STD 01-05-001 - PUB 8-1.7 - Guidelines for Laser Safety and Hazard Assessment

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OSHA Instruction PUB 8-1.7 August 5, 1991 Directorate of Technical Support

Subject: Guidelines for Laser Safety and Hazard Assessment

A. PURPOSE. This instruction provides guidelines to Federal OSHA and Plan States compliance officers, 7(c)(1) consultants, and employee for the assessment of laser safety.

B. SCOPE. This instruction applies OSHA-wide.

C. ACTION. Regional Administrators and Area Directors shall provide copies of the attached Guides for Laser Safety and Hazard Assessment to the appropriate State and Federal personnel and shall ensure that copies are available for distribution to the public upon request.

D. FEDERAL PROGRAM CHANGE.

This instruction describes a change in the Federal program for which a state response is not required. Each Regional Administrator, however, shall: 1. Ensure that this change is promptly forwarded to each state designee. 2. Explain the technical content of this change to the state as requested. 3. Inform the state designee that they are encouraged to make available the Guidelines to State Plan personnel and appropriate employers.

E. STATE CONSULTATION PROJECTS.

1. Regional Administrators shall forward a copy of this instruction to each consultation project manager and explain the technical content when requested. 2. Consultation Project Managers shall ensure that the information in the Guidelines is provided to appropriate employers and ensure that copies are available for distribution to the public upon request.

F. BACKGROUND. With the increase development, manufacturing, and use of devices and systems based on stimulated emissions of radiation (Lasers) in industrial applications, the compliance officer is now, more than ever, in need of a comprehensive laser reference. Because some primary users often misunderstood the different orders of magnitude of intensity levels found in the operational environment and the probability of potential accidental exposure, it was necessary for this reference laser document to be comprehensive, easily read and understood.

Gerard F. Scannell Assistant Secretary

Distribution: National, Regional and Area Offices State Plan Designees 7(c)(1) Consultation Project Managers NIOSH Regional Program Directors All Compliance Officers

GUIDELINES
FOR LASER SAFETY AND
HAZARD ASSESSMENT

Occupational Safety and Health Administration United States Department of Labor Washington, DC 20210

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GUIDELINES
FOR LASER SAFETY AND
HAZARD ASSESSMENT

I. INTRODUCTION

A. PURPOSE OF GUIDELINE:

This guideline is designed to provide a general overview to lasers, laser uses, laser hazards and hazards analysis that are required to provide appropriate background for understanding the applicable industry standards and regulatory requirements.

B. USE OF GUIDE:

The guide is divided into eleven topical sections. Sections I to III provide background information on laser and laser beams, laser bioeffects and ancillary hazards. Pertinent definitions are in the glossary in Appendix A. Sections IV to VI cover the aspects of laser standards, classifications and overall hazard analysis. Sections VII and VIII review laser controls and protective equipment. Section IX covers training requirement. A comprehensive reference listing is provided in Section X.

In general, each section is designed to cover one major aspect of the laser story and can be reviewed separately from the balance of the review. There is, of course, some need to have understanding of the earlier sections to fully apply information in the later sections, especially Section VII on laser hazard evaluation.

C. WHO USES LASERS?

Estimates of the number of workers involved on a routine basis with laser devises are difficult to perform. One method to estimate the number of workers is through the number of subscribers to the various laser related trade magazines. Estimates indicate that the number of non-overlapping subscribers to the three major laser/electro-optics magazines is approximately sixty thousand. This number is based upon a comparative evaluation of the total number of subscribers for each magazine using sample statistical information for the number of non-overlapping subscribers.

It should be stressed that these are controlled circulation magazines and are received by only 10-30% of the individuals at each facility involved with laser and electro-optics activities. Hence, one can estimate, using a multiplier ranging from three to ten, that the "total" laser worker universe in the early 1980's ranges from 180,000 to 600,000 people. Using estimates of the projected growth over the next decade of 20% to 25% per year, one can project a total laser-worker universe total in the early 1990's ranging from 520,000 to perhaps as high as 6,000,000 people.

A NIOSH report estimated that by 1980 about 9 million workers would have been potentially exposed to lasers and different arcs. These results were based upon U.S. Census Bureau estimates and other Government reports. This data was divided into the following major census bureau occupational categories as shown in Table I-1.

(Table I-1. Comparison of Occupational Category And Number of Workers, see printed copy)

If it is assumed that only 60% of the workers are potentially exposed to arcs alone, this would mean that 3.6 million workers are potentially exposed to lasers alone. This estimate is of the same basic magnitude as the estimate obtained previously (0.5 to 6 million) based upon magazine subscription data. Comparison of these two estimates permits the general conclusion that one can, with some certainty, conservatively project in excess of one million workers involved with the applications of lasers by the mid-to-late 1990's.

Inspection of Table I-1 also indicates that the greatest percentage of those involved with lasers fall in the categories of craftsman, operator and service. These represent approximately 89% of the total number. This would indicate that the potential for accidental exposures to laser radiation will shift from the developmental engineer and scientist group (where a high percentage of the previous incidents have occurred) to the general occupational work force. One might wonder how many more incidents will occur with this shift to personnel who are much less aware of laser damages?

D. LASER APPLICATIONS:

The following will review some of the more important laser applications and types of lasers used. Emphasis will be placed upon those lasers with the largest number of applications and, hence, involve the largest number of workers. The major categories of laser uses are summarized in Table I-2.

While the listing is extensive, it is certainly not exhaustive. The listing indicates numerous occupational and industry areas are involved in the laser use. The heading of "Research" was not included, although it is certainly a major area for each of the categories listed as-well-as in the area of laser research itself.

All of this indicates that potential for exposure to laser light has expanded beyond the scientific laboratory and workplace into the entertainment arena, museum, public building lighting, and even the home.

E. PROJECTIONS FOR THE 1990'S:

The current scope of laser applications is certainly extraordinary. Virtually every industry group is represented. The question to be asked is, perhaps, "WHAT NEW AREAS OF LASER APPLICATIONS WILL BE EXPLORED IN THE NEXT DECADE?"

First, there will be the normal extension of the current applications across industry lines. Also, the use of higher power systems to serve multiple work stations on a beam time sharing basis will become more common. Most laser devices will be dedicated systems, designed for a specific application.

New applications will most probably center on the use of tunable wavelength and ultraviolet laser devices (perhaps a second generation of excimer lasers). This lends itself to photochemistry and/or photobiological work where the need for a specific wavelength(s) is paramount for the application.

Medical applications will be expanded with the use of various adjuvants with the treatments. For example: dye injections will be administered to the patient which are selectively absorbed in tumors to enhance the selective absorption of laser energy in the tissues and provide a more specific therapy.

The uses of lasers with fiber optics will include, in addition to communications - which could become the singularly largest application area of all laser uses - more uses in the industrial laser area. For example, the natural extension of laser materials processing would be the incorporation of laser fiber optics to conduct the beam to remote places as in the field of robotics.

(Table I-2. Major Categories Of Laser Uses, see printed copy)

All other new applications will bring certain unknowns from a laser hazard and overall occupational health point of view. For example, development of the Free Electron Laser (FEL), although now located at only a few isolated research centers, has combined electron accelerator, high magnetic field and tunable laser technology together in a single installation. In addition, research is underway for lasers to emit in the X-ray spectrum. All of these developments implies that the hazards associated with laser facilities will most probably be more complex in the future.

In addition, it is most probable that the use of the laser with new procedures and processes will produce new and, perhaps, unknown substances that can present new hazards. It will be necessary, therefore that each of these new applications areas be approached with some caution and that the laser interaction be studied and, where hazards are identified, methods of control be established.

II. LASER TYPES AND OPERATION

A. BASIC LASER OPERATION:

The term "LASER" is an acronym. It stands 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 first postulated by Albert Einstein in 1917. The light which the laser produces is unique, for it is characterized by properties which are very desirable, but almost impossible to obtain by any means other than the laser.

To gain a better understanding of the laser and what it can do, a review is included of some of the phenomena involved.

B. ENERGY LEVELS:

Light can be produced by atomic processes, and it is these processes which are responsible for the generation of laser light. Let's look first at atomic energy levels and then see how changes in these energy levels can lead to the production of laser light.

A number of simplifications will be made regarding the concept of the atom. It can be assumed, for the purposes of this discussion, that an atom consists of a small dense nucleus and one or more electrons in motion about the nucleus.

The relationship between the electrons and the nucleus is described in terms of energy levels. Quantum mechanics predicts that these energy levels are discrete.

C. RADIATIVE TRANSITIONS:

The electrons normally occupy the lowest available energy levels. When this is the case, the atom is said to be in its ground state. However, electrons can occupy higher energy levels, leaving some of the lower energy states vacant or sparsely populated.

One way that electrons and atoms can change from one energy state to another is by the absorption or emission of light energy, via a process called a radiative transition.

