4 - 1.4 μm), Intrabeam Viewing, for Single Pulses or Exposures



NOTE: For correction factors at wavelengths between 0.7 and 1.4 μm, (see 8.5. – ANSI)

4. Hazard Evaluation Calculations (Contd.)

f. Summary

The chart shows the visible (0.4—0.7 μm) range IBV MPE values as plotted in Figure 4 of the ANSI Standard, for use in the problems.

17	LASERS II	HAZARD EVALUATION	24

REFLECTIONS MAY POSE UNEXPECTED HAZARDS

SPECULAR REFLECTIONS MAY PRODUCE POLARIZED LIGHT FOR DIRECT VIEWING

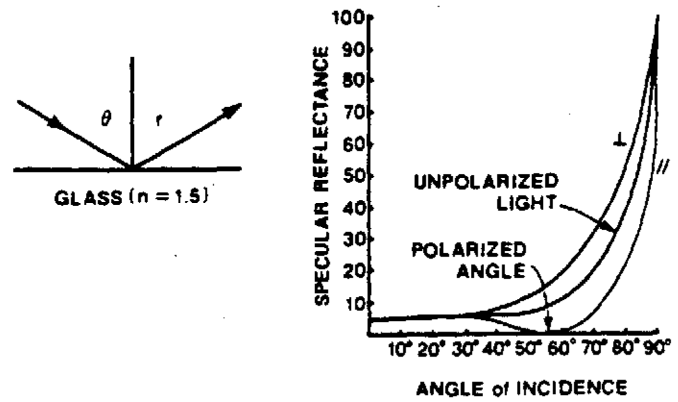
DIFFUSE REFLECTIONS MAY PRODUCE EXTENDED SOURCE VIEWING

4. Hazard Evaluation Calculations (Contd.)

g. Reflections

In laser hazard evaluation, one must be alert to hazards of reflected light, in particular that due to specular or shiny surfaces. Recall that unpolarized light may be polarized by reflection. If light is reflected from diffuse or rough surfaces, the viewing condition may be ESV.

SPECULAR REFLECTANCE
and POLARIZATION EFFECT of REFLECTION



4. Hazard Evaluation Calculations (contd.)

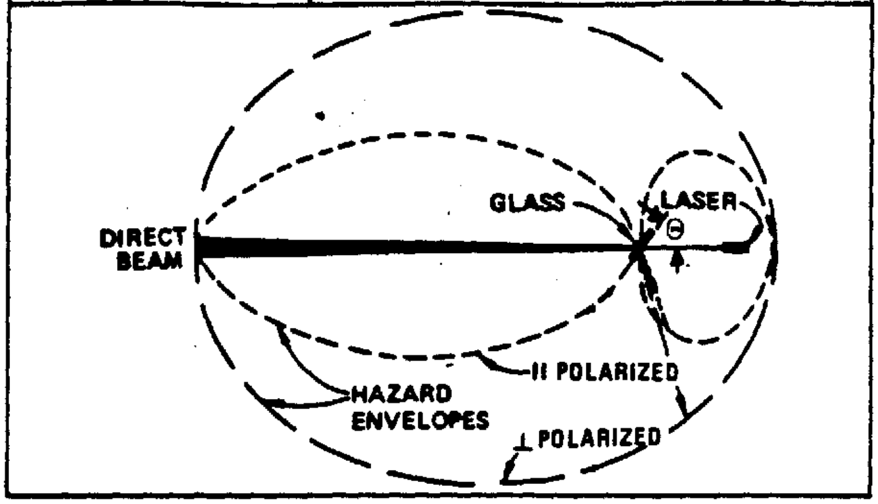
g. Reflections

The variation of reflectance producing polarized and unpolarized light is shown in the chart.

Specular reflection requires a smooth surface. If the reflecting surface is flat, the characteristics of the reflected beam may be considered identical to those of the direct beam except that the range is the sum of the distances from the laser source to reflector and from reflector to the eye. If the surface is not flat, the reflected light intensity arriving at the retina may be less and may be readily calculated for a uniformly curved surface, if the curvature is known. Discounting finely polished mirrors, reflecting surfaces will generally reflect only a fraction of the beam. The magnitude of the reflection is dependent upon the specular reflectivity coefficient and the angle of incidence.

For normal (perpendicular) incidence, typical plate glass and transparent plastics will reflect approximately 8 percent of the incident beam, but at near-gazing incidence, nearly all of the incident radiant energy is reflected. This effect is shown graphically in the figure above. The curves in the figure show reflectance for light of polarization perpendicular (⊥) to the plane of incidence and for light of polarization parallel (//) to the plane of incidence. Such a curve drawn for water would show 2 percent reflection at normal incidence and a polarizing angle at 53°.

17	LASERS II	HAZARD EVALUATION	26



4. Hazard Evaluation Calculations

   g. Reflections (contd.)

      The practical significance of reflectance is shown in the above chart where a collimated laser beam is incident upon a plate glass window at an angle θ.

      The hazard envelops labeled "II polarized" and "⊥ polarized" are isointensity loci for a constant irradiance that is polarized parallel or perpendicular to the plane of incidence (containing the incident light ray and the normal to the surface). What all this means to hazard evaluation is that one should not neglect polarization in measuring intensities around lasers and reflected laser light.

      The angle θ where fan $\theta = n$, the index of refraction of the glass, is called the "polarizing angle." The reflectance is zero and light enters the glass. At higher angles the reflected rays are strongly polarized.

REFLECTIONS FROM NATURAL OBJECTS

- HAZARD ONLY NEAR REFLECTOR

4. Hazard Evaluation Calculations

   g. Reflections

Reflections from Natural Objects

Although most targets encountered in a field situation are reasonably diffuse. some may behave as specular or semispecular reflectors and must be evaluated. Natural surfaces, which provide some form of specular reflection, generally have a small radius of curvature (e.g., water droplets, leaves) such that hazardous reflected levels exist only near the reflector. Still ponds and flat plate glass are the principal reflectors which could produce hazardous reflections at a distance. As a general rule, laser irradiances or radiant exposure which are safe to view by diffuse reflection will not create hazardous reflections from water droplets and natural foliage at viewing distances greater than 1 meter.

17	LASERS II	HAZARD EVALUATION	28

SURVEY LASER MEASUREMENTS ARE NECESSARY WHEN:

- **MANUFACTURER'S INFORMATION IS LACKING**
- **LASER SYSTEM IS NEAR A DIVIDING CLASS LINE**
- **ALTERATIONS HAVE CHANGED THE CLASS**
- **SPECULAR OR DIFFUSED REFLECTIONS NEED EVALUATION**

5. Hazard Evaluation Surveys

   a. Need for Measurement

The laser classification scheme described in Section 3 of the ACGIH Standard is designed to minimize the need for laser measurements and calculations by the user. Generally, such measurements are only required when there is no manufacturer's information available, or the laser or laser system's output is near the dividing line between laser classes, when alterations to a system may have changed its classification, or specular or diffused reflections need to be evaluated.

The cumulative errors due to all sources or inaccuracy, including human factors, operating conditions and instrumental errors, shall not exceed ± 20%, and if this is not possible, the best that the present state of the art will reasonably permit.

If a laser or laser system is used outdoors over long ranges, where the uncertainties of propagation influence exposures, or where the beam divergence is uncertain, measurements may be useful.

17	LASERS II	HAZARD EVALUATION	29

SURVEY

LASER MEASUREMENTS SHALL BE PERFORMED BY TRAINED OR EXPERIENCED PERSONNEL WITH LASER AT MAXIMUM NORMAL OUTPUT

5. Hazard Evaluation Surveys (contd.)

b. Personnel

Measurements should only be attempted by persons trained or experienced in laser technology and radiometry. Routine survey measurements of lasers or laser systems are neither required nor advisable when the laser classifications are known and the appropriate control measures implemented. Measurements made to determine compliance with a standard shall be made when the laser is adjusted for maximum normal output.

17	LASERS II	HAZARD EVALUATION	30

SURVEY

ENVIRONMENTAL FACTORS

EXPOSURE OF UNPROTECTED PERSONNEL TO PRIMARY OR SPECULARLY REFLECTED BEAM REQUIRES:

CALCULATED EXPOSURE

AND/OR

MEASURED EXPOSURE

5. Hazard Evaluation Surveys (contd.)

   c. Environment

      The importance of environmental factors in the total hazard evaluation depends upon the laser classification. The decision to employ additional hazard controls not specifically required in Section 5 of ACGIH Standards for Class II and Class IV laser devices may depend largely on environmental considerations.

      The probability of personnel exposure to hazardous laser radiation must be considered as it is influenced by whether the laser is used indoors, such as in a machine shop, in a classroom, in a research laboratory, or a factory production line; or outdoors, such as in a mine, at a highway construction site, on the open sea, on a military laser range, in the atmosphere above occupied areas, or in a pipeline construction trench. Other environmental hazards shall be considered.

      If exposure of unprotected personnel to the primary or specularly reflected beam is expected, calculations of measurements of either irradiance or radiant exposure of the primary or specularly reflected beam or radiance of an extended source, at that specific location are required.

17	LASERS II	HAZARD EVALUATION	31

INSTRUMENT SET-UP PRECAUTIONS

- NOTHING BETWEEN LASER OR REFLECTING SURFACE AND PROBE
- PROBE SHOULD BE ON TRIPOD
- KEEP PERSONNEL AWAY FROM THERMAL DEVICES
- AVOID REFLECTIONS FROM PROBE FACE
- AIR CONTAMINATION MAY AFFECT READINGS
- RE-ZERO INSTRUMENT & RECHECK READINGS

5. Hazard Evaluation Surveys (contd.)

d. Set-up Precautions

When setting up the instrument for measurements, certain precautions must be taken. There should be nothing between the laser probe and the laser reflective object. The detector probe should be on tripod or equivalent. Personnel should not look at or be around the detector head when taking readings. This is necessary with thermal devices since they are sensitive to body heat. There are possible hazardous reflections from the probe face. Air contamination may affect readings.

Most instruments are directional and need to be lined up properly for measurement.

Recheck instrument zero and recheck readings before recording your results. Some instruments will drift even after a warm-up period.

17	LASERS II	HAZARD EVALUATION	32

SURVEY

INSTRUMENT CLASSIFICATIONS

PHOTON DEVICES

THERMAL DEVICES

5. Hazard Evaluation Surveys (contd.)

e. Instrument Types (contd.)

Because of wide variety of lasers now available with their different wavelengths, pulse durations, power densities, and energy densities detection and measurement may involve more than one instrument or instrument type. A variety of detectors have been utilized and can be classified under one of two general categories: Photon devices and thermal devices. These two classifications of light detectors are based on the two ways in which light interacts with matter. Several laser detection accessories can be used in conjunction with these detectors to provide versatile measurements.

Photon devices measure the rate at which individual light quanta are absorbed. The response at any particular wavelength is proportional to the rate at which photons of that wavelength are absorbed. These detectors have a strong wavelength dependence. The energy output of the laser is directly related to the number of photoelectrons produced, and is based on the response of the particular detector.

There are three ways to categorize photon devices: photoelectric, photoconductive, and photovoltaic.

Thermal devices measure the effect of heat and temperature change on materials when absorbing light energy. There are three general categories: calorimeters, bolometers and thermocouples.

DETECTOR	APPROXIMATE INTENSITY RANGE	COMMENTS
VACUUM PHOTODIODE	0.1μW - 10W	BEST STABILITY, WAVELENGTH-DEPENDENT
PHOTOMULTIPLIER TUBE	< 10μW	MOST SENSITIVE, WAVELENGTH-DEPENDENT, LACK OF LINEARITY OVER INTENSITY RANGES, FOR VERY LOW C.W. POWER LEVELS
PHOTOCONDUCTIVE DETECTOR (SILICON BACK-BIASED)	10^{-9} - 10W	GOOD LINEARITY, WAVELENGTH-DEPENDENT, REQUIRES SEPARATE POWER SOURCE
PHOTOVOLTAIC DETECTOR	0.03 - 1000 mW	SELF-POWERED, POPULAR HE-NE POWER METER
CALORIMETER	0 - 1W 1 - 10,000W	COOLED BY AIR, WATER, OR OIL: LABORATORY STANDARD: WAVE-LENGTH RANGE DEPENDS ON ABSORBING SURFACE
THERMOPILE	0.25W MAX.	CAN BE WATER-COOLED, NOT AS SENSITIVE AS PHOTON DEVICES STANDARD
BALLISTIC THERMOPILE	10^{-3}-500J	LABORATORY STANDARD, WAVE-LENGTH RANGE DEPENDS ON ABSORBING MATERIAL

5. Hazard Evaluation Surveys (contd.)

e. Instrument Types (cont)

Many optical power, energy, pulse shape, and pulse-repetition frequency measuring devices available commercially can be used to determine classification and compliance with standards. Instruments shall be calibrated sufficiently well to permit overall measurement accuracies of ± 20% wherever possible.

Measurements with instruments having smaller effective limiting apertures than those in Table 28 are permitted, provided the appropriate correction factors are applied to assure the required accuracy of measurement.

A variety of such instruments is described in the references of Appendix H4, ANSI Standard.

The different types of instruments or their operating characteristics will not be covered here since they were covered in the Visible, UV, and IR section. Generally the same instruments used to detect visible, UV and IR have been used to measure laser light.

17	LASERS II	HAZARD EVALUATION	34

INSTRUMENTS READ OUT IN:

- WATTS
- JOULES
- AMPS.

CALCULATIONS ARE NEEDED TO DETERMINE IRRADIANCE OR RADIANCE

5. Hazard Evaluation Surveys (contd.)

f. Instrument Read Out

Measurements calculations for some instruments are simpler than others. Instrument readings need to be converted to watts if the instrument does not read directly in these units.

Generally the beam diameter and the power or energy needs to be known. Then divide the instrument reading by the area of the cross section of the beam. For example, exit radiance or irradiance of a laser with energy Q per pulse, or power level, ϕ, watts, and diameter a, is

$$Ho = \frac{4Q}{\pi a^2} = \frac{1.27Q}{a^2}\ ; \quad Eo = \frac{4\,\Phi}{\pi a^2} = \frac{1.27\,\Phi}{a^2}$$

To aid in determining the diameter of the beam at far distances one must consider the beam divergence:

$$D_L = a + \phi r \text{ (for small } \phi\text{); Beam Area} = \frac{\pi D_L^2}{4}\ .$$

Another means of determining the high energy or power beam diameter is to use thermally sensitive paper or emulsions which can be used for lower power lasers.

Instruments whose detectors register amperes or volts have a built-in conversion factor to convert to watts or watts cm^{-2}. Also there may be a response factor to make wavelength corrections.

Instruments were discussed in the visible, UV, IR section and will not be discussed further here. The student should review Lesson 15 and Lab 7 material if necessary.