D. ABSORPTION:

An electron can absorb energy from a variety of external sources. From the point of view of laser action, two methods of supplying energy to the electrons are of prime importance. The first of these is the transfer of all the energy of a photon directly to an orbital electron. The increase in the energy of the electron causes it to "jump" to a higher energy level; the atom is then said to be in an "excited" state. It is important to note that an electron can accept only the precise amount of energy that is needed to move it from one allowable energy level to another. Only photons of the exact energy acceptable to the electron can be absorbed. Photons of slightly more (or slightly less) energy will not be absorbed.

Another means often used to excite electrons is an electrical discharge. In this technique, the energy is supplied by collisions with electrons which have been accelerated by an electric field. The result of either type of excitation is that through the absorption of energy, an electron has been placed in a higher energy level than it originally resided. As a result, the atom of which it is a part is said to be excited.

E. SPONTANEOUS EMISSION:

The nature of all matter is such that atomic and molecular structures tend to exist in the lowest energy state possible. Thus, an excited electron in a higher energy level will soon attempt to DE-EXCITE itself by any of several means. Some of the energy may be converted to heat.

Another means of de-excitation is the spontaneous emission of a photon. The photon released by an atom as it is de-excited will have a total energy exactly equal to the difference in energy between the excited and lower energy levels. This release of a photon is called spontaneous emission. One example of spontaneous emission is the common neon sign. Atoms of neon are excited by an electrical discharge through the tube. They de-excite themselves by spontaneously emitting photons of visible light.

NOTE: The exciting force is not of a unique energy, so that the electrons may be excited to any one of several allowable levels. ---

Now let's look at the third, and probably the least familar, type of radiative transition.

F. STIMULATED EMISSION:

In 1917, Einstein postulated that a photon released from an excited atom could, upon interacting with a second, similarly excited atom, trigger the second atom into de-exciting itself with the release of another photon. The photon released by the second atom would be identical in frequency, energy, direction, and phase with the triggering photon, and the triggering photon would continue on its way, unchanged. Where there was one photon now there are two. These two photons could then proceed to trigger more through the process of stimulated emission.

If an appropriate medium contains a great many excited atoms and de-excitation occurs only by spontaneous emission, the light output will be random and approximately equal in all directions. The process of stimulated emission, however, can cause an amplification of the number of photons traveling in a particular direction - a photon cascade if you will.

A preferential direction is established by placing mirrors at the ends of an optical cavity. Thus the number of photons traveling along the axis of the two mirrors increases greatly and Light Amplification by the Stimulated Emission of Radiation may occur. If enough amplification occurs, LASER beam is created.

G. POPULATION INVERSION:

Practically speaking, the process of stimulated emission will not produce a very efficient or even noticeable amplification of light unless a condition called "population inversion" occurs. If only a few atoms of several million are in an excited state, the chances of stimulated emission occurring are small. The greater the percentage of atoms in an excited state, the greater the probability of stimulated emission. In the normal state of matter the population of electrons will be such that most of the electrons reside in the ground or lowest levels, leaving the upper levels somewhat depopulated. When electrons are excited and fill these upper levels to the extent that there are more atoms excited than not excited, the population is said to be inverted.

H. LASER COMPONENTS:

A generalized laser consists of a lasing medium, a "pumping" system and an optical cavity. The laser material must have a metastable state in which the atoms or molecules can be trapped after receiving energy from the pumping system. Each of these laser components are discussed below:

1. PUMPING SYSTEMS: a. The pumping system imparts energy to the atoms or molecules of the lasing medium enabling them to be raised to an excited "metastable state" creating a population inversion. Optical pumping uses photons provided by a source such as a Xenon gas flash lamp 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. b. Collision pumping relies on the transfer of energy to the lasing material by collision with the atoms (or molecules) of the lasing material. Again, energies which correspond to the allowed transitions must be provided. This is often done by electrical discharge in a pure gas or gas mixture in a tube. c. Chemical pumping systems use the binding energy released in chemical reactions to state. 2. 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 lost and the amplification process terminates. They may actually be reflected at the wall of the rod or tube, but sooner or later they will be lost in the system and will not contribute to the beam. If, on the other hand, one of the decaying atoms or molecules releases a photon parallel to the axis of the lasing material, it can trigger the emission of another photon and both will be reflected by the mirror on the end of the lasing rod or tube. The reflected photons then pass back through the material triggering further emissions along exactly the same path which are reflected by the mirrors on the ends of the lasing material. As this amplification process continues, a portion of the radiation will always escape through the partially reflecting mirror. When the amount of amplification or gain through this process exceeds the losses in the cavity, laser oscillation is said to occur. In this way, a narrow concentrated beam of coherent light is formed.

Table II-1 Most Common Laser Wavelengths

(Table II-1. Most Common Laser Wavelengths, see printed copy) 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. 3. LASER MEDIA: Lasers are commonly designated by the type of lasing material employed. There are four types which are: solid state, gas, dye, and semiconductor. The characteristics of each type will be described. Note the wavelengths in Table II-1. a. SOLID STATE LASERS employ a lasing material distributed in a solid matrix. One example is the Neodymium: YAG laser (Nd:YAG). The term: YAG is an abbreviation for the crystal: Yttrium Aluminum Garnet which serves as the host for the Neodymium ions. This laser emits an infrared beam at the wavelength of 1.064 ?m (?m = 10(-6) meters). Accessory devices that may be internal or external to the cavity may be used to convert the output to visible or ultraviolet wavelength. b. GAS LASERS use a gas or a mixture of gases within a tube. The most common gas laser uses a mixture of helium and neon (HeNe), with a primary output of 632.8 nm (nm = 10(-9) meter) which is a visible red color. It was first developed in 1961 and has proved to be the forerunner of a whole family of gas lasers. All gas lasers are quite similar in construction and behavior. For example, the carbon dioxide (CO(2)) gas laser radiates at 10.6 ?m in the far-infrared spectrum. Argon and krypton gas lasers operate with multiple frequency emissions principally in the visible spectra. The main emission wavelengths of an argon laser are 488 and 514 nm. c. DYE LASERS use a laser medium that is usually a complex organic dye in liquid solution or suspension. The most striking feature of these lasers is their "tunability." Proper choice of the dye and its concentration allows the production of laser light over a broad range of wavelengths in or near the visible spectrum. Dye lasers commonly employ optical pumping although some types have used chemical reaction pumping. The most commonly used dye is Rhodamine 6G which provides tunability over 200 nm bandwidth in the red portion (620 nm) of the spectrum. d. SEMICONDUCTOR LASERS (sometimes referred to as diode lasers) are not to be confused with solid state lasers. Semiconductor devices consist of two layers of semiconductor material sandwiched together. These lasers are generally very small physically, and individually of only modest power. However, they may be built into larger arrays. The most common diode laser is the Gallium Arsenide diode laser with a central emission of 840 nm. 4. TIME MODES OF OPERATION: The different time modes of operation of a laser are distinguished by the rate at which energy is delivered. a. CONTINUOUS WAVE (CW) lasers operate with a stable average beam power. In most higher power systems, one is able to adjust the power. In low power gas lasers, such as HeNe, the power level is fixed by design and performance usually degrades with long term use. b. SINGLE PULSED (normal mode) lasers generally have pulse durations of a few hundred microseconds to a few milliseconds. This mode of operation is sometimes referred to as long pulse or normal mode. c. SINGLE PULSED Q-SWITCHED lasers are the result of an intracavity delay (Q-switch cell) which allows the laser media to store a maximum of potential energy. Then, under optimum gain conditions, emission occurs in single pulses; typically of 10(-8) second time domain. These pulses will have high peak powers often in the range from 10(6) to 10(9) Watts peak. d. REPETITIVELY PULSED or scanning lasers generally involve the operation of pulsed laser performance operating at a fixed (or variable) pulse rates which may range from a few pulses per second to as high as 20,000 pulses per second. The direction of a CW laser can be scanned rapidly using optical scanning systems to produce the equivalent of a repetitively pulsed output at a given location. e. MODE LOCKED lasers operate as a result of the resonant modes of the optical cavity which can effect the characteristics of the output beam.

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 is a laser output which is observed as regularly spaced pulsations. Lasers operating in this mode-locked fashion, usually produce a train of regularly spaced pulses, each having a duration of 10(-15) (femto) to 10(-12) (pico) sec. A mode-locked laser can deliver extremely high peak powers than the same laser operating in the Q-switched mode. These pulses will have enormous peak powers often in the range from 10(12) Watts peak.

I. SPECIFIC LASER TYPES:

1. HELIUM NEON LASER: The first CW system was the helium neon (HeNe) gas mixture. Although its first successful operation was at an infrared wavelength of 1.15 ?m, the HeNe laser is most well known operating at the red 633 nm transition. Some HeNe lasers today also can emit operate at other wavelengths (594 nm, 612 nm, 543 nm). Some earlier HeNe lasers were excited by radio frequency (RF) discharge but virtually all HeNe lasers today are driven by a small DC discharge between electrodes in the laser tube. The HeNe laser operates by an excitation of the helium atoms from the ground state. This energy excess is coupled to an unexcited neon atom by a collisional process with the net result of an inversion in the neon atom population, thus allowing laser action to begin. Power levels available from the HeNe laser ranges from a fraction of a milliwatt to about 75 milliwatts in the largest available systems. The HeNe laser is noted for its high-frequency stability and TEM(oo) (single mode) operation. The HeNe laser is one of the most widely used laser in existence today. Its pencil-thin beam is used in surveying work, to align pipelines, as a sawing guide in sawmills, and is also used to "align" patients in medical X-ray units, just to name a few of its many applications. It is also used in many retail scanners, lecture hall pointers and display devices. In addition, holograms are often made using the coherent light of HeNe lasers. 2. ARGON, KRYPTON AND XENON ION LASERS The family of ion lasers utilize argon, krypton, xenon, and neon gases to provides a source for over 35 different laser frequencies, ranging from the near ultraviolet (neon at 0.322 ?m) to the near-infrared (krypton at 0.799 ?m). It is possible to mix the gases, for example, argon and krypton, to produce either single frequency or simultaneous emission at ten different wavelengths, ranging from the violet through the red end of the spectrum. The basic design of an ion gas laser is similar to the HeNe. The major difference is that the electrical current flowing in the laser tube will be 10-20 amperes; sufficient to ionize the gas. Population inversion is obtained only in the ionized state of the gas. An important feature of these lasers is the very stable (0.2%) high output power of up to 20 Watts/CW. Commercial models will normally have a wavelength selector (a prism) within the cavity to allow for operation at any one of the wavelengths available. In addition, approximately single frequency operation can be achieved by placing an etalon inside the optical resonator cavity. Argon ion lasers produce the highest visible power levels and have up to 10 lasing wavelengths in the blue-green portion of the spectrum. These lasers are normally rated by the power level (typically 1-10 Watts) produced by all of the six major visible wavelengths from 458 to 514 nm. The most prominent argon wavelengths are the 514 and 488 nm lines. Wavelengths in the ultraviolet spectrum at 351 and 364 nm available by changing resonator mirrors. To dissipate the large amount of generated heat, the larger argon ion laser tubes are water cooled. Although some lasers have separate heat exchangers, most use tap water. Simple pulsed versions of argon ion lasers also are available. Since the duty

cycle ("on" time divided by the time between pulses) is low, the heat energy generated is small, and usually only convective cooling is needed. The average power output may be as high as several Watts, thought the peak powers can be as high as several kilowatts. Pulse widths are approximately five to fifty microseconds, with repetition rates as high as 60 Hz. 3. CARBON DIOXIDE LASER The carbon dioxide laser is the most efficient and powerful of all CW laser devices. Continuous powers have been reported above 30 kilowatts at the far infrared 10.6 ?m wavelength. An electrical discharge is initiated in a plasma tube containing carbon dioxide gas. CO(2) molecules are excited by electron collisions to higher vibrational levels, from which they decay to the metastable vibrational level occurs; which has a lifetime of approximately 2x10(-3) seconds at low pressure of a few Torr. Establishing a population inversion between certain vibrational levels leads to lasing transitions at 10.6 ?m, while a population inversion between other vibrational levels can result in lasing transitions at 9.6 ?m. Although lasing can be obtained in a plasma tube containing CO(2) gas alone, various gases usually added, including N(2), He, Xe, CO(2) and H(2)O. Such additives are used to increase the operating efficiency of CO(2) lasers. The most common gas composition in CO(2) lasers is a mixture of He, N(2) and CO(2). Carbon dioxide lasers are capable of producing tremendous amounts of output power, primarily because of the high efficiency of about 30%, as compared to less than 0.1% for most HeNe lasers. The principal difference between the CO(2) and other gas lasers is that the optics must be coated, or made of special materials, to be reflective or transmissive at the far infrared wavelength of 10.6 ?m. The output mirror can be made of germanium, which, if cooled, has very low loss at 10.6 ?m. There are three common laser cavity configurations of the CO(2) laser. The first is the gas discharge tube encountered with the discussion of the HeNe laser. Secondly is the axial gas flow, where the gas mixture is pumped into one end of the tube and taken out the other. The gas flow allows for the replacement of the CO(2) molecules depleted (disassociated CO(2) molecules) by the electrical discharge. Nitrogen is added to the CO(2) to increase the efficiency of the pumping process and transfers energy by collisions. Associated effects enhance the de-excitation process. Helium is added to the mixture to further increase the efficiency of the process of pumping and stimulated emissions. The third method is the transverse gas flow. This technique can produce CO(2) laser emissions at power levels approaching 25 kW. The CO(2) laser has a strong emission wavelength at 10.6 micrp m. There is another strong line at 9.6 miceo m and a multitude of lines between 9 and 11 ?m. CO(2) lasers are highly efficient (10-30%), give high output powers (used for welding and cutting), and applications out-of-doors can take advantage of low transmission loss atmospheric window at about 10 ?m. 4. ND:YAG LASER SYSTEMS: One of the most widely used laser sources for moderate to high power uses a neodymium doped crystal Yttrium Aluminum Garnet (YAG), commonly designated Nd:YAG. In addition, other hosts can be used with Nd, such as calcium tungstate and glass. The Nd:YAG laser is optically pumped either by tungsten or krypton pump lamps and is capable of CW outputs approaching 2000 W at the 1.06 ?m wavelength. The ends of the crystal, which is usually in the form of a rod, are lapped, polished, and may be coated to provide the cavity mirrors. Nd:YAG lasers belong to the class of solid state lasers. Solid state lasers occupy a unique place in laser development. The first operational laser medium was a crystal of pink ruby (a sapphire crystal doped with chromium); since that time, the term "solid state laser" usually has been used to describe a laser whose active medium is a crystal doped with an impurity ion. Solid state lasers are rugged, simple to maintain, and capable of generating high powers.

Although solid state lasers offer some unique advantages over gas lasers, crystals are not ideal cavities or perfect laser media. Real crystals contain refractive index variations that distort the wavefront and mode structure of the laser. High power operation causes thermal expansion of the crystal that alters the effective cavity dimensions and thus changes the modes. The laser crystals are cooled by forced air or liquids, particularly for high repetition rates. The most striking aspect of solid state lasers is that the output is usually not continuous, but consists of a large number of often separated power bursts. Normal mode and Q-Switched solid-state lasers are often designed for a high repetition-rate operation. Usually the specific parameters of operation are dictated by the application. For example, pulsed YAG lasers operating 1 Hz at 150 Joules per pulse are used in metal removal applications. As the repetition rate increases, the allowable exit energy per pulse necessarily decreases. Systems are in operation, for example, which produce up to ten Joules per pulse at a repetition rate of 10 Hz. A similar laser, operated in the Q-Switched mode, could produce a one megawatt per pulse at a rate up to ten pulses a minute. 5. EXCIMER LASERS: High power ultraviolet (UV) lasers have been the desire of many in the laser applications community for over twenty-five years. Theoretically, such a laser could produce a focused beam of sub-micrometer size and, therefore, be useful in laser microsurgery and industrial microlithography. Also, photochemical processes which are dependent upon the shorter UV wavelength would be possible at significantly greater speeds because of the enormous UV photon flux presented by a laser beam. In 1975 the first of a family of new UV laser devices was discovered by Searles and Hart. This type laser was to be referred to as an excimer laser, an abbreviation for the term: Excited Dimer. It has taken about a decade for these devices to move from the development lab into real world applications. Excimer lasers operate using reactive gases such as chlorine and fluorine mixed with inert gases such as argon, krypton or xenon. The various gas combinations, when electrically excited, produce a pseudo molecule (called a "dimer") with an energy level configuration that causes the generation of a specific laser wavelength emission which falls in the UV spectrum as given in Table II-2. The reliability of excimer lasers has made significant strides over the past several years. Now, systems operating at average powers from 50-100 Watts are commercially available. A typical excimer operates in a repetitively pulsed mode of 30-40 ns pulses at pulse rates up to 50 Hz with pulse energies of 1-2 Joules/pulse. Some systems use x-rays to preionize the excimer laser's gas mixture so-as-to enhance lasing efficiency and increase the overall output power. TABLE II-2. EXCIMER LASE WAVELENGTHS (Table II-2. Excimer Lase Wavelengths, see printed copy) Until the late 1980s, excimer lasers were more commonly found in the research laboratory where they are used either as a specific UV source or, in many cases, to serve as a "pumping" or exciting source to generate visible laser emissions. In the latter case, the excimer's UV output is directed into a tunable dye laser or Raman shifter module and converted into a modestly high power visible frequency emission. TABLE II-3. LASER TYPES FOR CURRENT APPLICATIONS

(Table II-3. Laser Types for Current Applications, see printed copy)