EXPOSURE CALCULATION/COMPARISON WITH MPE

2 JOULE/PULSE RUBY; 20 μSEC PULSE, 10 Hz, 1 cm DIAMETER

$$E = \frac{\text{AVERAGE POWER}}{\text{BEAM AREA}} = \frac{\left(10\ \frac{\text{PULSES}}{\text{SEC}}\right)\left(2\ \frac{\text{JOULES}}{\text{PULSE}}\right)}{(1\ cm^2)(\pi/4)}$$

$$= \frac{20\ \text{WATTS}}{0.785\ cm^2} = 25.4\ W/cm^2$$

ANSI MPE $= 10^{-6}\ J/cm^2$ (H)

$= 4 \times 10^{-7}\ W/cm^2$ (E)

5. Hazard Evaluation Surveys (contd.)

g. Exposure Calculations

The calculated exposure results need to be checked with the regulations published by your State. Guidelines of the ACGIH or ANSI are given to check our results.

An example problem is as follows:

Problem
Ruby laser 694.3 μm.
(1) 2 joule output per pulse
(2) 20 microsecond pulse width and 10 pulses per second
(3) Beam diameter - 1 centimeter (unfocused)

Step 1
Convert joules to watts.

In this case the pulse width is not needed. Ten pulses of 2 joules each per second = 20 watts.

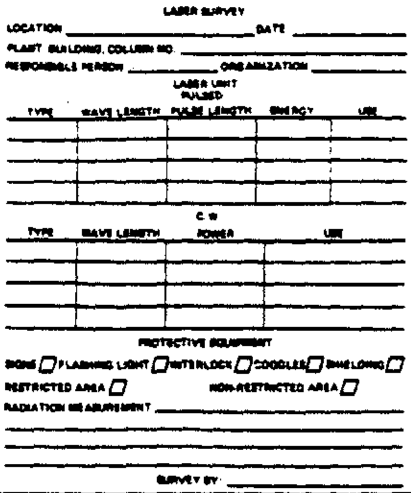
Step 2
Calculate area of cross section of beam

Area of Circle = πr^2
Area = 3.141 x .5^2 cm = 3.141 x .25 = .785 cm^2

Step 3
Divide the number of watts by the area of the cross section of the beam.

$$\frac{20}{.785\ cm^2} = 25.4\ \text{watts} \cdot cm^{-2}$$

The answer of 25.4 watts · cm^{-2} is the average irradiance, and can be correlated with the TLVs or MPE in the ACGIH or ANSI Standards. The student should verify the MPE value shown. Does this laser present a hazard? What precautions should be taken to avoid overexposures?



LASER SURVEY

LOCATION ____________________ DATE __________

PLANT BUILDING, COLUMN NO. ____________________

RESPONSIBLE PERSON __________ ORGANIZATION __________

LASER UNIT
PULSED

TYPE	WAVE LENGTH	PULSE LENGTH	ENERGY	USE

C W

TYPE	WAVE LENGTH	POWER	USE

PROTECTIVE EQUIPMENT

SIGNS ☐ FLASHING LIGHT ☐ INTERLOCK ☐ GOGGLES ☐ SHIELDING ☐

RESTRICTED AREA ☐ NON-RESTRICTED AREA ☐

RADIATION MEASUREMENT ____________________

SURVEY BY: __________

5. Hazard Evaluation Surveys (contd.)

h. Survey Form

The survey form is an important aid in helping control personnel exposure. Its requirements cause safety personnel to come in contact with users and record results of measurements for the safety officer to evaluate.

When completing the survey form you need the following information:

The date of the survey
Location (city, town, state etc.)
Plant, building, column number
Responsible person and his organization
Fill out section that applies–pulsed or continuous laser

Pulsed Laser
- Type of laser
- Wavelength
- Pulse Length & Repetition rate
- Energy
- Use

CW
- Type
- Wavelength
- Power
- Beam diameter at aperature
- Beam divergence

Indicate in the appropriate squares what protective equipment was being used. Indicate the calculation results and TLV or MPE limits in the measurement section along with corrective action.

SAFETY OFFICER NOTIFIES THE
LASER SUPERVISOR OF NEEDED
SAFETY REQUIREMENTS

5. Hazard Evaluation Surveys (contd.)

i. Corrective Action

After the safety officer receives the survey form, he makes his judgement on the control measures or corrective action needed. Corrective action is usually taken by writing a memo to the laser supervisor, and listing the corrections necessary to give his employees a safe environment. The memo and survey are kept as a record and legal proof. A follow-up survey is necessary to confirm that the recommendations have been complied with.

A lack of understanding of the different orders of magnitude of intensity levels found in the laboratory and of the probability of potential accidental exposure is common. A program of educating personnel concerned with laser hazards is an essential part of the total hazard control effort. This must be supplemented by continuing on-the-job supervision. The laser safety problem must be presented in perspective with other hazards encountered on an everyday basis.

B. INDUSTRIAL USES OF LASERS

17	LASERS II	INDUSTRIAL USES OF LASERS	38

MOTION PICTURE "INDUSTRIAL USES OF LASERS" SHOWS:

ALIGNMENT
QUALITY CONTROL
COMMUNICATIONS
HOLOGRAPHY
RESEARCH
WELDING AND CUTTING

ADDITIONAL USES ARE OUTLINED IN THE TEXT.

Laser Usage in Industry - An Outline

USES OF LASER RADIATION

A. Precision Measurement

1. Alignment
2. Distance Determination
3. Seismographic Monitoring

B. Welding

C. Material Removal

1. Drilling
2. Trimming
3. Evaporation and Deposition

D. Material Shaping

1. Cutting
2. Scribing
3. Controlled Fracturing

E. Thermal Induction

1. Annealing
2. Surface Oxidation
3. Diffusion
4. Photochemical Reactions

F. Scattering Effects

1. Contamination Measurements
2. Velocity Measurements

G. Interferometry and Holography

H. Research

1. Biology
2. Cancer
3. Ophthalmology
4. Dermatology
5. Dentistry
6. Communications
7. Guidance
8. Teaching
9. Data Processing and Recording

PROTECTIVE FACILITIES AND DEVICES

HELP PROVIDE A WORKING AND PUBLIC ENVIRONMENT FREE FROM LASER RADIATION HAZARD.

1. Classification

A complete safety program must be maintained for the protection of operating personnel and such other persons as may be required to be present at laser installations. When indicated, suitable facilities and devices should be provided as indicated by the nature of the operation.

PROTECTIVE FACILITIES REQUIREMENTS BY LASER CLASSIFICATION

LASER CLASS	FACILITIES & DEVICES
I	NONE
II	YES*
III	YES
IV	YES

* DEVICE ONLY

I. Classification (cont)

Protective facilities and devices vary, depending on the type of laser being used and the manner of its use. Most control facilities depend upon the lasers' classification. In general, a Class I Exempt Laser Device is one that is considered to be incapable of producing damaging radiation levels and is, therefore, exempt from any control measures or other forms of surveillance.

A Class II Low Power Laser Device may be viewed directly, but must have a cautionary label warning against continuous intrabeam viewing affixed to the device.

A Class III Medium-Power Laser Device requires control measures that shall prevent viewing of the direct beam.

A Class IV High-Power Laser Device requires the use of controls which shall prevent exposure of the eye and skin to the direct and diffusely reflected beam.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	41

ENVIRONMENTAL & PERSONNEL CLASSIFICATION REQUIRE THAT

A LASER CONTROL OFFICER SHOULD BE CONSULTED ON ANY PROTECTIVE FACILITIES OR DEVICES PLANNED FOR ANY LASER OPERATION

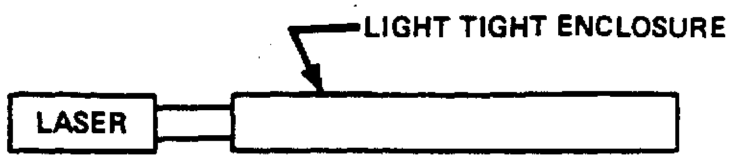
I. Classification (cont)

It must be remembered that the classification scheme relates specifically to the laser itself and its potential hazard, based on operating characteristics. However, environmental and personnel factors may play a role in determining the full extent of hazard control measures and facilities. A responsible person, designated as Laser Safety Officer should be consulted. He will be responsible for providing informed judgments on situations not specifically covered by available standards. Only properly indoctrinated persons shall be designated Laser Safety Officers or be placed in charge of Class III and IV laser installations or operations.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	42

THE SAFEST SYSTEM

A COMPLETE ENCLOSURE OF A LASER BEAM SHOULD BE USED WHEN FEASIBLE



2. Closed Installation

The complete enclosure of a laser beam (an enclosed laser) shall be used when feasible. A closed installation provides the next most desirable hazard control measure.

By enclosing the laser beam in a light-tight enclosure, all of the light hazards can be eliminated. This is probably the safest system for use of laser equipment.

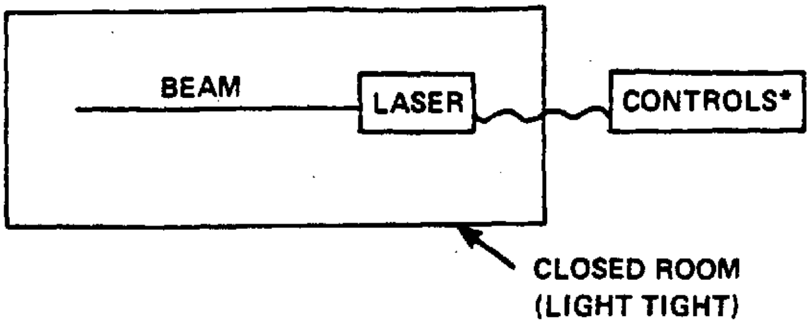
17	LASERS II	PROTECTIVE FACILITIES & DEVICES	43

ENCLOSED LASER BEAMS

The picture shows a mill operation in which three laser units are used to program the machine's movement. They are all 2mW Helium–Neon Interferometers.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	44

A CLOSED INSTALLATION IS DESIRABLE FOR SAFETY



*CONTROL FOR REMOTE FIRING

2. Closed Installation (cont)

Provision of a closed installation is desirable. A closed installation is any location where lasers are used which will be closed to personnel during laser operation, such as by remote firing and TV monitoring operations.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	45

CLOSED INSTALLATION

This laboratory can be classified as a closed installation. The room is light-tight. It has locks on the doors to prevent anyone from entering when the laser is operational and all the control mechanisms are located outside of the room. This is a Class IV CO_2 laser system which is a safe operation because it is enclosed.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	46

PROTECTIVE FACILITIES ANᴰ DEVICES PLAY A MAJOR ROLE IN HAZARDS CONTROL FOR INDOOR OPERATIONS OF LASERS

2. Closed Installation (cont)

Protective facilities and devices play major roles in hazard control for the indoor operation of lasers. It is easiest to see these roles by discussing each indoor laser classification and by listing the protective requirements.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	47

CLASS IV HIGH POWER LASER INSTALLATION REQUIREMENTS:

1. RESTRICTED AREA
2. FAIL-SAFE FIRING CIRCUIT
3. ALARM SYSTEM
4. GOOD ROOM ILLUMINATION
5. REMOTE FIRING - T.V. MONITOR
6. BEAM STOPPER & VENTILATION
7. BEAM ENCLOSURE, CO_2 LASER

3. Class IV Requirements

   a. General

Class IV High-Power Laser Installations: Pulsed Class IV visible and near-infrared lasers are hazardous to the eye from direct beam viewing and from specular and diffuse reflections of the laser beam, and are generally also hazardous to the skin. Class IV pulsed ultraviolet, infrared, and all CW lasers present a potential fire and skin hazard.

Safety precautions associated with high-power lasers generally consist of using door interlocks to prevent exposure to unauthorized or transient personnel entering the laboratory, the use of baffles to terminate the primary and secondary beams, and the wearing of safety eyewear by personnel within the interlocked facility.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	48

CLASS IV HIGH POWER LASERS
RESTRICT ENTRY TO LASER

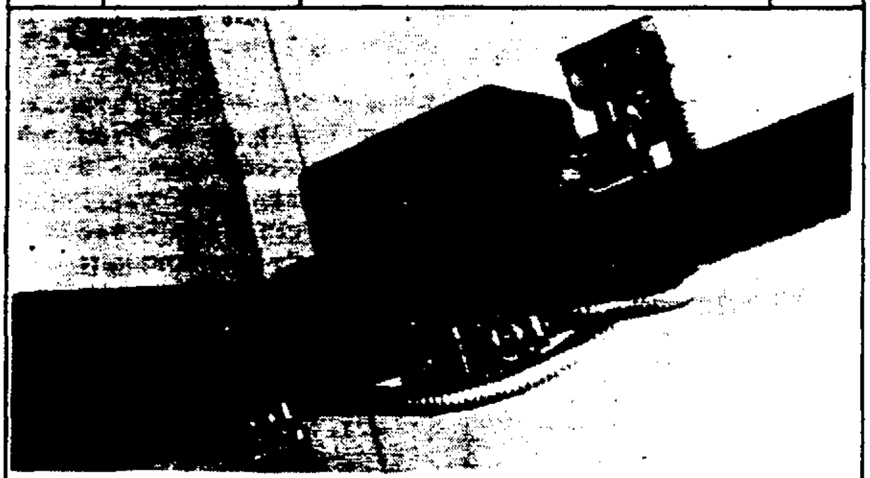
1. INTERLOCKS
2. LOCK AND KEY
3. COMBINATION LOCKS
4. SIGNS

3. Class IV Requirements (cont)

b. Restricted Entry

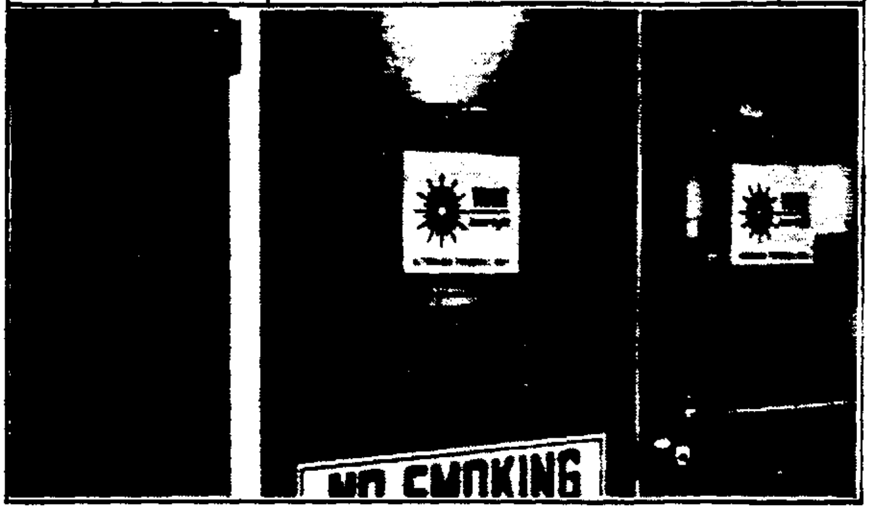
Unauthorized or transient personnel shall be denied access to the facility while the laser is capable of operating by using safety interlocks or similar devices at the entrance of the laser facility.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	49



The interlock shown here functions both in the interlock mode and also what is called a prison lock mode. If the experiment requiring the operation of a laser is critical and should not be stopped unexpectedly by someone tripping the interlock, the prison bolt may be activated. With the bolt activated, no one can enter the hazard area.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	50



3. Class IV Requirements

   b. Restricted Entry (cont)

      This is an example of a controlled laser laboratory area. The area is not only controlled by an electronic combination lock shown on the left side of the door, but also has warning signs on the doors themselves. With the combination electrical lock system, only personnel knowing the push button combination may enter the laboratory. These locks can be interlocked to any of the lasers in the facility. In this way a particularly hazardous laser could be deactivated when the door was opened.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	51

CLASS IV HIGH POWER LASERS

MUST HAVE A FAIL SAFE SYSTEM FOR FIRING.