Excimer lasers are now making the transition from the lab to the production area for a few unique uses in industry or in the operating room for exploratory surgical applications. 6. SEMICONDUCTOR DIODE LASERS The semiconductor or diode injection laser is another type of solid state laser. The energy level scheme is constructed by charge carriers in the semiconductor. They may be pumped optically or by electron beam bombardment, but most commonly, they are pumped by an externally applied current. Although all of these devices operate in the near infrared spectral region,visible laser diodes are being made today. A useful feature is that many are tunable by varying the applied current, changing temperature, or by applying an external magnetic field. Laser diodes are used extensively for communications, in compact disc players, retail scanners, printer, and are beginning to be used in ophthalmology. A summary of applications of the more common lasers is given in Table II-3. Semiconductor lasers are used in distance detectors and remote sensing systems, rangefinders, and for voice and data communications. Many of the diode lasers may be operated on a continuous wave basis. The most common diode uses a gallium-arsenide junction which emits a fan shaped infrared beam at 840 nm. 7. OTHER LASERS: Dye Lasers were the first true tunable laser. Using different organic dyes, a dye laser is capable of producing emission from the ultraviolet to near infrared. Most are operated in the visible with tunable emissions of red, yellow, green, or blue laser emission at almost any wavelength. The more common organic dye lasers are optically pumped. The most common dye used is Rhodamine-6G in solution. Such lasers may either be flashlamp pumped, or more commonly pumped with another laser such as an Argon or Nitrogen laser. To obtain CW reliable operation the dye is made to flow through a thin cell. Using the appropriate dye solutions, an argon-ion laser as a pump, and a prism, the dye laser is tunable across most of the visible spectrum. Tunable dye lasers are now widely used in high resolution atomic and molecular spectroscopy.

J. LASER BEAM PARAMETERS:

The following seven properties are common to the beams emitted from all laser types and are the factors which, when combined together, distinguish laser outputs from other sources of electromagnetic radiation:

1. A nearly single frequency operation of low bandwidth (i.e., an almost pure monochromatic light beam). 2. A beam with a Gaussian beam intensity profile. 3. A beam of small divergence. 4. A beam of enormous intensity. 5. A beam which maintains a high degree of temporal and spatial coherence. 6. A beam that is, in many laser devices, highly plane polarized. 7. A beam with enormous electromagnetic field strengths.

Each of these laser beam properties are briefly reviewed in the following sections.

K. SINGLE FREQUENCY OPERATION (MONOCHROMATICITY):

The frequency of any electro-magnetic wave is related to the number of cycles the electric or magnetic field undergo each second. A completely coherent, monochromatic wave oscillates exactly at a constant frequency. Most laser systems display a narrow multifrequency characteristic. This frequency spread is, however, very narrow when compared to the average laser frequency.

In most lasers, the frequency degeneracy is solely dependent upon the quantum transition characteristics of the active media, and the geometry of the laser resonator cavity (Fabry-Perot). In this sense, the laser media may be considered as a high number of isolated light generators placed between two mirrors. The electromagnetic field developed between the mirrors may be regarded as a superposition of plane waves at each of the slightly different frequencies which the laser media generates and allows to oscillate. These different frequencies are termed the "modes" of the laser resonator. The off-axis modes result from plane waves propagating at an angle with respect to the axis of the resonator. These different modes are produced by diffraction effects in the Fabry-Perot cavity. The lowest order axial mode is designated as the TEM(oo) mode. This mode has the lowest diffraction losses and often will be the predominant mode of oscillation.

For each transverse mode, there will be many longitudinal modes which can oscillate; hence the output of a multimode laser will actually contain a superposition of plane waves oscillating at many discrete frequencies. However, as previously mentioned, this frequency spread will be very small. In each laser, there will be specific "allowed" frequencies of the resonator cavity (Fabry-Perot modes). For most cases, the average wavelength at which the laser oscillates is sufficient to describe it's operation. If more precision is needed, then the frequency spread or bandwidth is given. Depending on the type of laser, bandwidths range typically from 10(-4) to 10(-9) times the average frequency of the laser; although bandwidths as low as 0.1 Hz. have been reported for stabilized gas lasers.

The wave nature of light most often allows adequate description of the output of the laser, and for most cases it will be sufficient to use geometrical optics to describe the output as a beam with well defined edges and some beam divergence. The beam is emitted from the laser with a beam diameter (alpha) and a beam divergence (PHI), as though it came from a small point source far behind the laser output aperture.

L. POINT SOURCE EMISSION:

The emission from most lasers can be considered as emanating from a "virtual point source" located within or behind the laser device. A "virtual point source" is one which really doesn't exist, but the properties of the emitted beam are such that there appears to be a source at this position.

The distance of the point source behind the front mirror of the laser can be related to the size of the beam at the mirror (X) and the laser beam divergence (phi) by the equation:

(Equation, see printed copy)

Thus, the virtual point source is located two meters behind the exit mirror.

M. GAUSSIAN DISTRIBUTION OF THE BEAM:

The intensity profile across a TEM(oo) laser beam will be in the form of a bell-shaped (Gaussian) distribution. The decrease in intensity at the edge of the beam is the result of diffraction effects produced at the edges.

The spatial intensity distribution of this mode may be expressed by equation:

(Equation, see printed copy)

where R is the radius and W is a constant which defines the mean radius and is commonly referred to as the "spot size." At this point the intensity has fallen to e(-2) of the peak intensity at the center of distribution.

In fact, the edges of the laser beam are not well defined. If one were to measure the energy or power per unit area point by point across the center of the output aperture, a Gaussian beam distribution is defined. The peak intensity is in the center of the beam and approaches zero as one moves from the center. This shape is maintained as the beam propagates through space subject to broadening and distortion by atmospheric effects.

Important points on the distribution curve are the e(-1) and e(-2) intensity points since they are used as standard quantities to define the laser beam divergence parameter. (The e is the natural number associated with the natural logarithm and is equal to: e= 2.7183). The e(-1) point is where the intensity is reduced by the factor

(Equation see printed copy)

or approximately 63% of the energy (or power) is contained within the aperture of diameter (a) centered in the beam.

Note: In most all laser safety and compliance standards, the output aperture, a, and the beam divergence, (PHI), are defined relative to the e(-1) points. The total laser energy (Q(t)) or beam power (PHI) is defined as that which is collected from the entire beam (total values). ---

Many manufactures specifications use the e(-2) i points to define beam divergence. In this case, e(-2) i = 0.1353, or the total power (energy) is: 100% - 0.13 3 x 100% = 86.47% or approximately 86% of the total energy /power is within the e(-2) aperture. In some cases, they specify relative to the 90% point. Note that the beam divergence is larger at the e(-2) or 90% point. Hazard calculations are sensitive to the beam divergence and conversions from e(-2) points to e(-2) power points are often performed on beam sizes.

The beam diameters at the two points are related:

(Equation, see printed copy)

Departure from the Gaussian distribution arise when independent oscillation occurs within the resonator at higher order modes. For example, some gas lasers may be designed to have sufficient gain to support simultaneous oscillation in many different transverse modes. Mode selection may often be accomplished by slight adjustment of the mirror alignments. With this technique, one can observe the different complex intensity distributions of each mode.

The lowest order TEM(oo) mode with the nearly Gaussian intensity distribution has the lowest cavity losses and hence will generally be the dominant mode of oscillation.

Optically pumped solid-state lasers such as the normal mode Nd:YAG laser usually display a randomly varying mode output. Thermal gradients in the optical media (i.e., the crystal) caused by nonuniform absorption of the pump light give rise to lens effects in the crystal which change during the pumping cycle. The result is a sporadic switching of transverse modes during the laser pulse. The time average is generally a bell-shaped distribution which is dependent upon the optical purity of the laser crystal, the pumping scheme, and the level at which the system is operated above lasing threshold.

Some pumping schemes produce pronounced "hot spots" in the intensity distributions. For long range transmission, atmospheric effects can also produce intensity variations by a factor of ten over localized regions of the beam. Such non-uniformities distribution make it difficult to specify the cross sectional area of the beam. As a result, an average value of beam radius must be chosen. Typically, this is often (1) the half-power point; (2) the e(-1) power point; or (3) the e(-2) power point.

A more precise laboratory practice is to measure the diameter at the stated power point on a densitometer recording obtained from a photographic negative of the output beam distribution.

In the case of optically pumped solid-state lasers, the size of the beam cross section is generally a function of the pumping level of the laser. In general, the higher the pumping level, the wider the beam size. Only when pulsed lasers are operated near threshold, or in special cavity conditions, will the zero order mode (lowest beam spread) predominate.

N. BEAM DIVERGENCE

Beam divergence is a very important laser parameter and is often expressed in units of milliradians. The symmetry of the laser beam allows the geometry to be reduced to the two dimensions of a plane. The angle (phi), in radians can be related to degrees by noting that for a full circle, phi is 360 degrees.

For some smaller angle, the arc length(s) intercepted along the circumference of the circle can be used to define the angle as:

(Equation, see printed copy)

The minimum beam divergence, called the diffraction limited beam divergence, is related by the equation:

(Equation, see printed copy)

This concept is expanded to three dimensions by introducing the concept of solid angle. The solid angle (OMEGA) is expressed in units of steradians (sr) and is determined by using the area cut out of a surface of a sphere divided by the square of the distance to that surface; that is:

(Equation, see printed copy)

For a sphere, the solid angle may be opened up to include the entire sphere surface area (A = 4 pi R(2)), therefore:

(Equation, see printed copy)

The output of a typical laser will be confined to less than 10(-6) sr.

O. INTENSITY OF LASER EMISSION:

In many applications, the most important laser beam charactertic is the enormous intensity of the beam. Intensity is related to the beam power the cross sectional area and the manner in which the beam spreads from one point in space to the next.

Power, by definition, is the time-rate at which work is done; specifically, it is the rate at which energy is used or produced. Energy relates the ability to do work. As with other forms of energy (eg, chemical, mechanical, electrical), electromagnetic energy (light energy) is a conserved quantity. The relationship between energy, power, and time is defined by the integral equation:

(Equation see printed copy)

The intensity of the laser is usually expressed by the IRRADIANCE (power/area) of the beam. This is determined by dividing the average value of beam power by the average value of the beam cross section. Irradiance units are expressed in Watts per square centimeter.

In pulsed laser operation, instantaneous (peak) Irradiances in excess of 100,000 W/cm(2) are quite easily generated in an unfocused high energy pulsed solid state laser pulse. If this output were contained within a typical beam divergence of 20 milliradians and focused by only moderate power optics, the Irradiance at the focal plane would be increased at least one-hundred fold.

A CW laser is rated in Watts and a pulsed laser is normally rated according to the total energy (Joules) per pulse. Pulsed outputs are also expressed as a RADIANT EXPOSURE in units of Joules per square centimeter.

In order to determine the peak power of pulsed laser, it is necessary to know the pulse shape and duration. The peak power may be closely approximated by assuming a triangular pulse shape and dividing the energy per pulse by the pulse duration at half power.

That is: (Equations, see printed copy)

For example, a 100 mJ/pulse laser with a pulse of 20 ns will have a peak power in excess of:

(Equation, see printed copy)

If the beam is focused to a 1 ?m spot, the Irradiance at the focal plane will be:

(Equations, see printed copy)

This average power is an important factor for high PRF lasers when determining the laser classification and maximum permissible exposure levels.

The radiometric units of RADIANCE and INTEGRATED RADIANCE are used to describe the diffuse reflection of a continuous wave or pulsed laser beam.

Radiance is expressed, by definition, as the Irradiance per unit solid angle (Watts per square centimeter per steradian).

Integrated Radiance is expressed as the Radiant Exposure per unit solid angle (Joules per square centimeter per steradian).

The unit of solid angle is defined such that all space about a point source (i.e., the source of light) will encompass 4 pi sr.

P. FOCUSED LASER BEAMS:

The beam from an ideal laser, i.e., a laser which emits a coherent wave, can be considered as a diffraction-limited beam. In this case, divergence of the beam is limited to the effects of diffraction at the beam edges. The emission from such a laser will display a far-field diffraction pattern at a distance (Equation, see printed copy) where a is the diameter of the emergent laser radiation.

The TEM(oo) beam from a typical helium neon laser will display a 0.5-1.0 milliradian beam spread at a distance of 1.0-2.0 meters from the laser.

Due to the high degree of coherence of a laser beam, it is theoretically possible to focus the beam to the diffraction limit of the wavelength of light. Typically, however, the laser will have a finite beam spread and can be expressed by the simple equations of geometrical optics.

The spot diameter (d) is given by the simple equation:

d = f phi

where: d = spot diameter at focus f = focal length of lens phi = laser beam divergence (radians)

As an example, one can calculate the spot size of a beam focused on the human retina. For this case, consider a "typical" HeNe laser where: phi = 1.0 milliradian and assume that the effective focal length (f) of the human eye is 1.7 cm.

Thus: d = f phi

= (1.7 cm) x (1.0 x 10(-3) rad.) = 17 x 10(-4) cm = 17 ?m

To give some idea of how small this focused spot is, consider that 17 micrometers is approximately the size of two or three human blood cells stacked end-to-end.

Using the equation for the area of a circle (Equation, see printed copy), one can now calculate the focused beam area:

(Equation, see printed copy)

The Irradiance (power per unit area) of a 1 mW He-Ne laser beam focused by the lens of the eye into the retina (assuming no reflection of transmission losses) will be:

(Equation, see printed copy) (Equation, see printed copy)

As the spot diameter approaches the wavelength of light, the spot becomes diffraction-limited. For example, the beam from a highly coherent single transverse mode (TEM(oo)) gas laser will produce a Gaussian intensity pattern when focused. This distribution may be described mathematically by an equation where it is considered that the beam energy will be contained in a diameter defined at the e(-2) power point:

(Equation, see printed copy)

Therefore, the smallest possible spot size of a focused laser beam will approach the dimensions the wavelength of light which is being focused.

Combining the equations above can yield an expression for the spot area:

(Equation, see printed copy)

Thus, the Irradiance (power per unit area) of a focused laser beam will vary inversely with the square of the focal length of the lens and with the square of the beam divergence angle. Hence, these two factors have dramatic effects on the power distribution at the focal plane of the lens.

Consequently, either a reduction in the focal length of the lens used to focus the beam or a reduction in the beam spread by a factor of ten will produce a one-hundred fold increase in the irradiance at the focal plane of the lens. Simultaneous reduction of both by a factor of ten would increase the Irradiance at the focal plane by a factor of 10(4).

In practice, however, it is usually the beam divergence value that limits the focal spot diameter. This is especially true with pulsed laser systems. To achieve high power outputs, the laser crystal is usually pumped well over threshold; consequently, the beam will contain a conglomerate of high order "off-axis" modes which subsequently increase the beam size.

Typical beam divergence values for gas lasers (helium-neon, argon, etc.) will be about one milliradian, (1 milliradian = 3.44 minutes of arc). Solid-state ruby and neodymium lasers generally have a higher beam spread (1- 30 milliradians), due primarily to the high beam divergence associated with the random multimode operation of such devices.

Q. SCANNING LASERS:

Some laser applications employ electro-mechanical or electro-optical scanner units to allow a raster-scan capability to the beam. In this way, the beam can be scanned over a large area (such as in a laser print maker) or over a small area (such as a laser UPC label reader) in a repeated geometry.

The relationships for a scanning laser geometry appropriate for laser hazard analysis are as follows:

(Equations, see printed copy)

For example, the ocular exposure for a Helium Neon laser (beam size 1mm) scanner with 20 degrees scan angle located at a distance of 30 cm from the eye (r = 30 cm) which scans at a rate of 50 Hz will be: (assume d(p) = 7mm):

(Equation, see printed copy)

R. COHERENCE:

The coherency of a laser beam relates to the constancy of the spatial and temporal variations in the radiation wavefronts. A high degree of coherence implies a constant phase different between two points on a series of equal-amplitude wavefronts (spatial coherence), and in a correlation in time between the same points on different wavefronts (temporal coherence). The two coherence terms are a part of the overall four-dimensional coherence function which completely describes the degree of coherency of the beam.

If the laser beam is considered as a plane wave traveling in one direction, it will be spatially coherent due to the perpendicularity of the wavefronts in the direction of propagation. Also, due to the monochromatic nature of the laser light, the beam will be temporally coherent; that is, it will display a fixed-phase relation between a part of the beam emitted at one time and portion emitted at another. Should the wavelength (or frequency) change, then the temporal coherency would degrade.

In 1802, Thomas Young performed his classic double-slit experiment to demonstrate the wave nature of light. Sunlight though one pinhole was allowed to illuminate two closely spaced pinholes. Each pinhole acted as a "new source" for light and the waves from each of the two pinholes interfered with one another so-as-to produce corresponding light and dark regions (or fringes - as they are called) at the observation screen. If light was not a wave, it would travel in a straight line from one pinhole to another to fall at two points on the screen. As a wave, however, it is diffracted and bent about the edges of the pinholes such that each pinhole illuminates the entire screen.

In part, if it were not for the diffraction effects produced as a light wave passes through a finite aperture, the plane wave output of laser could theoretically be focused by a lens (such as the human eye) to a real point with minimal spot diameter. Thus, the image Irradiance , (Equation, see printed copy) would have an infinite value. That would indeed be hazardous!

Due to the wave nature of light and the corresponding diffraction effects produced by finite apertures, the image a point source of light (provided by any real optical system) is not actually a point.

Such a distribution has a bright central area surrounded by light and dark rings. The diameter of the first dark ring of this distribution, which is called the Airy Disk

(D(AD)) is given by the equation:

(Equation, see printed copy)

When an optical system's resolution is only limited by the diffraction effects, it is said to be diffraction limited. Even in this condition, a point is "spread out" as it is imaged. The more defects and aberrations introduced by the optical system, the more the spreading. Each lens images a point with some spreading and the manner which it behaves is defined as the point spread function.