1. **LOCK KEY SYSTEM**
2. **DELAY COUNT DOWN SYSTEM**
3. **COVER BOX OVER SWITCH**

3. Class IV Requirements (cont)

c. Fail Safe System

Laser electronic-firing systems for pulsed lasers should be so designed that accidental pulsing of a stored charge is avoided. The firing circuit design should incorporate a "Fail-safe" system in this regard.

In order to ensure a fail-safe system for firing a high powered laser, one or a combination of the three above systems should be used. The lock and key system is a positive lockout type where only the operator of the laser has a key to activate the system. Operating procedures should be set up to ensure that the key is never left in the lock unattended. A delay countdown system consists of an electronic delay of 30 seconds or more which is required before the laser system can be activated. During this electronic delay a manual countdown or automatic countdown can be utilized. If the system cannot accept a lock and key then a locked cover box may be installed over the "ON" switch.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	52

CLASS IV HIGH POWER LASER

MUST HAVE AN ALARM SYSTEM TO SIGNAL LASER HAZARD.

1. **SOUND DEVICE**
2. **FLASHING LIGHT**
3. **AUTO DELAY COUNTDOWN**

3. Class IV Requirements (cont)

d. Alarm System

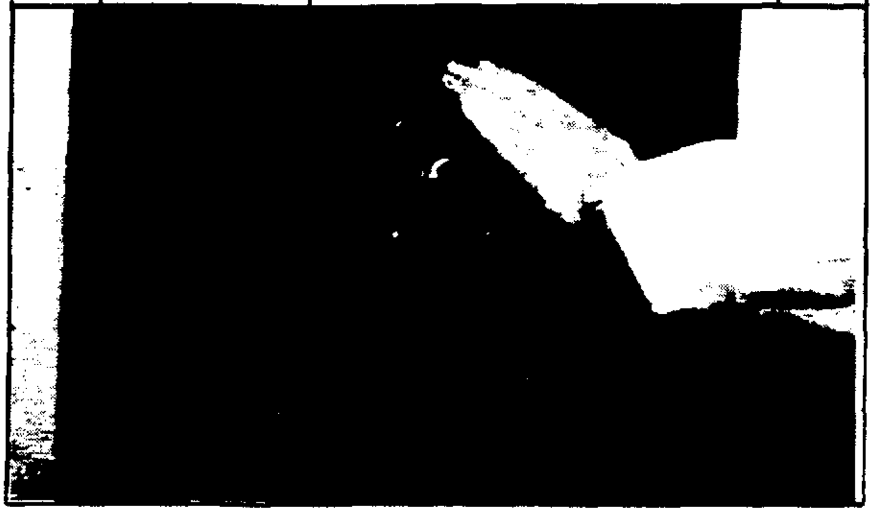
An alarm system including a muted sound and/or flashing lights (visible through laser protective eyewear) and a countdown procedure should be used with pulsed lasers once the capacitor banks begin to charge.

When the capacitor bank is charged, a flashing light or sound device should so indicate. Again, the automatic delay countdown system can be used prior to activation of the laser.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	53

The horn and television camera are part of a safety system on a Class IV CO_2 Laser system. The horn is activated 30 seconds prior to operation of the laser. The television camera is on whenever there is activity in the hazard area.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	54



3. Class IV Requirements (cont)

   e. Panic Button

      Located within each high hazard area should be a Panic Button. This electrical switch will stop the operation of any high powered laser when pushed. Once pushed, it must be re-set by the operator. If a worker is inadvertently caught in the hazard area and he hears the warning horn, he may "scram" the laser by pushing the button.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	55

CLASS IV HIGH POWER LASERS

MUST HAVE GOOD ROOM ILLUMINATION WHERE THEY ARE USED.

1. **ILLUMINATION**
2. **LIGHT COLORED DIFFUSE ROOM SURFACES**

3. Class IV Requirements (cont)

f. Illumination

Good room illumination is important in areas where laser eye protection is required. Light colored, diffuse surfaces, in the room help achieve this condition.

Thought should be given to the type of lighting and paint used within a laser facility. The lighting should be at least 50 foot candles, and the walls painted with a light color to help brighten the room. The bright area will help reduce eye retinal exposure by restricting the pupil opening. The walls should also be rough so that they can present a diffuse surface for the laser light if it is accidentally placed upon the wall.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	56

3. Class IV Requirements

   f. Illumination (cont)

      This area is well lighted and will certainly help restrict the pupil opening. Also note that the walls are a light color and have a diffused surface. One other protection feature that should be pointed out in this facility is the black curtain which can be used as a shield between the laser operations within the room. The curtain does not necessarily have to be black, and in some cases it is better to have a light colored curtain if illumination of the room is a problem.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	57

CLASS IV HIGH POWER LASERS

SHOULD BE OPERATED BY REMOTE CONTROL.

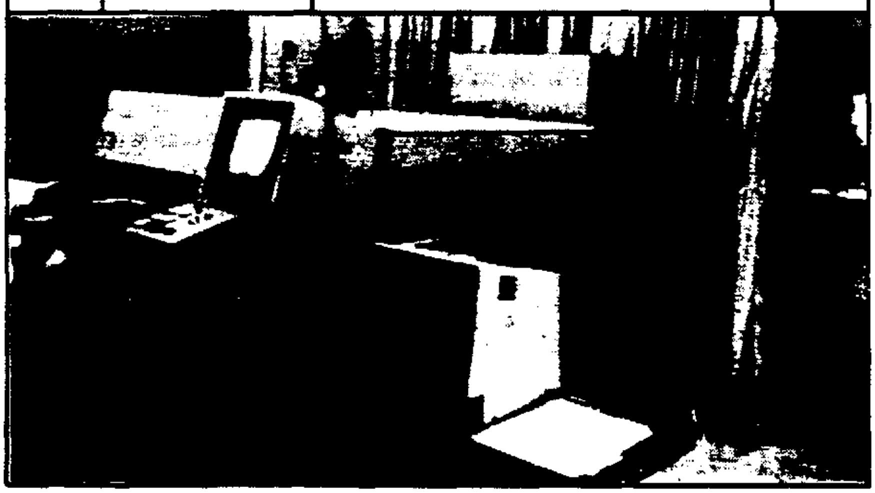
1. **TELEVISION**
2. **LIGHT TIGHT BOX**

3. Class IV Requirements (cont)

g. Remote Controls

Very high-energy or high-power lasers should be operated by remote control firing with television monitoring, if feasible. This eliminates the need for personnel to be physically present in the same room. The enclosure of the laser, the associated beam, and the target in a light-tight box is an equivalent alternative.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	58



A high powered Class IV laser is enclosed in a light-tight box but viewed through a television in this printed circuit cutting system. The laser is a Neodynium YAG of 1 Watt power. This trimmer operation can certainly be classified as a closed system. The same principle can be used on lasers located within a room.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	59

CLASS IV HIGH POWERED INFRARED LASER.

MUST HAVE FIRE AND REFLECTION PROBLEMS SOLVED

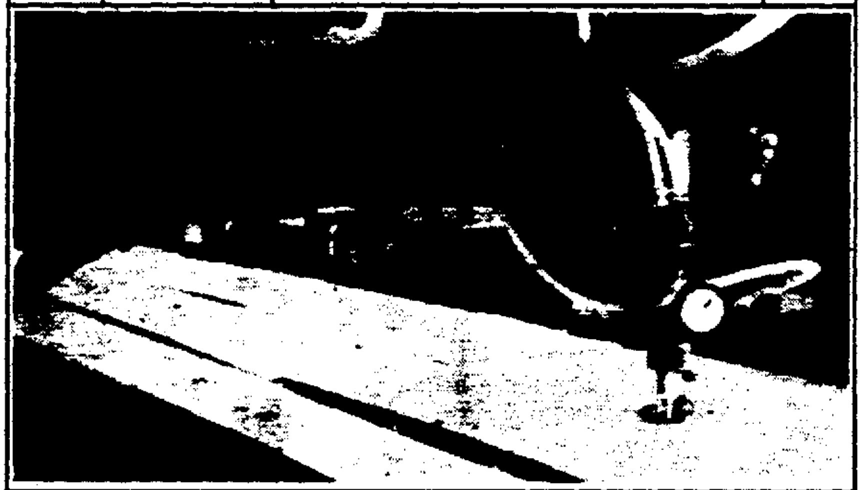
1. **FIREBRICK BACK STOP**
2. **LUCITE OR PLEXIGLASS SHIELDS**
3. **VENTILATION**

3. Class IV Requirements (cont)

h. Fire Protection and Ventilation

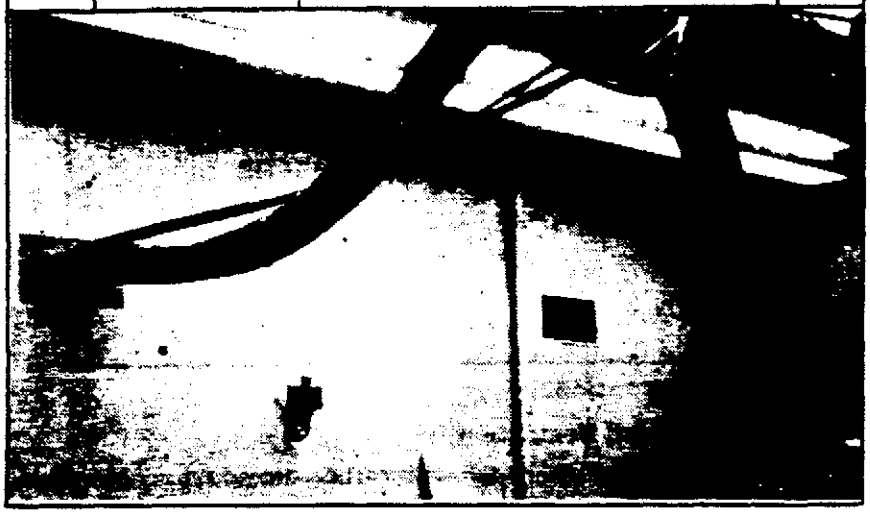
The principal hazard associated with carbon-dioxide, hydrogen-fluoride deuterium-fluoride, and carbon-monoxide lasers and other high-power infrared lasers is the fire hazard. A sufficient thickness of firebrick or asbestos should be provided as a backstop for the beam. Reflections of far-infrared laser beams should be attenuated by enclosure of the beam and target area or by eye-wear constructed of a material such as Lucite or Plexiglass opaque to the laser wavelength. Even dull metal surfaces may be highly specular at the CO_2 laser wavelength of 10.6 μm.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	60



A 250 Watt CO_2 cutting laser is located within this system. The picture does not show it but the laser is backstopped under the cutting edge by a series of firebricks. Local ventilation is located under the cutting table, pulling the smoke and toxic fumes down and away from the cutting area. The beam itself is enclosed, and not even the scatter can be seen by the operator of the unit. This is accomplished by the light-tight tube that rides on the surface of the cutting material, thus shielding the laser beam and its reflected energy.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	61

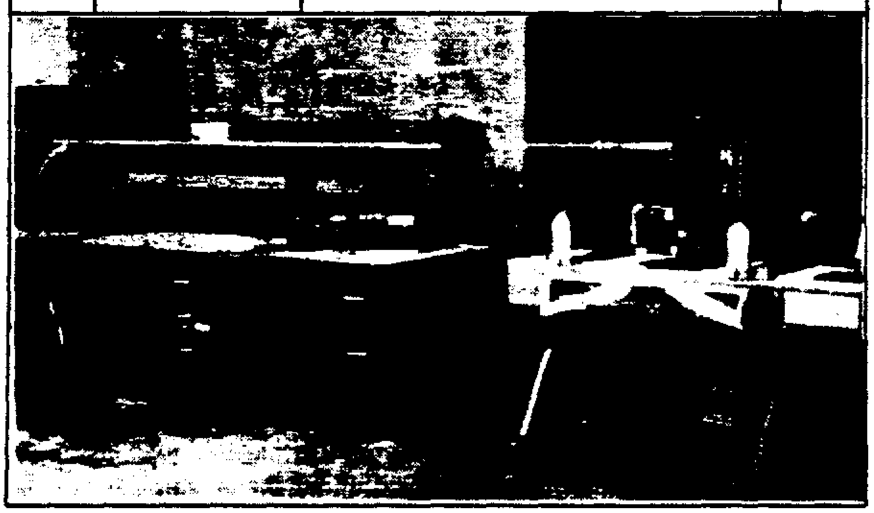


3. Class IV Requirements

h. **Fire Protection and Ventilation (contd.)**

This is an experimental setup with localized ventilation which will be used in a laser cutting operation. As you can see, the flex pipe can be moved and located where necessary to remove any smoke or fumes.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	62



This is also a CO_2 laser system. It's being used in an experimental setup. The operation is set under a ventilation system and portable plexiglass shields are used around the cutting area.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	63

CLASS III MEDIUM POWER LASERS

INSTALLATION REQUIREMENTS

1. **WELL CONTROLLED AREA**
2. **NO SPECULAR SURFACES**
3. **TERMINATE BEAM WITH DIFFUSE MATERIAL AND MINIMUM REFLECTION**
4. **EYE PROTECTION FOR DIRECT BEAM VIEWING**

4. Class III Requirements

a. General

III Medium Power CW or Pulsed Laser Systems have special installation requirements and precautions. These laser systems are potentially hazardous if the direct beam is viewed by the unprotected eye (intrabeam viewing). Care is required to prevent direct beam viewing and to control specular reflections. Some special considerations are:

(1) Well controlled area

(2) No specular surfaces

(3) Terminate beam with diffuse material and minimum reflection

(4) Eye protection for direct beam viewing

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	64

CLASS III MEDIUM POWER LASERS.

SHOULD NOT BE AIMED AT SPECULAR SURFACES

1. **INTERLOCK LASER POSITION OR TRAVEL STOPS**
2. **REMOVE SPECULAR SURFACES**
3. **BEAM ENCLOSURE**

4. Class III Requirements (cont)

   b. Specular Surfaces

   Medium powered lasers present an eye health hazard, therefore great care must be taken not to aim the laser at any specular surfaces. The reflected light would certainly cause an injury. Methods of preventing this type of reflection are as follows: Interlock the laser position so that it cannot move either horizontally or vertically. If the laser must move in a tracking mode then travel stops should be installed on the system. Removing specular surfaces from the laser area is also a good policy. If at all possible, the best solution is to enclose the laser beam.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	65

4. Class III Requirements

b. Specular Surfaces (cont)

This slide shows the operation of an argon laser where all of the reflective surfaces have been removed from the operation area. A black curtain has been placed around the beam to eliminate any possibility of scatter. The laser here is being used to monitor the plume of a jet engine.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	66

CLASS III MEDIUM POWER LASER.

SHALL OPERATE IN A WELL CONTROLLED AREA.

1. **PERSONNEL CONTROL**
2. **INTERLOCKS**
3. **POSTED**

c. Controlled Area

Class III medium powered lasers should be operated in well controlled areas. This means areas that are controlled to eliminate unauthorized personnel. This can be accomplished by interlocking the doors and posting them, placing electric combination locks on the doors, or by a receptionist in the lobby of the laser laboratory.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	67

4. Class III Requirements

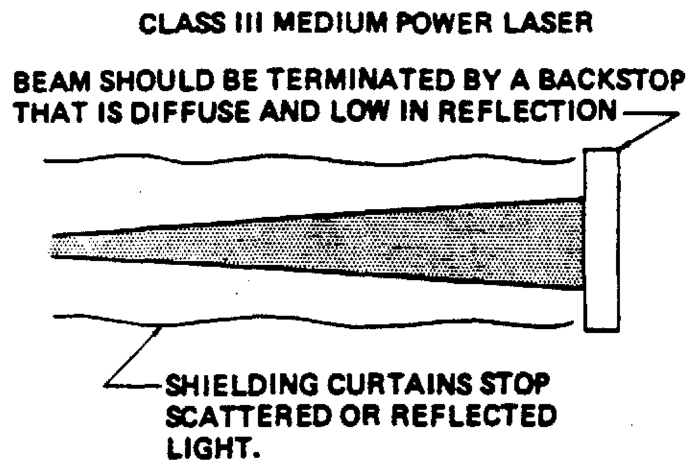
   c. Controlled Area (cont)

   This slide shows the reception area which is guarded both by the receptionist and an electronic lock on the door. Only authorized personnel are allowed in the hazard area.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	68

A 9.4 Watt argon laser is used in this electronic circuit board inspection system. The laser and beam is placed within a light-tight box and interlocked so that it cannot be operated with the lid in the open position. The pencil is pointing to the interlock system.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	69

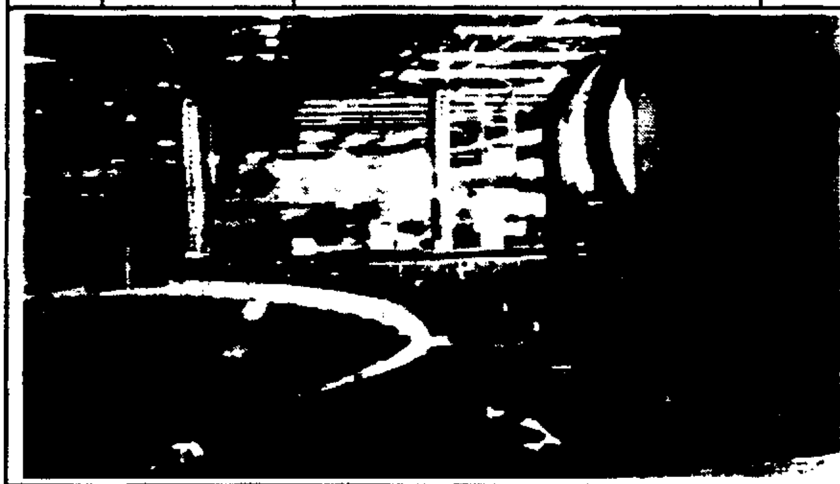


4. Class III Requirements (cont)

   d. Beam Termination

   The laser beam should be terminated where feasible at the end of its useful beam path by a material that is diffuse and of such color or reflectivity to make positioning possible but minimize the reflection. This can be accomplished by backstopping the operation, a shielding curtain is used to stop any scattered or reflected light.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	70



This slide shows the operation of a Helium-Neon 1.5 mW laser being used to map a radar antenna enclosure. The laser was both interlocked into that position along with a backstop above the antenna enclosure to stop the laser beam.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	71

CLASS II LOW POWER LASERS:

REQUIREMENTS

1. **WARNING LABEL**
2. **SHUT OFF FOR SCANNING LASERS**

5. Class II Requirements

Specific Precautions Applicable to Class II Low-Power Visible Lasers:

Installation precautions are required only to prevent continuous staring into the direct beam; momentary (0.25s) exposure as would occur in an unintentional viewing situation is not considered hazardous.

a. The laser beam shall not be purposefully directed toward the eye of any person for hazardous exposure durations.

b. A warning label reading, "CAUTION DO NOT STARE INTO LASER BEAM" (see Section 5c ACGIH) shall be located in a conspicuous location on the laser.

c. Scanning lasers which must be scanning to meet the requirements of a Class II laser shall be designed to prevent laser emission if scanning ceases.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	72

5. Class II Requirements (cont)

It is necessary to place this type of sign on all Class II low power lasers. It must be in a conspicuous location so that all personnel are aware of the laser's operation and are cautioned not to stare into the beam.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	73

EQUIPMENT REQUIREMENT FOR OUTDOOR OR FIELD OPERATIONS

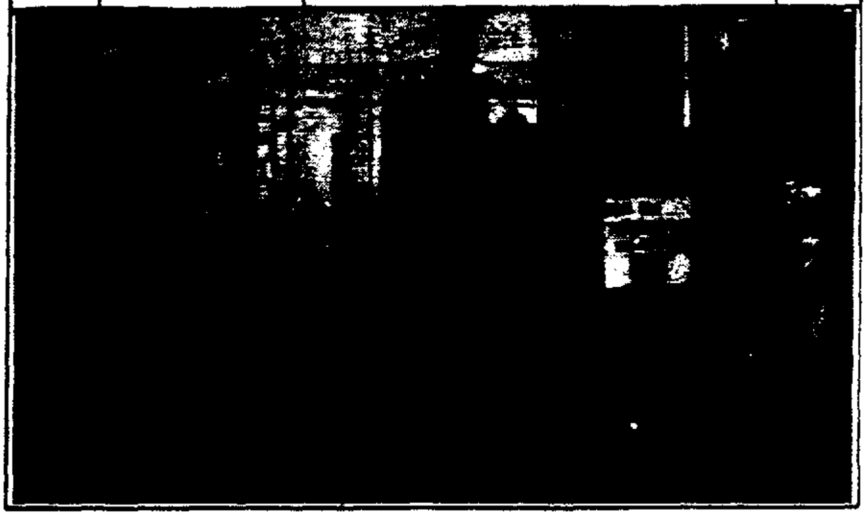
1. SIGNS & FLASHING LIGHTS
2. PHYSICAL BARRIERS (ROPE, FENCE, ETC.)
3. BACKSTOP
4. LASER ELEVATION & TRAVERSE LIMITS

6. Other Equipment

   a. General

      For outdoor or field operations, certain equipment is required. This equipment will help ensure that the out-of-doors or field operation is conducted in a safe manner. Signs and flashing lights should warn passersby that it is a laser operation and they should not enter the hazard area. The hazard area should be enclosed within a physical barrier. This barrier could be ropes, saw horses, or fencing material. A backstop for the beam is necessary. The laser which is to be taken into the field should be interlocked so that it cannot travel either in elevation or traverse beyond the backstop. Other equipment which can be taken are portable bullhorns and light monitoring equipment.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	74



6. Other Equipment

a. General (cont)

This slide shows a field operation utilizing three 1.5 mW Helium-Neon alignment lasers. As can be seen, there is a backstop for the laser beam and the hazard area is roped off and posted before the operation begins.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	75

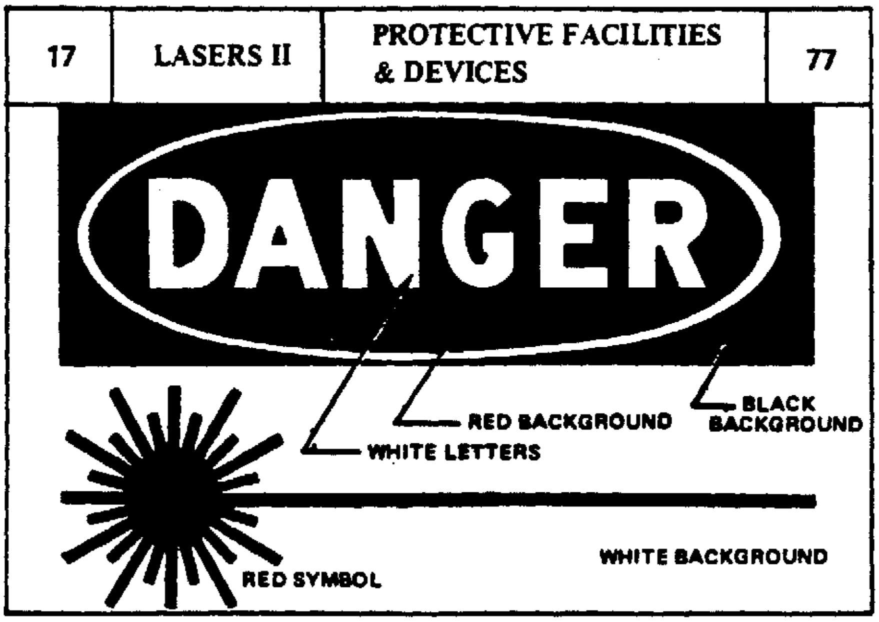
b. Signs

There are three kinds of warning signs that inform people of the degree of danger from laser operations. This sign is for LOW POWER LASERS only.

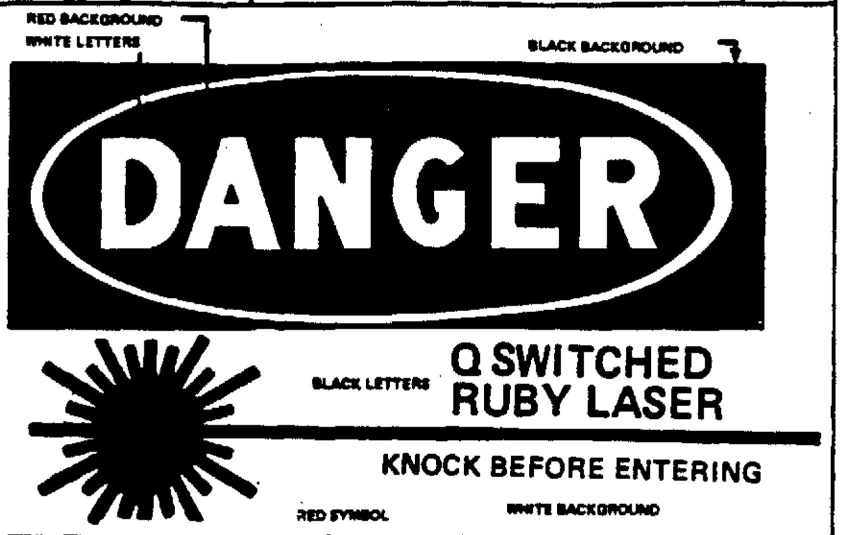
6. Other Equipment

b. Signs (contd.)

Label for MEDIUM POWER VISIBLE LASER having a total power output below 5mW but a maximum beam irradiance less than 2.5mW cm^{-2}.



Labels and Signs for MEDIUM AND HIGH POWER LASERS Only: (Blank format)



6. Other Equipment

   b. Signs (cont)

      This is an example of a MEDIUM AND HIGH POWER LASER sign with sample hazard control information filled in.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	79

LASER PROTECTIVE EYEWEAR IS AVAILABLE FROM COMMERCIAL SOURCES

1. **BUT CONSIDER -IS EYEWEAR NECESSARY?**

2. **DETERMINE THE PROPER EYEWEAR FOR THE SPECIFIC SITUATION**

7. Protective Eyewear

a. Background

Laser protective eyewear is presently available from several commercial sources and in many varieties. Several factors should be considered in determining whether eyewear is necessary and, if so, selecting the proper eyewear for a specific situation. At least two output parameters of the laser must be known, as well as knowledge of environmental factors such as ambient lighting and the nature of the laser operation. Laser eye protection generally consists of a filter plate or stack of filter plates, or two filter lenses, which selectively attenuate at specific laser wavelenghts, but transmit as much visible radiation as possible. Eyewear is available in several designs—spectacles, coverall types with opaque side-shields, and coverall types with somewhat transparent side-shields.

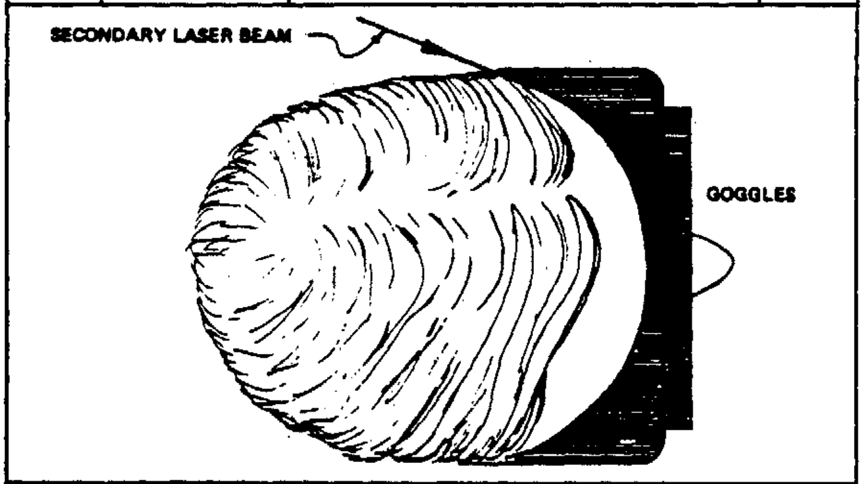
17	LASERS	PROTECTIVE FACILITIES & DEVICES	80

7. Protective Eyewear

   a. Background (cont)

   Present,commercially-available laser eye protection has a variety of designs.

17	LASERS	PROTECTIVE FACILITIES & DEVICES	81



There is a potential hazard of observing a specular reflection when individual is turned away from laser. This could be a more serious problem with glasses.

REQUIREMENTS FOR LASER EYE PROTECTION

OUTDOOR SITUATIONS
CLASS III & IV

INDOOR OR LABORATORY SITUATIONS
CLASS IV

7. Protective Eyewear (cont)

b. Protection Requirements

The experience gained from evaluating ocular hazards of a large variety of field lasers shows that requirements for eye protection vary considerably. The primary usefulness of laser eye protection is in testing of, and training with, laser devices.

Requirements for Laser Eye Protection

(1) Outdoor Application

Eye protection is seldom required for personnel downrange within the laser beam or for other personnel if the laser is a Class II device. For Class III or IV lasers the more desirable hazard control procedure is to remove specular targets from the beam path area to eliminate the requirement for eye protection for all but the personnel within the beam path.

(2) Indoor Shop or Laboratory Applications

Eye protection is required for high-energy or high-power lasers and where viewing the beam is non-essential. However, eye protection has not been recommended for holographic viewing and optical alignment procedures if reasonable precautions are taken.