Since an optical system spreads a point source image, there is a corresponding limit to its resolution or ability to separate two points close together. This is especially important when looking at stars through a telescope. There are at least two criteria used to define the resolution of two points close together. A simple one, and the one most commonly used, is the Rayleigh criterion. This states that when the peak of one Airy disk is over the first dark ring of the other, the points are resolved. This is normally defined in terms of the apparent angle between the two points and is given by the equation:

(Equation, see printed copy)

Lasers are often referred to as coherent sources, but in fact, they really only partially coherent. Only absolutely monochromatic or single frequency waves are truly coherent; however, lasers are so close, relative to anything else, that a loose definition may seem justified. The degree to which two waves are coherent determines how well they interfere when brought together at some point in space.

A thorough treatment of the subject of partial coherence is far beyond the scope of this guideline; however, there are a few properties worth discussing. One frequently encounters the terms spatial and temporal coherence. Temporal coherence effects are those which arise from the finiteness of the spectral band. An increase in fringe visibility with a decrease in source size is a measure of the spatial coherence. An important measure of coherence is the coherence length, dL, which can be conceptually related to the duration of an uninterrupted wavetrain. Even in the beam from an "ideal" laser, there will be random fluctuations in the phase difference of the electromagnetic fields at two separate points on a wavefront. The distance between points on the wavefront for which the average of this phase different is equal to (Equation, see printed copy) adians is generally defined as the lateral coherence distance. Recombination of the light samples from points separated by a distance equal to, or less than, this amount can produce interference fringes. The distance is a classical measure of the spatial coherence of a light beam as observed in the famous "double slit" experiment of Young.

The temporal coherence is a measure of the length of time that the beam is truly monochromatic. Since lasers have a finite spectrum width (d(v)), the "coherence time" is defined as:

(Equation, see printed copy)

This may be considered as the time during which the amplitude of the electromagnetic field will remain constant at a given point in space while the phase varies linearly with time. During this time, the beam will travel a length dL = c dT defined as the coherence length (where c = 3 x 10(8) m/sec., the velocity of light). Thus the coherence time is the time required for light to travel the coherence length in the direction of travel of the beam.

By virtue of this argument, it is seen that the frequency bandwidth is actually a measure of temporal coherence. Thus a frequency stabilized HeNe gas laser (d(v) = 3-5 hertz) will have a coherence time of several hundred milliseconds and a corresponding coherence length of 10(5) km.

In contrast to the high spectral purity of gas lasers, the coherence lengths of pulsed ruby lasers are in the order of 15 meters with corresponding coherence times in the order of only 100 nanoseconds.

S. POLARIZATION OF THE LASER OUTPUT:

The polarization of most lasers is directly related to the nature of the resonator. For example, many high power gas lasers are built with Brewster's angle windows on both ends of the gas discharge tube. Such windows present virtually no losses to a beam which has a linear polarization component lying in the plane of incident. Hence the output will be linearly polarized in this plane.

In some solid-state crystal lasers, for example, the ruby laser, the output will be linearly polarized. This is a result of the birefringent nature of the crystal in which the slower "ordinary" polarized photons will have a longer time to interact with the excited chromium ions, thereby favoring a polarized output in this plane. This is generally only true for ruby crystals operating near lasing threshold unless Brewster's angles are fabricated on the ends of the crystal. This latter practice is often necessary for very high power Q-switched laser systems.

In diode lasers, linear polarized light is also observed. This may be attributed to the linear symmetry of the junction region.

T. ELECTRICAL FIELD STRENGTH:

The electromagnetic theory of light depicts a light wave as having instantaneous electric and magnetic fields which oscillate at the same frequency. The electrical (E) and magnetic (H) fields are fixed at right angles and are mutually perpendicular to the direction of propagation of the wave. Of particular importance in the description of laser beam interactions is the magnitude of the electric field associated with the beam.

From classical considerations (using Maxwell's equations) the electric field (E) in volts per centimeter associated with a light beam in a vacuum (or air) of average power (PHI) in Watts, spread over a cross-sectional area (A) in cm(2) is given by:

(Equation, see printed copy)

Prior to lasers, the electric fields associated with commonly occurring light sources were most nominal. For example, the electric field of sunlight occurring at the earth's surface is about (Equation, see printed copy). This constitutes an average field spread over all the wavelengths present in the "white light" of the sun.

In contrast, the instantaneous electric field associated with an unfocused "Q-Switched" Nd:YAG laser burst operating at a level of 100 megawatts and confined to 3 mm beam diameter will approach (Equation, see printed copy). Should this beam be focused to 100 micrometer spot, the field at the focal plane would exceed

(Equation, see printed copy)

Such strong fields are also found elsewhere in nature, as they are at the magnitude of the electrostatic cohesive forces which bind atomic structures. Such binding forces range from (Equation, see printed copy). Consequently, when a laser beam with a field of comparable magnitude enters a transparent structure, an instantaneous massive redistribution of the electric system of the material can occur due to the interaction of the fields. At the present, the interaction of these enormous electromagnetic fields is not fully understood, to be sure. The production of free electrons, ionized atoms, and X-rays have been detected in the reaction association with the interaction of high power laser beams.

U. COMPARISON WITH OTHER SOURCES:

Light from conventional thermal sources is emitted over a wide spectral band. The polarizations of the photons are distributed over all possible states of polarization and leave the source in all possible directions (Lambertian source). In contrast, a laser source has a very narrow spectral linewidth even in comparison to special, narrow band thermal sources; the photons may have, essentially, the same polarization and they are highly directional as they leave the laser cavity.

Conventional optical sources can most certainly constitute a hazard to the human eye and/or skin, particularly close up and when focused. For example, one's first introduction to optical physics might well have been using a magnifying glass to focus the sun's rays on dry leaves to start a fire. However, even a relatively small laser is capable of producing power/energy distributions much greater that conventional sources. In addition, the hazard can exist at very long ranges due to the highly directional nature of the laser output.

A conventional thermal source will emit light into a sphere or hemisphere. The power/energy per unit area (intensity) may be large at the source; however, the intensity at the observer falls off rapidly as the observer moves away from the source. The intensity at the observer can be dramatically increased by using optics to reduce the divergence, making a searchlight; however, the effect is limited by the size of the source.

The output of the laser has a very small divergence, typically less that 1 milliradian (1 mrad = 0.0573 degrees), and the intensity decreases very slowly as the distance to the observer increases. It would take a very powerful thermal source to put as much power into as tight a beam as offered by even the smaller lasers. If one were to insert a very narrow bandpass filter into the searchlight (in order to approximate the spectral purity of monochromatic nature of the laser output), the laser would be brighter than any thermal source by an enormous factor, where brightness is defined as the power output per steradian of solid angle.

To illustrate the relative brightness of the laser over its narrow band, one notes that the sun emits, at its surface, approximately 10(4) W/cm(2)/sr/?m and lasers can produce greater than 10(10)W/cm(2)/sr/?m in single pulse. Therefore, it is not difficult for a laser to be a million times brighter that the sun. Indeed, a laser can not only burn dry leaves, but some are used to weld metal. The most significant factor is not total power, but rather the power per unit area, where the laser may be focused to an extremely small spot (approximately a wavelength in diameter). For example, a one milliwatt laser focused to a one micrometer spot will produce a focused irradiance greater than 1x10(5) W/cm(2).

III. LASER HAZARDS

A. GENERAL OVERVIEW:

Laser radiation of sufficient intensity and exposure time can cause irreversible damage to the skin and eye of man. The most common cause of laser induced tissue damage are thermal in nature. The process is one where the tissue proteins are denatured due to the temperature rise following absorption of laser energy. The thermal damage process is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wavelength region from the near ultraviolet to the far infrared (0.315 - 103 ?m).

Other damage mechanisms have also been demonstrated for other specific wavelength ranges and/or exposure times as shown in Table III-1. For example, photochemical reactions are the principal cause of tissue damage following exposures to either actinic ultraviolet radiation (200 - 315 nm) for any exposure time or "short- wave" visible radiation (400 - 550 nm) when exposures are greater than 10 seconds. Tissue damage may also be caused by thermally induced acoustic-shock waves following exposures to very short-time laser exposures (submicrosecond).

The principle tissue damage mechanism for repetitively pulsed or scanned laser exposures is still in question. Current evidence would indicate that the major mechanism is a thermal process wherein the effects of the individual pulses are additive. There appears to be a different damage process for repetitively pulsed laser exposures when the individual pulses are shorter than 10 microseconds than when the pulses are longer. Both acute and chronic exposures to all forms of optical radiation can produce skin damage of varying degrees.

Numerous types of lasers have been explored rather extensively for the treatment of skin disorders. Certainly, skin injury is of lesser importance than eye damage; however, with the expanding use of higher-power laser systems, the unprotected skin of personnel using lasers may be exposed more frequently to hazardous levels.