REQUIREMENTS FOR LASER EYE PROTECTION

OUTDOOR SITUATIONS
CLASS III & IV

INDOOR OR LABORATORY SITUATIONS
CLASS IV

7. Protective Eyewear

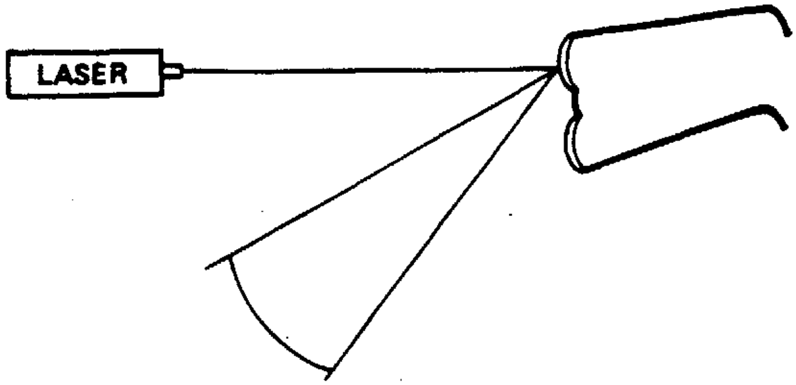
   b. Protection Requirements (cont)

      (3) Test and Training

      In test and training activities, eye protection has been required for personnel downrange within the laser beam target area and for other personnel if the target area cannot be cleared of specular reflective surfaces. However, the more desirable hazard control procedure of removing specular targets from range target areas eliminates the requirement for eye protection for all but the personnel within the target area.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	84

CURVED LENSES ARE MORE DESIRABLE THAN FLAT



7. Protective Eyewear (cont)

c. Curved Lenses

If curved protective filters are required for personnel in a laser target area, personnel in the vicinity of the laser and elsewhere would not necessarily also require eye protection. Potentially hazardous specular reflections can exist to significant distances from Flat-lens surfaces. Hence, the curved filters are far more desirable than flat lens filters.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	85

EYEWEAR PARAMETERS THAT MUST BE CONSIDERED IN SELECTING LASER EYEWEAR.

1. **WAVELENGTH**
2. **OPTICAL DENSITY**
3. **LASER BEAM IRRADIANCE**
4. **VISIBLE TRANSMITTANCE**
5. **LASER FILTER DAMAGE THRESHOLD**

d. Eyewear Parameters

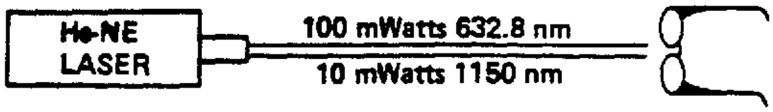
Eyewear parameters that must be considered in selecting laser eyewear are:

(1) Wavelength
(2) Optical Density
(3) Laser Beam Irradiance
(4) Visible Transmittance
(5) Laser Filter Damage Threshold

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	86

EYEWEAR PARAMETERS   WAVE LENGTH(S)

SAFETY EYEWEAR MUST REDUCE THE IRRADIANCE AT ALL WAVELENGTH(S) OF THE LASER TO SAFE LEVELS.



FILTERS MUST ABSORB BOTH WAVELENGTHS

7. Protective Eyewear

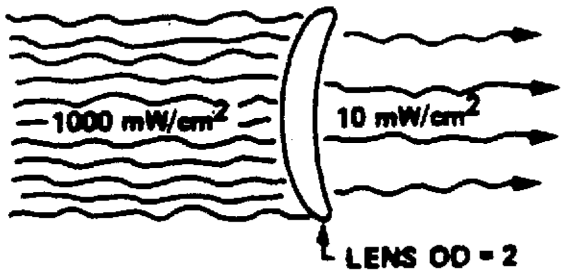
d. Eyewear Parameters (cont)

The wavelength(s) of laser radiation limits the type of eyeshields to those which prevent the particular wavelength(s) from reaching the eye. It is emphasized that many lasers emit more than one wavelength and that each wavelength must be considered. Considering the wavelength corresponding to the greatest output intensity is not always adequate. For instance, a helium-neon laser may emit 100 mW at 632.8 nm and only 10 mW at 1150 nm, but safety goggles which absorb the 632.8 nm wavelength may absorb relatively little or essentially nothing at the 1150 nm wavelength.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	87

EYEWEAR PARAMETERS

THE OPTICAL DENSITY (BEAM ATTENUATION NOTATION) MUST BE LARGE ENOUGH TO REDUCE THE INTENSITY TO AN ACCEPTABLE LEVEL, NOT EXCEEDING MPE



7. Protective Eyewear

   d. Eyewear Parameters (cont)

Optical density is a parameter for specifying the attenuation afforded by a given thickness of any transmitting medium.

Since laser beam intensities may be a factor of a thousand or a million above safe exposure levels, percent transmission notation can be unwieldy. For instance, goggles with a transmission of 0.000001 percent can be described as having an optical density of 8.0. Optical density (O.D.) is a logarithmic notation and is described by the following (mathematical) expression:

$$\text{O.D.} = \log_{10}\left[\frac{E_o}{E}\right] = -\text{Log}_{10}\,\tau$$

where E_o is the intensity of the incident beam and E is the intensity of the transmitted beam. Thus a filter attenuating a beam by a factor of 1,000 or 10^3 has an optical density of 3, and attenuating a beam by 1,000,000 or 10^6 has an optical density of 6. The required optical density is determined by the maximum laser beam intensity to which the individual could be exposed. The optical density of two highly absorbing filters when stacked is essentially the sum of two individual optical densities.

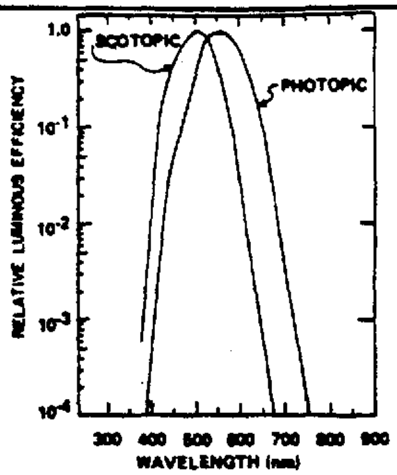
17	LASERS II	PROTECTIVE FACILITIES & DEVICES	88

EYEWEAR PARAMETERS
(MAXIMUM VISIBLE TRANSMITTANCE)

LASER PROTECTIVE EYEWEAR SHOULD FILTER OUT THE LASER WAVELENGTHS WHILE TRANSMITTING AS MUCH OF THE VISIBLE LIGHT AS POSSIBLE.

Since the object of laser protective eyewear is to filter out the laser wavelengths while transmitting as much of the visible light as possible, visible (or luminous) transmittance should be noted. A low visible transmittance (usually measured in percent) creates problems of eye fatigue and may require an increase in ambient lighting in laboratory situations. However, adequate optical density at the laser wavelengths should not be sacrificed for improved visible transmittance.

RELATIVE SPECTRAL LUMINOUS EFFICIENCY (NORMALIZED)



RELATIVE SPECTRAL LUMINOUS EFFICIENCY (NORMALIZED)

7. Protective Eyewear

   b. Eyewear Parameters (cont)

      For nighttime viewing conditions, the effective visible transmittance will be different since the spectral response of the eye is different.

      This figure shows the scotopic (night vision) and photopic (cone vision) responses of the eye. Blue-green filter lenses therefore have higher scotopic transmission values than red or orange lenses and vice-versa.

EYEWEAR PARAMETERS

THE LASER FILTER DAMAGE THRESHOLD MUST BE CONSIDERED AS AN EYEWEAR PARAMETER.

DAMAGE THRESHOLD		EYEWEAR TYPE
10-100 J/cm^2	→	ABSORBING GLASS
1-100 J/cm^2	→	PLASTICS & DIELECTRIC COATINGS

7. Protective Eyewear

d. Eyewear Parameters (cont)

At very high beam intensities filter materials which absorb the laser radiation are damaged, thus it becomes necessary to consider a damage threshold for the filter. Typical damage thresholds from q-switched pulsed laser radiation fall between 10 and 100 joules/cm^2 for absorbing glass, and 1 to 100 joules/cm^2 for plastic and dielectric coatings. Irradiances from CW lasers which would cause filter damage are in excess of those which would present a serious fire hazard, and therefore need not be considered because personnel should not be permitted in the area of such lasers.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	91

PROTECTIVE EYEWEAR

METHODS OF CONSTRUCTION

THERE ARE TWO BASIC METHODS OF CONSTRUCTION

1. **SPECTRAL ABSORPTION BY COLORED GLASS OR PLASTIC**
2. **SELECTIVE REFLECTION FROM DIELECTRIC COATING OR GLASS**

7. Protective Eyewear

d. Eyewear Parameters (cont)

There are basically two effects which are utilized to selectively filter out laser wavelengths. Filters are designed to make use of selective spectral absorption by colored glass or plastic, or selective reflection from dielectric coatings on glass, or both. Each method has its advantages.

The simplest method of fabrication is to use colored glass absorbing filters which are generally the most effective in resisting damage from wear and from very intense laser sources. Unfortunately, most absorbing filters cannot be case hardened to provide impact resistance, and clear plastic sheets are often placed with the glass filter.

The advantage of using reflective coatings is that they can be designed to selectively reflect a given wavelength while transmitting as much of the rest of the visible as possible. However, some angular dependence of spectral attenuation factor is generally present.

The advantage of using absorbing plastic filter materials are greater impact resistance, lighter weight, and ease of molding into curved shapes. The disadvantages are that they are more readily scratched, quality control appears to be more difficult and the organic dye used as absorbers are more readily affected by heat and ultraviolet radiation and may saturate or bleach under q-switched laser irradiation.

17	LASERS II	PROTECTIVE FACILITIES & DEVICES	92

SELECTING APPROPRIATE EYEWEAR

STEP 1 - DETERMINE LASER WAVELENGTHS

STEP 2 - DETERMINE REQUIRED OPTICAL DENSITY

7. Protective Eyewear (cont)

e. Selecting Appropriate Eyewear

In selecting appropriate eyewear use the following procedure:

(1) Determine wavelength(s) of laser output.

(2) Determine required optical density.

Simplified Method for Selecting Laser Eye Protection for Intrabeam Viewing for Wavelengths Between 400 and 1400 nm

Q-Switched Lasers (1 ns to 0.1 ms)		Non-Q-Switched Lasers (0.4 ms to 10 ms)		Continuous Lasers Momentary (0.25 s to 10 s)		Continuous Lasers Long-Term Staring Greater than 3 hrs		Attenuation	
< 7 mm Maximum Output Energy (J)	> 7 mm Maximum Beam Radiant Exposure ($J \cdot cm^{-2}$)	< 7 mm Maximum Laser Output Energy (J)	> 7 mm Maximum Beam Radiant Exposure ($J \cdot cm^{-2}$)	< 7 mm Maximum Power Output (W)	> 7 mm Maximum Beam Irradiance ($W \cdot cm^{-2}$)	< 7 mm Maximum Power Output (W)	> 7 mm Maximum Beam Irradiance ($W \cdot cm^{-2}$)	Attenuation Factor	OD
10	20	100	200	NR	NR	NR	NR	100,000,000	8
1.0	2	10	20	NR	NR	NR	NR	10,000,000	7
10^{-1}	2×10^{-1}	1.0	2	NR	NR	1.0	2	1,000,000	6
10^{-2}	2×10^{-2}	10^{-1}	2×10^{-1}	NR	NR	10^{-1}	2×10^{-1}	100,000	5
10^{-3}	2×10^{-3}	10^{-2}	2×10^{-2}	10	20	10^{-2}	2×10^{-2}	10,000	4
10^{-4}	2×10^{-4}	10^{-3}	2×10^{-3}	1.0	2	10^{-3}	2×10^{-3}	1,000	3
10^{-5}	2×10^{-5}	10^{-4}	2×10^{-4}	10^{-1}	2×10^{-1}	10^{-4}	2×10^{-4}	100	2
10^{-6}	2×10^{-6}	10^{-5}	2×10^{-5}	10^{-2}	2×10^{-2}	10^{-5}	2×10^{-5}	10	1

NR = Not Recommended

7. Protective Eyewear

e. Selecting Appropriate Eyewear (cont)

This table provides the required optical densities (or alternatively attenuation factors) for various laser beam irradiances which could be incident upon safety eyewear. To determine the maximum incident beam irradiance, consider the following:

If the emergent beam is not focused down to a small spot and is greater than 7 mm in diameter, the emergent beam radiant exposure/irradiance may be considered the maximum intensity that could reach the unprotected eye.

If the emergent beam is focused after emerging from the laser system or if the emergent beam diameter is less than 7 mm in diameter, one should assume that all of the beam energy/power could enter the eye. In this case use the columns marked "Maximum Laser Output Power/Energy" in this table.

If the observer is in a fixed position and cannot receive the maximum output radiant exposure/irradiance, then a measured value may be used (e.g. down-range from laser beam).

For example a 10 mw HeNe laser which may momentarily be viewed (0.25 s to 10 s) would require eye protection with an attenuation factor of 10 or an O.D. of 1.

TESTING LASER EYE PROTECTION

LASER EYE WEAR SHOULD BE CHECKED PERIODICALLY FOR INTEGRITY.

7. Protective Eyewear (cont)

f. Testing Eyewear

Eye protection should be checked periodically for integrity. The measurement of eye-protection-filter optical densities in excess of 3 or 4 without destruction of the filter is very difficult. Because of this problem, requirements originally proposed for many laser hazard control guidelines, that the optical density of protective eyewear be periodically checked, have been deleted. The greatest concern has been with goggles having specified optical densities at or only slightly above the density required for protection.

Densities greater than 8 normally are not required. Goggles having densities less than 8 are normally designed for use at either the helium-neon or ruby laser wavelengths. Therefore, if a more comprehensive goggle testing program were initiated the goggles which should receive first attention are those having a density less than 8 for the ruby and helium-neon lasers.

D. OPERATING PROCEDURES

17	LASERS II	OPERATING PROCEDURES	95

PROCEDURES

AN OPERATING OR ADMINISTRATIVE CONTROL PROCEDURE MUST BE WRITTEN TO:

1. **PROTECT HEALTH**
2. **MINIMIZE DANGERS TO LIFE**
3. **MINIMIZE DANGERS TO PROPERTY**

1. General

Operating and administrative control procedures must be written prior to operation of a laser to ensure the health protection of employees and the general public. The procedures should be written to minimize the dangers to life and property.

17	LASERS II	OPERATING PROCEDURES	96

PROCEDURES SHOULD INCLUDE:

1. **HANDLING AND USE OF LASERS SUCH THAT NO ONE IS OVEREXPOSED**
2. **METHODS AND OCCASIONS FOR SURVEYS**
3. **METHOD TO CONTROL ACCESS TO LASER AREAS**
4. **METHODS AND OCCASIONS OF LOCKING LASERS**

2. Scope

These procedures should include sections on the safe handling and use of lasers such that no one individual can be overexposed to laser light. Methods and occasions for performing surveys of laser installations should be included. The general methods of controlling access to laser hazard areas should be outlined in the procedure. Methods and occasions for locking lasers when they are not in use should be outlined in the procedures.

17	LASERS II	OPERATING PROCEDURES	97

PROCEDURES SHOULD INCLUDE: (CONT)

5. **POSTING AND SECURING HAZARD AREAS**
6. **EMERGENCY EVENTS**
7. **NOTIFICATION OF PROPER PERSON IN THE EVENT OF AN ACCIDENT**
8. **NOTIFICATION OF PROPER ORGANIZATION OF FIELD ACTIVITY**

2. Scope (cont)

The methods for posting and securing hazard areas should be fully described in the procedures. This would include the type of sign used for posting and what type of physical barrier should be used around each type of laser. Procedures on handling emergency events should be included. This would include notification of the proper person or organization in case of an accident. Procedures for notification of the proper organizations when lasers are to be taken into the field should also be included.

17	LASERS II	OPERATING PROCEDURES	98

OUTDOOR OR FIELD INSTALLATION
CLASS II LASER DEVICES

1. TERMINATE USEFUL BEAM.
2. KEEP PERSONNEL OUT OF BEAM.

3. Outdoor or Field Installation

a. Class II

When using Class II Laser Devices (Low Power Lasers or Laser Systems), the beam should be terminated where readily feasible at the end of the useful beam path. The laser should not be directed at personnel who are unaware of their illumination.

17	LASERS II	OPERATING PROCEDURES	99

OUTDOOR OR FIELD USE CLASS III LASER DEVICES
FOR SURVEYING ALIGNMENT AND LEVELING

1. USE CLASS II IF POSSIBLE
2. CLASS III LASERS LIMITED TO A MAXIMUM OUTPUT OF 5 mW

b. Class III

Class III Visible CW Lasers are used for surveying, alignment and leveling. Although it is desirable to utilize Class II laser systems for construction applications, where high ambient illumination levels exist, require output of approximately 2mW, but in no case should exceed 5 mW.

17	LASERS II	OPERATING PROCEDURES	100

OUTDOOR OR FIELD USE CLASS III LASER DEVICES FOR SURVEYING ALIGNMENT AND LEVELING

3. OPERATED ONLY BY QUALIFIED PERSONS
4. PROOF OF QUALIFICATION AVAILABLE ON THE JOB
5. POSTED AREAS WITH WARNING SIGNS
6. SHUT OFF BEAM WHEN **NOT IN USE**

3. Outdoor or Field Installation

   b. Class III (cont)

   Other procedures which must be followed are:

   (1) Only qualified and trained employees shall be assigned to install, adjust, and operate laser equipment.

   (2) Proof of qualification of laser equipment operator shall be available and in possession of operator at all times. This operator card may be obtained from a representative of the manufacturer when the operator has completed a minimum of one hour training in the safe use of this equipment by that representative.

   (3) If Class III lasers are used, the area shall be posted with standard laser warning placards.

   (4) When the laser is not required for a substantial period of time such as during lunch hour, overnight or at change of shifts, beam shutters or caps shall be utilized or the laser turned off.

17	LASERS II	OPERATING PROCEDURES	101

OUTDOOR OR FIELD USE CLASS III LASER DEVICES FOR SURVEYING ALIGNMENT AND LEVELING

7. MECHANICAL OR ELECTRICAL MEANS OF GUIDING THE ALIGNMENT
8. NO INTRABEAM VIEWING
9. TERMINATE BEAM WITHIN THE CONTROLLED AREA
10. LASER SHALL BE LABELED FOR MAXIMUM OUTPUT AND FOR NOMINAL HAZARDOUS DISTANCE.

3. Outdoor or Field Installation

   b. Class III (cont)

      Mechanical or electronic means shall be used as a detector for guiding the alignment of the laser where feasible.

      Precautions shall be taken to assure that persons do not look directly into the beam (intrabeam viewing is hazardous) unless the beam irradiance is below the applicable TLV at that observing location.

      The laser beam should be terminated at the end of its useful beam path and shall in all cases be terminated if the beam path beyond the controlled area (construction site) exceeds the hazardous distance.

      Laser equipment shall bear a label to indicate maximum output and the nominal hazardous distance beyond which the laser beam irradiance does not exceed $2.5 mW \cdot cm^{-2}$.

OUTDOOR OR FIELD USE CLASS III LASER DEVICES FOR SURVEYING ALIGNMENT AND LEVELING

11. SAFE STORAGE
12. DO NOT USE BEAM NEAR EYE LEVEL
13. REMOVE SPECULAR SURFACES IF POSSIBLE, NEVER POINT THE LASER AT SPECULAR SURFACES

3. Outdoor or Field Installation

   b. Class III (cont)

      When the laser is not being used it should be stored in a location where unauthorized personnel cannot gain access to the laser unit. Placement of the laser beam path at or near eye level should be avoided whenever feasible.

      Precautions shall be taken to assure that the laser is not pointed at mirror like (specular) surfaces.

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OUTDOOR OR FIELD USE
CLASS III & IV LASERS

OTHER THAN ALIGNMENT

1. **EXCLUDE PERSONNEL FROM HAZARD AREA WITH PHYSICAL BARRIERS OR INTERLOCKS**
2. **DO NOT TRACK NON-TARGET AIRCRAFT OR VEHICLES**
3. **REMOVE SPECULAR SURFACES OR REQUIRE EYE PROTECTION**

3. Outdoor or Field Installation (cont)

c. Class III and IV, Other Than Alignment

Personnel shall be excluded from the beam path at all points where the beam irradiance or radiant exposure exceed the appropriate TLV's. This shall be accomplished by the use of physical barriers, administrative controls, the use of elevation inter-locks and by limiting the beam traverse.

The tracking of non-target vehicular traffic or aircraft, whether intentional or inadvertent, shall be prohibited within the calculated hazardous distances of Class III or IV lasers unless the aircraft windows are opaque to the laser wavelength.

The beam path(s) shall be cleared of all flat specular surfaces capable of producing reflections that are potentially hazardous, or eye protection shall be required for all personnel within the hazardous area.

17	LASERS II	OPERATING PROCEDURES	104

CLASS IV LASER

DO NOT OPERATE IN

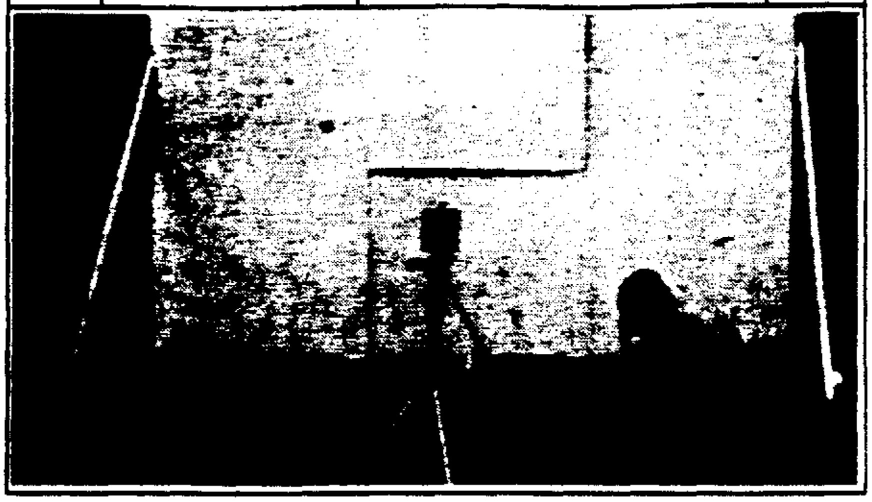
RAIN
SNOW
DUST
FOG

WITHOUT EYE PROTECTION

3. Outdoor or Field Installation

c. Class III and IV (cont)

Operation of Class IV high-power laser systems while it is raining or snowing or when there is dust or fog in the air should be avoided without the wearing of laser protective eyewear by personnel within the immediate vicinity of the beam. This is because of potential hazards from scattered light from the air-borne particles. A high-powered laser (Class III or IV) could produce enough scattered intensity to present a hazard.



3. Outdoor or Field Installation (cont)

   d. Example

   This is a photograph of the terminal end of an alignment-construction laser used out-of-doors. There is a backstop provided and the helper is required to wear protective glasses.

3. Outdoor or Field Installation

   d. Example (cont)

   This is a field operation of an alignment laser used in the aircraft industry. The lasers are Helium-Neon, 1.5mW. The area is controlled both by a physical rope barrier and warning signs. The beam is terminated at a backstop at the end of the wing job. All reflective surfaces have been removed from the laser's path.

SUMMARY

A CONTROL PROCEDURE FOR LASERS SHOULD COVER THESE AREAS:

1. **GENERAL INFORMATION**
2. **HAZARDOUS PROPERTIES**
3. **PRECAUTIONS**
4. **RESPONSIBILITIES**

4. Summary

A control procedure for the operating of lasers has four major areas: (1) General Information: (2) Hazardous Properites; (3) Precautions; and (4) Responsibilities.

The General Information section should contain answers to such questions as: "What is a laser?", and "Where are they used?". The answers to these questions will make the reader aware of just what the operating procedure pertains to and where he could expect to find it being used.

Hazardous Properties should include health, fire, and safety hazards associated with the operation of lasers.

The Precautions section should outline precautions taken to safeguard individuals, under "Personnel Protection." It also requires a section on the maximum permissible exposure limits.

The Responsibilities section outlines the responsibility of each affected organizational group.

E. TRAINING PROGRAM

17	LASERS II	TRAINING PROGRAM	108

A TRAINING PROGRAM SHALL INCLUDE PROVISIONS FOR:

1. **EDUCATION OF LASER OPERATORS IN THE POTENTIAL HAZARDS OF LASERS AND THEIR CONTROL**
2. **EDUCATION OF RADIATION PROTECTION (SAFETY) PERSONNEL IN THE ASSESSMENT AND CONTROL OF LASER HAZARDS**

1. Background

Training programs shall be provided for two major areas within an industrial complex utilizing laser radiation.

The first is a training program for the education of Laser Operators. This program should include information both on the potential hazards and their control. The second major portion of the training program is the education of the Radiation Protection or Safety Personnel.

In this program, the Radiation Protection Professionals should be trained in the assessment and control of laser hazards. The program is usually under the direction of the Laser Safety Officer.

17	LASERS II	TRAINING PROGRAM	109

TRAINING REQUIREMENTS

LASER OPERATORS SHALL BE TRAINED IN THE FOLLOWING AREAS:

1. **LASER FUNDAMENTALS**
2. **HAZARDOUS EFFECTS OF LASERS**
3. **HAZARD CONTROLS**
4. **USE OF LASER EQUIPMENT**

2. Training Requirements

The Laser Operator's Course should be broken down into the following areas:

(1) Laser Fundamentals
(2) Hazardous Effects of Lasers
(3) Hazard Controls
(4) Use of Laser Equipment

The Fundamentals section should include the basic principles of laser light, where laser light originates, and a few of its characteristics.

The Hazardous Effects section should include the biological effects of laser radiation on both the eye and the skin, and the various energy fluxes and power densities which cause hazards. Also in the Hazardous Effects portion, some mention of the associated non-light hazards should be included. This would be hazards such as extreme gas pressures, high voltages, toxic gases and fumes, radiation and cryogenic gases.

Control of Hazards should include the various classifications of lasers, the ANSI and ACGIH recommended Standards and Guidelines for exposure to lasers, and various forms of protective facilities and equipment.

The Use of Laser Equipment portion of the training can be devoted to the safe use of the laser equipment which they will be using in the job function.

17	LASERS II	TRAINING PROGRAM	110

TRAINING REQUIREMENTS

RADIATION PROTECTION (SAFETY) PERSONNEL SHALL BE TRAINED IN THE FOLLOWING AREAS:

1. **FUNDAMENTALS OF LASERS**
2. **HAZARDOUS EFFECTS OF LASER**
3. **HAZARD CONTROLS**
4. **HAZARD ASSESSMENT**
5. **LASER SURVEY METHODS AND EQUIPMENT**
6. **REQUIREMENTS OF PERTINENT FEDERAL AND STATE REGULATIONS**

2. Training Requirements (cont)

The training requirements for radiation protection (Safety) personnel include the first three sections given to the operational personnel. These are: Fundamentals of Lasers, Hazardous Effects of Lasers, and Hazards Control. Considerably more time should be spent on these subjects by the professional safety personnel.

In addition to these three areas, Hazard Assessment must be taught. This includes use of the ANSI and ACGIH Standards and Guidelines and the necessary laser calculations for their utilization.

Laser Survey Methods and Equipment must be taught to professional safety people. This includes how to make a laser survey and the use of the proper equipment.

The last requirement is a section on the pertinent Federal and State Regulations for laser use and control.

MOVIE FOR TRAINING LASER ALIGNMENT PERSONNEL

3. Movie for Training Laser Alignment Personnel

This ten-minute movie was developed to train Laser Alignment Personnel.

F. MEDICAL SURVEILLANCE

17	LASERS II	MEDICAL SURVEILLANCE	112

TO DATE ONLY TWO ORGAN SYSTEMS HAVE BEEN FOUND TO BE AFFECTED BY LASER ENERGY

THE EYES

THE SKIN

1. Background

To date only two organ systems have been found to be affected by laser energy; the eyes and the skin. Therefore, a program of medical surveillance at this time need include only the ophthamological and dermatological aspects.

17	LASERS II	MEDICAL SURVEILLANCE	113

THE PURPOSE OF MEDICAL SURVEILLANCE IS TWO-FOLD:

1. TO ESTABLISH A BASELINE OF OCULAR AND SKIN CONDITIONS
2. TO DETECT AND DOCUMENT OCULAR AND SKIN DAMAGE

NO MEDICAL SURVEILLANCE REQUIRED FOR CLASS I, II BUT REQUIRED FOR CLASS III, IV LASER WORKERS.

1. Background (cont)

The purpose of medical surveillance of personnel working in a laser environment is twofold. The first purpose is to establish a baseline of ocular and skin conditions before potential exposure to laser radiation. The second purpose is to detect and document as early as possible ocular and skin damage. Both purposes serve to assess the effectiveness of control measures and to protect personnel from dangerous exposure and to institute appropriate therapeutic measures promptly. No medical surveillance is required for personnel associated with Class I or Class II lasers and laser systems. However, it is required for occupational personnel involved with Class III or IV lasers and laser systems.

17	LASERS II	MEDICAL SURVEILLANCE	114

PHYSICAL EXAMINATION

TO BE CARRIED OUT BY QUALIFIED PERSONS ONLY:

1. **OPHTHALMOLOGISTS**
2. **DERMATOLOGISTS**
3. **PHYSICIANS TRAINED IN LASER SKIN HAZARDS MAY DO SKIN EXAMINATIONS**

I. Background (cont)

Only qualified persons should carry out these programs of medical surveillance. Qualified persons include ophthalmologists to do eye examinations and dermatologists and other physicians trained in laser skin hazards to do skin examinations. Other personnel may carry out portions of the examinations under medical supervision.

RISK CLASSIFICATION

PERSONNEL UNDER THE LASER MEDICAL SURVEILLANCE PROGRAM ARE DEFINED AS:

MINIMAL RISK

MODERATE RISK

HIGH RISK

2. Risk Classification

Those persons who should be under laser medical surveillance for possible eye or skin damage are defined as:

Minimal-Risk Personnel - Those whose work makes it possible, but unlikely, that they are exposed to laser energy sufficient to damage their eyes or skin.