(Table III-1. Summary of Basic Biological Effects of Light, see printed copy)

For the common laser sources in the 0.3 to 1.0 ?m range, almost 99% of the radiation penetrating the skin will be absorbed in at least the outer 4 mm of tissue. The absorption of light in tissues obeys an exponential relationship:

(Equation, see printed copy)

Values for the absorption coefficient are shown in Table III-2. In most all cases, the absorption will occur in tissue thicknesses less than 4mm.

For wavelengths greater than 400 nm, the reaction of the skin to absorbed optical radiation is essentially that of a thermal coagulation necrosis. This type of injury can be produced by any optical radiation source of similar parameters and is, therefore, not a reaction specific to laser radiation. It is similar in causality and clinical appearance to the tissues reaction of the deep electrical burn.

For pulsed laser irradiation, including exposures of the picosecond domain, there may be other secondary reactions in the tissue. Studies have shown that the volume of vaporized tissues produced by high-level irradiation with laser pulses in the millisecond domain can backscatter a significant portion of the incident energy. This effectively reduces the amount of absorbed radiation in the tissues.

The principal thermal effects of laser exposure depend upon the following factors:

. Absorption and scattering coefficients of the tissues at the laser wavelength. . Irradiance or radiant exposure of the laser beam. . Duration of the exposure and pulse repetition characteristics, where applicable. . Extent of the local vascular flow. . Size of the area irradiated.

B. ULTRAVIOLET EFFECTS ON THE SKIN:

The ultraviolet spectrum is divided into three specific regions which are related to the different biological responses of these regions. In the skin, UV-A (315 - 400 nm) can cause erythema and hyperpigmentation.

In addition to thermal injury caused by ultraviolet energy, there is the possibility of radiation carcinogenesis from UV-B (280 - 315 nm) either directly on DNA or from effects on potential carcinogenic intra-cellular viruses.

(Table III-2. Absortion Coefficients of Human Skin, see printed copy)

(Table III-3. 50% Minimal Reactive Dose Levels for Skin Laser Damage, see printed copy)

There is limited data available describing the reaction of skin exposed to ultraviolet radiation in the range from 200 nm to 280 nm from highly monochromatic laser sources. Chronic exposure to narrow-band, non-laser ultraviolet wavelengths in this range can result in carcinogenic effects on the skin as well as producing a severe erythematous response.

On the basis of these studies with non-coherent ultraviolet radiation, exposure in the UV-B range is most injurious to skin. Exposure in the shorter UV-C (200 - 280 nm) and the longer UV-A ranges seems less harmful to human skin. The shorter wavelengths are absorbed in the outer dead layers of the epidermis (stratum corneum) and the longer wavelengths have an initial pigment-darkening effect followed by erythema if there is exposure to excessive levels.

It should be kept in mind that phototoxic and photosensitizing chemicals in the skin may potentiate the effects of laser operating in the visible and ultraviolet regions. Studies on the stimulating effect of very low level exposures of the ruby laser on hair growth, phagocytosis index and wound healing are of interest in any consideration of chronic effects.

Recent studies with Excimer ultraviolet lasers have, however, demonstrated a specific, nearly non-thermal, tissue reaction that causes a molecular bond breaking at wavelengths below 340 ?m. This may offer a unique tool in the future for some surgical applications.

Biological effects of laser radiation have not been observed on internal organs of man except for very severe conditions where the outer tissues were either surgically removed or massive laser exposures were delivered to the tissue surface to cause surface ablation. In this condition sufficient energy may be transmitted to the underlying organs and produce tissue damage.

The results of studies on the exposure levels required to produce minimal reactions in the human skin for six common laser types emitting in the visible and IR are summarized in Table III-3. The data presents the minimal reactive dose (measured at the 50% probability level) for the different wavelengths and lasers. The variations, or spread, in the data were found to be directly related to the degree of absorption in the tissues.

The thermal reaction of absorbed radiant energy in tissues is strongly dependent upon both duration and area of the exposure. The early work of Henriques and Moritz investigated the time-temperature response for tissue exposures of thermal insults of to 70 deg. C. Their data indicates that skin can withstand brief temperature rises for very short exposure times. The response appears to be logarithmic as the exposure times become shorter.

For example, a 21 deg. C rise above body temperature (37 deg. C) to 58 deg. C will produce cell destruction for exposures longer than 10 seconds. Tissues, however, can withstand temperatures up to 70 deg. C if the duration of the exposure is maintained less than 1 sec. The basic mechanisms of thermally induced tissue destruction result from denaturation of cell protein, interference with basic cell metabolism and secondary effects such as interference with vascular blood supply.

Healing of laser induced skin lesions is similar to any localized thermal wound and should be medically treated in a similar fashion. Laser induced lesions on the retina tissues of the eye will usually cause irreversible vision function loss and is difficult to medically treat.

C. OCULAR EFFECTS OF LASER RADIATION:

The principal hazard associated with laser radiation is exposure to the eye. This is particularly important in the visible and near-infrared spectral regions (400 - 1400 nm). There are, however, other serious potential hazards in other spectral regions as outlined in the following sections.

The eye may be conceptually considered as a slightly flattened globe which is transparent to the light passing through an aperture pupil) and which has an efficient light absorber on the inside (retinal surface), opposite the aperture. The transparent region of the eye includes several structures which operate to control the exposure to the retina.

The cornea, the transparent window, is the primary refracting structure of the eye. Because of the differences in refractive indices of air and the cornea, more than 80 percent of the refraction of light takes place as the light enters the eye. Between the cornea and the lens is one of the two chambers of the eye. The aqueous chamber contains the aqueous fluid.

The lens is the dynamic refractive medium in the eye, and is responsible for the range of focus of the eye. The retina is the light absorbing structure of the eye containing the neural receptors which initiate the vision process. A blind spot in the retinal surface is located at the point where the optic nerve enters into the eye. The fovea is the portion of the retina which is most sensitive to detail and which discriminates color. This structure fills an angle of approximately two degrees in the central portion of the retina. The fovea is located in a small dip in the center of the area called the macula lutea. The macula fills an area of about 1 mm diameter.

The various structures of the eye transmit, reflect, and absorb optical energy. The effects of laser exposure on the retina are influenced by the transmission losses of the ocular media. The transmittance of the ocular media are such that retinal effects can be anticipated only for laser wavelengths between 400 nm and 1400 nm. Outside that range, structures other than the retina are affected.

The retinal effects of visible optical radiation are also influenced to some degree by the size of the retinal image and the time duration of the laser exposure.

Early in the history of lasers, it was recognized that lasers and great potential for causing retinal injury. The reason was that a laser could produce retinal intensities orders of magnitude greater than conventional light sources, and, in fact brighter than the sun.

The optical system of the eye, like any optical system, will have a limitation (called the diffraction limit) on the smallest size of image it may resolve and focus. To determine the effect of a source imaged on the retina it is necessary to know the retinal image size. A large amount of the research on retinal burns indicates that the size of the source is an important variable. For a first approximation, one can show that a laser with a 1 milliradian beam spread can produce a retinal spot of approximate size of 17 ?m if sharply focussed.

If an unaccommodated eye (an eye focused at infinity) views a collimated source such as a distant star in the night sky or a laser, a "point" image should be produced on the retina. In practice, however, a true point image of that light source is not produced. The optical system of the eye, or any optical instrument, has certain limitations caused by diffraction which will cause the light rays passing through an aperture to bend. The aperture of an optical system is the edge which produces the diffraction. The aperture in the eye is the iris. If a laser beam is larger than the pupil, diffraction of the beam occurs at the edge of the iris.

If the beam is smaller than the pupil, spherical aberrations and forward scattering cause the "point" image to spread. The actual distribution of light from a point source will be spread out somewhat rather than be focused to a diffraction limited spot. In general, the larger the pupil, the smaller the point spread and the greater the magnification factor (concentration) of light at the retina as compared with the irradiance at the cornea. Estimations of the magnification factor, based on diffraction effects only, range from 10(5) to 10(7) for pupil diameters between 2 and 7 mm.

In any event, the optical gain for a 7 mm diameter pupil is at least 1 x 10(5) and may be greater, depending on the magnitude of the experimental error in determining the data used in the estimates.

The location of the exposure in the eye determines the degree of incapacitation from a retinal injury. The fovea (the central two degrees of the visual field) is the region of the retina which is most sensitive to visual detail. The remainder of the retina, the parafovea to the peripheral retina, is increasingly less sensitive to light.

However, the parafovea and peripheral retina are not as sensitive and do not contribute significantly to fine detail in the vision process. Therefore, and injury to the fovea will severely reduce visual functions of visual detail and resolution. An injury to the parafovea or peripheral retina is less incapacitating and may be undetectable from a functional point- of-view.