Moderate-Risk Personnel - Those who work routinely in laser environments but who are ordinarily fully protected by safety features built into machines and procedures.

High-Risk Personnel - Those who run a high risk of exposure to laser energy sufficient to do eye or skin damage.

17	LASERS II	MEDICAL SURVEILLANCE	116

GENERAL MEDICAL EXAMINATION PROCEDURES

MINIMAL RISK
- **VISUAL ACUITY**

MODERATE RISK
- **OCULAR HISTORY**
- **VISUAL ACUITY**
- **FUNDUS EXAM**

HIGH RISK
- **COMPLETE EYE EXAM**
- **COMPLETE SKIN EXAM**

3. General Medical Procedures

General Procedures for exams are:

Minimal-risk personnel shall have an eye examination for visual acuity.

Moderate-risk personnel shall be subject to a modified protocol covering the following:

(1) Ocular history

(2) Visual acuity

(3) Examination of the ocular fundus with an ophthalmoscope

If best corrected visual acuity in either eye is less than 20/20, or if any pathologic phenomenon is seen, the potential worker is advised to have a complete eye examination done.

For high-risk personnel, both a complete eye examination and a complete skin examination, are required.

17	LASERS II	MEDICAL SURVEILLANCE	117

FREQUENCY OF MEDICAL EXAMS

MINIMAL RISK
PRELASER WORK

MODERATE RISK
PRELASER WORK
ON DISCHARGE FROM LASER WORK
IMMEDIATELY AFTER LASER DAMAGE EXPOSURE

HIGH RISK
SAME AS FOR MODERATE RISK, PLUS
EVERY THREE YEARS DURING WORK WITH LASERS

3. General Medical Procedures (cont)

Frequency of Medical Examinations shall be:

For minimal-risk personnel, required examinations shall be done previous to participation in laser work.

For moderate-risk personnel, required examinations shall be done as follows:

(1) Previous to participation in laser work.

(2) On discharge from laser environment.

(3) Immediately after suspected laser eye or skin damage.

For high-risk personnel, required examinations shall be done as follows:

(1) Previous to participation in laser work.
(2) On discharge from laser environment.
(3) Immediately after suspected laser eye or skin damage.
(4) Every 3 years while working with lasers.

G. LAWS AND REGULATIONS

17	LASERS II	LAWS & REGULATIONS	118

O. S. H. A.

**OCCUPATIONAL SAFETY
AND
HEALTH ACT**

1. OSHA

The Occupational Safety and Health Act–(OSHA) governs laser usage.

17	LASERS II	LAWS & REGULATIONS	119

DEP'T. OF LABOR – OSHA
USE OF LASERS IN CONSTRUCTION

DEP'T. OF HEW – FDA/BRH
LASER PERFORMANCE STANDARDS
(EQUIPMENT MANUFACTURED)

DEP'T. OF HEW – NIOSH
RESEARCH/RECOMMENDATIONS FOR SAFETY STANDARDS

ANSI–ACGIH: NON-GOVERNMENT RECOMMENDING GROUPS

The chart shows the various groups involved in regulations and standards for laser safety. OSHA is established to make rules, inspect for compliance and levy fines as appropriate. The FDA through its Bureau of Radiological Health makes rules relating to manufactured equipment, including lasers. NIOSH, also in HEW, performs research, trains manpower, and makes recommendations regarding occupational safety. Groups such as ANSI and ACGIH are unofficial, but their committees develops recommended standards that are often incorporated into the law.

Title 29—LABOR

Chapter XIII—Bureau of Labor Standards, Department of Labor

PART 1526—SAFETY AND HEALTH REGULATIONS FOR CONSTRUCTION

NOTE: PART 1518 HAS BEEN REDESIGNATED AS PART 1526

2. Title 29-Labor

The only law in effect for laser usage at present is Title 29-Labor, Chapter XII-Bureau of Labor Standards, Department of Labor, Part 1526 Safety and Health Regulations for Construction. This part is the redesignation of the previous 29 CFR 1518. (See Federal Register Vol. 36, p. 25232)

17	LASERS II	LAWS & REGULATIONS	121

SECTION 1526.102

EYE AND FACE PROTECTION SHALL BE PROVIDED BY EMPLOYER.

EYE AND FACE PROTECTION SHALL MEET THE ANSI STANDARD.

2. Title 29-Labor (cont)

   a. Eye and Face Protection

      The Section **1526.102** of the law falls under Part E and is entitled "Eye and Face Protection."

      General

      Employees shall be provided with eye and face protection equipment when machines or operations present potential eye or face injury from physical, chemical, or radiation agents.

      Eye and face protection equipment required by this part shall meet the requirements specified in American National Standards Institute, Z87.1-1968, "Practice for Occupational Eye and Face Protection."

17	LASERS II	LAWS & REGULATIONS	122

PERSONS WITH CORRECTIVE LENSES IN SPECTACLES SHALL BE PROTECTED BY

- **PROTECTIVE LENSES WITH OPTICAL CORRECTION**
- **GOGGLES WORN OVER SPECTACLES**
- **GOGGLES WITH BOTH CORRECTIVE AND PROTECTIVE LENSES**

2. Title 29-Labor (cont)

   b. Eyewear

   Employees whose vision requires the use of corrective lenses in spectacles, when required by this regulation to wear eye protection, shall be protected by goggles or spectacles of one of the following types:

   (1) Spectacles whose protective lenses provide optical correction;

   (2) Goggles that can be worn over corrective spectacles without disturbing the adjustment of the spectacles;

   (3) Goggles that incorporate corrective lenses mounted behind the protective lenses.

17	LASERS II	LAWS & REGULATIONS	123

EYEWEAR

- WILL PROTECT AT THE FREQUENCIES OF THE LASER IN USE AND
- WILL HAVE ADEQUATE OPTICAL DENSITY

2. Title 29-Labor

b. Eyewear (cont)

Employees whose occupation or assignment requires exposure to laser beams shall be furnished suitable laser safety goggles which will protect for the specific wavelength of the laser and be of optical density (O.D.) adequate for the energy involved.

17	LASERS II	LAWS & REGULATIONS	124

SELECTING LASER SAFETY GLASS

INTENSITY CW maximum power density (watts/cm^2)	ATTENUATION Optical Density (O.D.)	Attenuation Factor
10^{-3}	5	10^5
10^{-1}	6	10^6
1.0	7	10^7
10.0	8	10^8

2. Title 29-Labor

   b. Eyewear (cont)

   This slide lists the maximum power or energy density for which adequate protection is afforded by glasses of optical densities from 5 through 8. Output levels falling between these lines shall require the higher optical density.

17	LASERS II	LAWS & REGULATIONS	125

TITLE 29 . . . SECTION 1526

ALL PROTECTIVE GOGGLES SHALL BEAR LABEL GIVING:

- LASER WAVELENGTH
- OPTICAL DENSITY (O.D.) OF WAVELENGTH
- VISIBLE LIGHT TRANSMISSION

2. Title 29-Labor

   b. Eyewear (cont)

      All protective goggles shall bear a label identifying the following data:

      (1) The laser wavelengths for which use is intended.

      (2) The optical density at those wavelengths.

      (3) The visible light transmission.

17	LASERS II	LAWS & REGULATIONS	126

EYEWEAR MUST BE KEPT CLEAN

AND IN GOOD REPAIR

2. Title 29-Labor

   b. Eyewear (cont)

      Face and eye protection equipment shall be kept clean and in good repair. The use of this type equipment with structural or optical defects shall be prohibited.

17	LASERS II	LAWS & REGULATIONS	127

SUBPART C OF OSHA

TRAINING

EMPLOYER WILL USE TRAINING PROVIDED BY DIRECTOR OF OSHA

EMPLOYER WILL INSTRUCT EACH EMPLOYEE ON UNSAFE CONDITIONS AND APPLICABLE REGULATIONS

3. OSHA, Subpart C.

1526.21 Safety training and education.

General requirements

The Director shall, pursuant to section 107(f) of the Act, establish and supervise programs for the education and training of employers and employees in the recognition, avoidance and prevention of unsafe conditions in employments covered by the act.

Employer responsibility.

The employer should avail himself of the safety and health training programs the Director provides.

The employer shall instruct each employee in the recognition and avoidance of unsafe conditions and the regulations applicable to his work environment to control or eliminate any hazards or other exposure to illness or injury.

17

128A

OPTICAL FIBER COMMUNICATION SYSTEMS UTILIZING LASER DIODE(S) AND LED SOURCES

ANSI Standard Z136.2-1988 et seq.

SUBPART C OF OSHA

SAFE WORKING CONDITIONS

COMPLIANCE INSPECTIONS

ONLY QUALIFIED EMPLOYEES OPERATE EQUIPMENT

3. OSHA Subpart C. (cont)

1526.20 General safety and health provisions.

Contractor requirements

Section 107 of the Act requires that it shall be a condition of each contract which is entered into under legislation subject to Reorganization Plan Number 14 of 1950 (64 Stat. 1267), as defined in **1526.12**, and if for construction, alteration, and/or repair, including painting and decorating, that no contractor or subcontractor for any part of the contract work shall require any laborer or mechanic employed in the performance of the contract to work in surroundings or under working conditions which are unsanitary, hazardous, or dangerous to his health or safety.

Accident prevention.

It shall be the responsibility of the employer to initiate and maintain such programs as may be necessary to comply with this part.

Such programs shall provide for frequent and regular inspections of the job sites. materials, and equipment to be made by competent persons designated by the employers.

The use of unsafe machinery, tools, materials, or equipment is prohibited. Unsafe tools, materials or equipment shall be identified as unsafe by tagging or by locking the controls to render them inoperable, or they shall be removed from service.

The employer shall permit only those employees qualified by training or experience to operate equipment and machinery.

HEW/FDA STANDARD

DEPARTMENT OF
HEALTH,
EDUCATION, AND
WELFARE

Food and Drug Administration
LASER PRODUCTS

Performance Standard

Effective Date: August 1976

4. HEW/FDA Standard

a. General

The Department of Health, Education and Welfare, through the Food and Drug Administration, has completed the rulemaking process and issued a performance standard. See the Federal Register Volume 40, pp. 32253–32266 and 21 CFR 1010 and 21 CFR 1040. It defines, for laser manufacturers the certification and identification requirements. It also defines and mandates, in part 1040, many of the provisions of the ANSI Z136.1–1976 Standard discussed here earlier. In the following charts we discuss some of the provisions of 21 CFR 1010 and 1040.

HEW/FDA STANDARD

CERTIFICATION - CONFORMS TO THIS STANDARD

IDENTIFICATION - BY PERMANENT LABEL GIVING REQUIRED INFORMATION

4. HEW/FDA Standard (contd.)

   b. Certification

      Every manufacturer of an electronic product for which an applicable standard is in effect under this subchapter will furnish to the dealer or distributor, at the time of delivery of such product, the certification that such product conforms to all applicable standards under this subchapter.

   c. Identification

      Every manufacturer of an electronic product to which a standard under this subchapter is applicable shall set forth the information specified. This information shall be provided in the form of a tag or label permanently affixed or inscribed on such product so as to be legible and readily accessible to view when the product is fully assembled for use or in such other manner as may be prescribed in the applicable standard.

HEW/FDA STANDARD (21 CFR 1040)

EMISSION LIMITS FOR COLLATERAL RADIATION

WAVELENGTHS > 250 TO ≤ 13,000nm ARE IDENTICAL TO CLASS I ACCESSIBLE EMISSION LIMITS

X-RAY RANGE IS .5mR/hr.

4. HEW/FDA Standard (contd.)

   d. Emission Limits

   The F.D.A. also calls out accessible emission limits for collateral radiation from Laser products. They are as follows:

   (1) Accessible emission limits for collateral radiation having wavelengths greater than 250 nm but less than or equal to 13,000 nm are identical to the accessible emission limits of Class I laser radiation.

   (2) Accessible emission limit for collateral radiation within the x-ray range of wavelengths is 0.5 milliroentgen in an hour, averaged over a cross-section parallel to the external surface of the product, having an area of 10 square centimeters with no dimension greater than 5 centimeters.

HEW/FDA STANDARD

OPERATIONAL REQUIREMENTS

1. PROTECTIVE HOUSING
2. SAFETY INTERLOCKS
3. REMOTE CONTROL CONNECTOR
4. KEY CONTROL

4. HEW/FDA Standard (contd.)

e. Operational Requirements

The FDA Performance Standards also detail for the laser manufacturer what is **necessary for laser operational requirements:**

(1) Protective housing. Each laser product, regardless of its class, shall have a protective housing which, when in place, prevents human access during operation.

(2) Safety interlocks. Each laser product, regardless of its class, shall be provided with a safety interlock for each portion of the protective housing which could be removed or displaced and cause a radiation hazard.

(3) Remote control connector. Each laser system classified as a Class III or IV laser product shall incorporate a readily accessible remote control connector having an electrical potential difference on the remote control connector no greater than 130 root-mean-square volts. When the terminals of the connector are not electrically joined, human access to all laser and collateral radiation from the laser product in excess of the accessible emission limits of Class I shall be prevented.

(4) Key control. Each laser system classified as a Class III or IV laser product shall incorporate a key-actuated master control. The key shall be removed and laser shall not be operable when the key is removed.

17	LASERS II	LAWS & REGULATIONS	133

HEW/FDA STANDARD
OPERATIONAL REQUIREMENTS (contd)

5. LASER RADIATION EMISSION INDICATOR
6. BEAM ATTENUATOR
7. LOCATION OF CONTROLS
8. VIEWING OPTICS
9. SCANNING SAFEGUARDS

4. HEW/FDA Standard (contd.)

e. Operational Requirements (cont)

(5) Laser radiation emission indicator. Each laser system classified as a Class II, III. or IV laser product shall provide a visible or audible indication immediately before and during the emission of accessible laser radiation in excess of the limits of Class I. Any visual indicator shall be clearly visible through protective eyewear designed specifically for the wavelength(s) of the emitted laser radiation.

(6) Beam attenuator. Each laser system classified as a Class II, III, or IV laser product shall be provied with one or more permanently attached means, other than laser energy source switch(es), electrical supply main connectors or the key-actuated master control, capable of preventing human access to all laser and collateral radiation in excess of the accessible emission limits of Class I and Table III of the Standard.

(7) Location of controls. Each Class II, III, or IV laser product shall have operational and adjustment controls located so that human access to laser and collateral radiation in excess of the accessible emission limits of Class I and Table III or paragraph (d) of the Standard is unnecessary for operation or adjustment of controls.

HEW/FDA STANDARD
OPERATIONAL REQUIREMENTS (contd)

1. PROTECTIVE HOUSING
2. SAFETY INTERLOCKS
3. REMOTE CONTROL CONNECTOR
4. KEY CONTROL
5. LASER RADIATION EMISSION INDICATOR
6. BEAM ATTENUATOR
7. LOCATION OF CONTROLS
8. VIEWING OPTICS
9. SCANNING SAFEGUARDS

4. HEW/FDA Standard (contd.)

e. Operational Requirements (cont)

(8) Viewing optics. All viewing optics, viewports, and display screens incorporated into a laser product, regardless of its class, shall attenuate at all times the accessible levels of transmitted laser and collateral radiation to less than the accessible emission limits of Class I.

(9) Scanning safeguard. Laser products which emit accessible scanned laser radiation shall not, as a result of scan failure or other failure causing a change in either scan velocity or amplitude, permit human access to laser radiation in excess of the accessible emission limit(s) which are applicable to the scanned laser radiation when the product is functioning as intended.

LABELING REQUIREMENTS

- APERTURE LABELING
- RADIATION OUTPUT INFORMATION
- LABELS FOR NONINTERLOCKED PROTECTIVE HOUSING

4. HEW/FDA Standard (contd.)

f. Labeling Requirements

The Food and Drug Administration spells out other requirements that must be complied with such as the following:

(1) Aperture label. Each laser product, except medical laser products, shall have affixed, in close proximity to each aperture through which is emitted accessible laser or collateral radiation in excess of the accessible emission limits of Class I and Table III of paragraph (d) of the Standard, a label(s) bearing the following wording: "AVOID EXPOSURE - Radiation is emitted from this."

(2) Radiation output information. Each Class II, III and IV laser product shall state in appropriate units, at position 2 on the required warning logotype, the maximum output of laser radiation, the pulse duration when appropriate, and the laser medium or emitted wavelength(s).

(3) Labels for noninterlocked protective housings. For each laser product labels shall be provided for each portion of the protective housing having no safety interlock, which is designed to be displaced or removed during operation, maintenance or servicing, and which thereby could permit human access to laser or collateral radiation in excess of the limits of Class I and Table III in paragraph (d) of the Standard. Such labels shall be visible on the protective housing prior to displacement or removal of the protective housing and visible on the product in close proximity to the opening created by removal or displacement of the protective housing, and shall include the wording:

"CAUTION - Laser radiation when open. DO NOT STARE INTO BEAM," for accessible laser radiation:

LABELING REQUIREMENTS (cont)

FOR DEFEATABLY INTERLOCKED PROTECTIVE HOUSINGS

4. HEW/FDA Standard (contd.)

   f. Labeling Requirements (cont)

   Labels for Defeatably Interlocked Protective Housings

   For each laser product, labels shall be provided for each defeatably interlocked protective housing which is designed to be displaced or removed during operation, maintenance or servicing, and which thereby could permit human access to laser or collateral radiation in excess of specified limits.

   Such labels shall be visible on the protective housing prior to displacement or removal of the protective housing and visible on the product in close proximity to the opening created by the removal or displacement of the protective housing.

   The wording on the label includes:

   "CAUTION - Laser radiation where open and interlock defeated."

   Additional wording such as:

   "INVISIBLE RADIATION" and "AVOID DIRECT EXPOSURE TO BEAM"

   is required and depends upon the class, frequency and power of the laser. The requirements are detailed in the HEW/FDA Standard.

LABEL REQUIREMENTS (Cont'd.)

- WARNING FOR INVISIBLE RADIATION
- POSITIONING OF LABELS
- LABEL SPECIFICAITONS

4. HEW/FDA Standard (contd.)

f. Labeling Requirements (cont)

On the labels specified in this paragraph, if the wavelength(s) of the laser is: outside the range 400 nm through 700 nm the word "invisible" shall appropriately precede the words "Laser Radiation". Also, within the range of greater than 400 nm but less than or equal to 700 nm, the words "visible and invisible" shall appropriately precede the words "Laser Radiation."

All labels affixed to a laser product shall be positioned to make unnecessary, during reading, human access to laser and radiation.

Label specifications shall be permanently affixed, legible, and clearly visible during operation, maintenance or service.

INFORMATION REQUIREMENTS TO BE PROVIDED BY MANUFACTURER:

- INSTRUCTION AND OPERATION MANUAL
- PURCHASING AND SERVICING INFORMATION

4. HEW/FDA Standard (cont)

g. Information Requirements

Information Requirements - User Information

Manufacturers of laser products shall provide adequate instructions for proper assembly and safe use including clear warnings concerning precautions to avoid possible exposure to laser and collateral radiation.

Purchasing and Servicing Information

Manufacturers of laser products shall provide, in all catalogs, specification sheets and descriptive brochures pertaining to each laser product, a legible reproduction of the warning logotype required to be affixed to that product, adequate instructions for service adjustments and service procedures for each laser product model including clear warnings and precautions to be taken to avoid possible exposure to radiation and a schedule of maintenance necessary to keep the product in compliance with the Standard.

MODIFICATION REQUIREMENTS

MODIFICATION OF A CERTIFIED PRODUCT THAT CHANGES THE PERFORMANCE OR INTENDED USAGE REQUIRES NEW CERTIFICATION AND NEW IDENTIFICATION.

4. HEW/FDA Standard (cont)

   h. Modification Requirements

   The modification of a laser product by any person engaged in the business of manufacturing, assembling or modifying laser products shall be construed as manufacturing. If the modification effects any aspect of the product's performance or intended function(s), the manufacturer who performs such modification shall recertify and reidentify the product.

17	LASERS II	SUMMARY	140

- THEORY OF LASER OPERATION
- CHARACTERISTICS OF LASERS
- LASER USAGE IN INDUSTRY
- HAZARDS FROM LASERS
- CONTROL OF HAZARDS

H. SUMMARY

This session in lasers has presented some basic theory and operation, characteristics of lasers, how they are being used in industry, and some of the hazards associated with their operation. You should have some appreciation for the controls that are necessary in laser usage, their classification, safety systems–features, protective procedures and equipment necessary for a safe work environment.

17	LASERS	SUMMARY	141

DEFINITION OF TRUE COHERENT LIGHT

- TIME COHERENCE

  MONOCHROMATIC, ONE FREQUENCY, ONE COLOR

- SPATIAL COHERENCE

  WAVES ARE IN PHASE OR IN STEP

1. Theory of Laser Operation

True coherence has two prerequisites: time coherence and spatial coherence. Time coherence implies one frequency - one color; it is monochromatic. Spatial coherence means the waves are in phase or in step.

The laser comes the closest to true coherence of any light source in that its light is directional in one narrow beam.

17	LASERS II	SUMMARY	142

LASER MODE	TYPE	SOME CHARACTERISTICS
CW	HE-NE	VERY RELIABLE
LONG PULSE	RUBY	• SINGLE PULSE
Q SWITCH	Nd(YAG)	• SHORT DURATION • HIGH POWER
MODE LOCKING	CHEMICAL	• TRAIN OF PULSES • SHORT DURATION • HIGH PEAK POWER
RAPID PULSE	ARGON	PRF > 10 MHz

2. Characteristics of Lasers

Some typical laser modes, types and characteristics were covered.

The common Helium Neon (HeNe) continuous laser is one of the most reliable and popular lasers on the market. The ruby can be single pulsed or Q switched and is also popular. Q. Sw. neodymium (YAG) is popular in the electronic industry because of its capability to trim and cut circuit boards. Mode locking is used mainly on chemical research lasers because of its pulse train, short duration, and high energy or power pulse capability.

Rapid pulse lasers like the argon have very high frequencies.

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INDUSTRIAL USES OF LASERS

- PRECISION MEASUREMENT
- WELDING
- MATERIAL REMOVAL
- MATERIAL SHAPING
- THERMAL INDUCTION
- SCATTERING EFFECTS
- INTERFEROMETRY AND HOLOGRAPHY
- COMMUNICATIONS
- RESEARCH

3. Laser Usage in Industry

Nine major classes of industrial usage of lasers are shown on the chart.

17	LASERS	SUMMARY	144

THE TYPE AND EXTENT OF BIOLOGICAL DAMAGE FROM LASERS IS A FUNCTION OF:

- ENERGY ABSORBED
- WAVELENGTH OF RADIATION
- DURATION OF EXPOSURE
- SPECIFIC BODY ORGAN EXPOSED

4. Biological Effects

Biological damage from lasers is a function of energy-absorbed, wavelength, duration of exposure and specific body organ exposed. You should be concerned especially with high energy densities from lasers because they are capable of damaging living tissue in a short period of time. The eye is of major concern.

17	LASERS II	SUMMARY	145

TWO METHODS OF CAUSING DAMAGE AT THE CELL LEVEL:

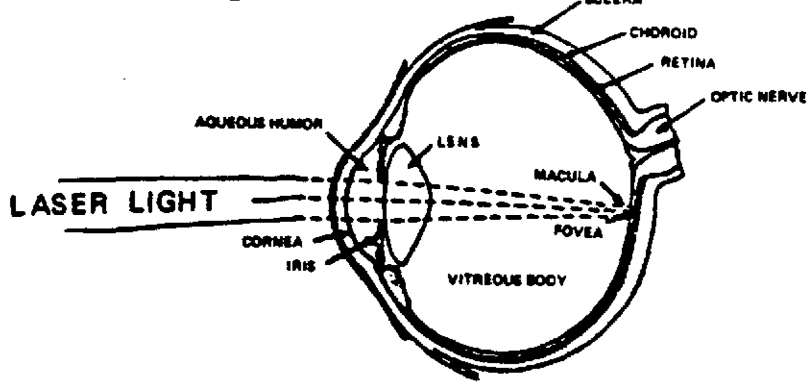
- HEAT
- CHEMICAL CHANGE

4. Biological Effects (cont)

There are two methods that cause cell damage within the human body, they are high temperature changes (heat) and chemical changes.

17	LASERS	SUMMARY	146

BURN ON THE RETINA



CAN RESULT IN SERIOUS IMPAIRMENT OF VISION

4. Biological Effects (cont)

When looking directly into a laser beam the energy is concentrated onto the fovea, which is very susceptible to damage from laser light. Any damage to the fovea, which is only about 1 mm in diameter, can result in serious impairment of vision.

17	LASERS II	SUMMARY	147

LASER LIGHT SKIN EFFECTS VARY

ALL EXPOSURE SHOULD BE AVOIDED

4. Biological Effects (cont)

Skin damage from laser exposure may vary from a mild reddening to blisters or charring of skin, depending on the energy absorbed.

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ANSI STANDARD
Z136.1 - 1976

"SAFE USE OF LASERS"

GUIDELINE RECOMMENDATIONS

MANY PROVISIONS INCORPORATED INTO FEDERAL LAWS: 21 CFR 1040, 29 CFR 1526, 29 CFR 1910

5. ACGIH Standards and ANSI Guidelines (cont)

The American National Standard Institute (ANSI) also has recommended guidelines for laser users. It is more extensive than the ACGIH Standard.

The ANSI standard spells out the rules for operating lasers at virtually any wavelength or pulse duration. It defines control measures for each of four laser classifications, and it provides technical information on measurements, calculations, and biological effects. It covers lasers in use at nearly all power levels. The title of this standard is "Safe Use of Lasers" (Z136.1-1976). Many of the provisions of this standard have been incorporated into Federal regulations.

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HAZARDS

CLASSIFICATION AND CONTROL MEASURES ARE USUALLY SUFFICIENT, HOWEVER, IF UNPROTECTED PERSONNEL ARE EXPOSED TO A PRIMARY OR SPECULARLY REFLECTED BEAM, CALCULATED EXPOSURE AND/OR MEASURED EXPOSURE ARE REQUIRED

6. Hazards

Following laser-device classification, according to the ANSI Standard, environmental factors require consideration. Their importance in the total hazard evaluation depends upon the laser classification. The decision to employ additional hazard controls not specifically required for Class III and Class IV laser devices may depend largely on environmental considerations. The probability of personnel exposure to hazardous laser radiation must be considered. If exposure of unprotected personnel to the primary or specularly reflected beam is expected, calculations or measurements of either irradiance or radiant exposure of the primary or specularly reflected beam, or radiance of an extended source, at that specific location are required.

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ASSOCIATED HAZARDS

- CRYOGENIC GAS BOTTLES
- TOXIC SOLVENTS & CHEMICALS
- HIGH VOLTAGE EQUIPMENT
- PRESSURIZED GASES
- U. V. SOURCES
- ELECTRON GUNS – X-RAYS
- FIRE & EXPLOSION

6. Hazards (cont)

There are numerous kinds of associated equipment around a laser that are hazardous. There are cyrogenic gas bottles that can freeze your skin, solvents and chemicals that can be toxic, gas pressure hazards, voltage above 42.5 V, (non-laser) UV, X-ray hazard from electron guns, and fire and explosive problems. These should cause you to look for specialized assistance preferably from Industrial Hygiene and Safety Organizations.

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CONTROL OF LASERS

PROTECTION FACILITIES AND DEVICE REQUIREMENTS IN LASER CLASSIFICATION

LASER CLASS	FACILITIES & DEVICES
I	NONE
II	YES*
III	YES
IV	YES

* DEVICE ONLY

7. Controls and Protection Programs

A summary of protective facilities and devices applicable to each class of laser is shown on the chart.

In some cases only safety devices are necessary, in others the whole facility should be enclosed.

17	LASERS II	SUMMARY	152

CONTROL OF LASERS

OPERATING AND ADMINISTRATIVE CONTROL PROCEDURES MUST BE WRITTEN TO:

- **PROTECT HEALTH**
- **MINIMIZE DANGERS TO LIFE**
- **MINIMIZE DANGERS TO PROPERTY**

7. Controls and Protection Programs (cont)

Operating and administrative control procedures must be written prior to operation of a laser to ensure the health protection of employees and the general public. The procedures should minimize the dangers to life and property.

REFERENCES

1. "OSHA" Occupational Safety and Health Act, Title 29-Labor. *Chapter XIII, Part 1926, Safety and Health Regulations for Construction.*

2. ANSI Standard, *American National Standard for the Safe Use of Lasers,* ANSI Z136.1-1976, American National Standards Institute, New York, New York, 10018.

3. ACGIH Standard, The American Conference of Governmental Industrial Hygienists, *A Guide for Control of Laser Hazards,* ACGIH, P.O. Box 1937, Cincinnati, Ohio 45201, 1973.

4. *Laser Products, Performance Standard,* Department of Health, Education and Welfare, Food and Drug Administration. Federal Register Vol. 40, No. 148, Part II, 31 July 1975. See also 21 CFR 1040.

5. "Laser Safety—Introduction to Hazard Calculations," by Rockwell, Sliney and Smith, in Electro Optical System Design, p. 32, August 1978; and p. 25, November 1978. "Laser Safety Guide," Laser Institute of America, 1977.

6. (The Laser Institute of America (LIA) publishes Laser Safety material, and should be contacted for current listings: 4100 Executive Park Dr., Cincinnati, Ohio, 45241.)

*U.S. GOVERNMENT PRINTING OFFICE: 1983/659-096/631

REFERENCES

American National Standards Institute (ANSI) "Standard for the Safe Use of Lasers", Z136.1 - 1993 (current edition) covers Maximum Permissible Exposures (MPE's) for eye and skin for essentially all combinations of pulse length, pulse format and wavelength for most common laser usages. It also covers safety controls, facilities and procedures for the various laser classes.

ANSI Z136.2 - 1988 "Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources" covers its title applications.

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