D. EXTENDED SOURCE VIEWING:

When viewing an extended source, such as the reflection of a laser from a highly reflective diffuse surface, the geometry of the situation results in a retinal image which is of constant brightness (constant retinal irradiance) until the observer moves away so far that the eye can no longer resolve the spot of the laser light. At this point a critical image size is reached. When this occurs, the brightness will stay constant or decrease in value. Retinal spot size effects are related to the differential effects of conduction of heat away from the image which are a function of both exposure time and image size. For long exposures, the large and small image size damage thresholds are different because of thermal conduction. By thermal conduction in this context is meant the cooling of laser heated tissue by contact with surrounding tissue and by circulation of the blood.

E. EYE EFFECTS AT DIFFERENT WAVELENGTHS:

1. EXPOSURE TO ULTRAVIOLET WAVELENGTHS Excessive ultraviolet exposure of the eye can produce photophobia accompanied by redness, tearing, discharge from the mucous membrane that lines the inner surface of the eyelid (conjunctiva), corneal-surface cell-layer splitting (exfoliation) and stromal haze. This is the syndrome of photokeratitis which is radiant energy induced damage to the outer epidermal cell layer of the cornea. In the ultraviolet "C" and "B" regions (UVC and UVB), photokeratitis is the primary result of excessive acute (short-term) exposures. In the ultraviolet "A" region (UVA), cataracts may result from chronic high-level exposures. The actions of ultraviolet "A" and "B" radiation are believe to be photochemical. However, some recent evidence suggests that the damage mechanism of UVA is thermal in nature particularly at wavelengths above 340 nm. In the skin of the eyelid, UVA can cause skin redness (erythema, lenticular fluorescence), and can cause increased pigmentation ("tanning"). Exposure to UVB is, perhaps, of most potential hazard to the skin. Exposures in this range are known to cause cancer and severe erythemal reactions. Exposures to the short-wavelength UVC while potentially hazardous, may not be as dangerous since this wavelength can be easily absorbed by protective clothing or in the outer dead layers of the epidermis (stratum corneum). It is important to note that phototoxic and photosensitizing drugs or chemicals taken internally or applied on the skin may intensify the effects of lasers operating in the ultraviolet and/or visible wavelength regions. 2. EXPOSURE TO VISIBLE AND NEAR INFRARED WAVELENGTHS: The ocular hazards which represent a potential for injury to the different structures of the eye generally depend upon which structure absorbs the most radiant energy per unit volume of tissue. Retinal effects are possible when the laser wavelength is in the visible and near-infrared spectral regions. Laser radiation directly from the laser or from a specular reflection entering the eye at these wavelengths can be focused to an extremely small spot-image on the retina causing an excessive irradiance (W/cm(2)) or radiant exposure (J/cm(2)) incident on the retinal tissues even for modest corneal exposure levels. In the visible portion of the spectrum (beginning near 380 nm and extending to nearly 760 nm), the cornea, lens, and ocular media are largely transparent. Only about 5% of the incident radiation is actually used for vision; the remainder is absorbed in the pigment granules in the pigment epithelium layer of the retina and the choroid layer which lies under the rods and cones (photoreceptors). The absorbed energy is converted into heat and, if the incident laser energy is too great, can cause an irreversible retinal burn. a. INTRABEAM VIEWING: A retinal injury occurring in the macula is a very serious trauma since the vision functions are most highly developed in that area. Destruction of this area (less than one-millimeter in diameter) degrades one's visual

acuity to the point where the "large E" on the Snellen chart is no longer discernible; vision function is reduced to 10/200 or worse. In this case, the individual is legally blind. Of major concern is the fact that blindness can be the result of a laser exposure that lasts only an infinitesimal fraction of a second. On the other hand, similar damage in the periphery of the retina will often have minimal, if any functional significance since a large "blind spot" in the periphery has only a small effect on vision function. A macular burn would be the most probable result if the individual is viewing the beam directly or via a specular reflection under conditions where the eye is resolving the laser source directly onto the macula. A peripheral burn might occur through an accidental exposure when the eye is not directly viewing the beam and the eye is not "relaxed" but viewing something other than the laser point source. b. EXTENDED-SOURCE VIEWING: Viewing extended source lasers or diffuse reflections of a laser beam can sometimes produce a much larger retinal image spot size than direct intra-beam viewing. This provides, at first consideration, some degree of protection since the retinal irradiance will be significantly lower due to the larger spot size. Some lasers are, however, of sufficient power (Class IV) as to be extended source (diffuse reflection) hazards. In this case, the degree of retinal damage would be significant due to the larger retinal spot-sizes associated with a typical extended source viewing condition. Also, larger image sizes (typically 100 ?m or greater) of longer exposure times (greater than 10 seconds) do not dissipate the heat build up as rapidly as smaller image sizes. Consequently, the retinal irradiance which produces a minimal burn on the retina will be about 10-100 times lower for larger image sizes than for the smaller (20 ?m) point source image sizes. Hence, different exposure criteria are needed for the two exposure conditions (point source and the larger extended source criteria). 3. EXPOSURE TO FAR INFRARED WAVELENGTHS: A transition zone between retinal effects and effects on the front segments of the eye (cornea, lens, aqueous media) begins at the far-end of the visible spectrum and extends into the infrared "A" region (0.700 -1.4 ?m). In the infrared "B" region (1.4 - 3.0 ?m) damage is observed to both the lens and cornea. The ocular media becomes opaque to radiation in the infrared "C" region (3.0 ?m - 1 mm) as the absorption by water (a major portion of all body cells) is high in this region. In the infrared "C" region, as in the UVA and UVB regions, the threshold for damage to the cornea is comparable to that of the skin. Damage to the cornea, however, is much more disabling and of much greater concern.

F. BIOLOGICAL DAMAGE MECHANISMS:

Until the late 1970's, it was assumed that all permanent retinal injury from intense visible light sources was thermal in nature when exposures durations exceeded more than 10 microseconds. It had been recognized that there would be a temporary loss of visual function (flashblindness) from sudden exposure to bright light, but it was not known that photochemical retinal injury mechanisms existed in addition to thermal injury.

The laser safety thresholds and exposure limits for exposure durations from 10 microseconds up to 10 seconds seem to follow a constant power function which is dependent upon exposure duration which implies only a thermal damage process. In this time domain, the retinal tissue is raised in temperature to a point where protein (or enzyme) damage takes place.

1. THERMAL INJURY: The thermal injury threshold levels were initially established in the period 1965-1975 through the biological research investigations conducted at various university and military laboratories in the U.S. and by numerous research groups in Europe. The threshold studies of all these groups generally lend strong support to the present levels for allowable exposure limits for exposure durations of less than 10 seconds provided that only a single long duration exposure is considered. Repetitive short exposures (less than 20 ?s) show a curious reduction in the threshold, which cannot be completely explained purely on the basis of thermal injury. The effects from pulses separated by several milliseconds appear to add, which would not be predicted on the basis of heat flow. For example, the effects from two or three exposures of 10 ?s pulses spread over several milliseconds are almost linearly additive. It is important to note that the Federal Laser Product Performance Standard does not include any corrections whatsoever for multiple pulse exposures. Such pulse additivity may be related to some interference with the normal repair mechanisms of the retinal tissue. The safety limits in all standards are typically a factor of ten or more lower than the actual damage "thresholds" commonly encountered in the biological literature. This factor of ten is sometimes erroneously referred to as a "safety factor." In fact the values often termed thresholds in the biological literature are often termed ED (50) doses, that is, doses where 50% of the exposures resulted in injury and 50% of the exposures did not result in changes which were visible by an ophthalmoscope. Obviously safety limits must be concerned with whether there may be permanent or delayed visual loss and tissue damage and not whether the damage is (or is not) simply visible ophthalmoscopically. Many studies have been performed to determine at what levels below the ED(50) dose some loss of visual function (or morphological change in the retinal tissue) will be encountered. These studies generally suggest that for exposure durations of 10 ?seconds to 10 seconds, changes are still observed (by histological evaluation) at power/energy levels reduced from the ED(50) value by a factor in the range of from 2 to 5. Hence, the apparent safety factor of 10 based on ophthalmoscopic (visible burn) criteria is, in reality, only a value of 2 above the level of actual morphological or histological change. The present exposure limits for single pulses in the time domain from 10 ?seconds to 10 seconds are probably realistic and unlikely to be changed unless there is substantive new biological data generated which obviates the vast quantities of data currently available. When the amount of time (and money) already spent in determining these thresholds is considered, it seems unlikely that future research will reveal any unexpected injury at levels near to the present safety limit for these exposure times. 2. PHOTOCHEMICAL RETINAL INJURY: Non-thermal, presumably photochemical damage mechanism for long term laser exposure to short wavelengths in the visible and UVA regions were first shown in 1975 by Dr. William T. Ham, Jr. and colleagues at the Medical College of Virginia. This injury is unlike thermal damage in which a threshold variation over perhaps an order of magnitude might be expected in shifting from 0.400 to 1.10 ?m SOLELY on the basis of changes in retinal absorption. In reality, a range of greater than 1000-fold in retinal

sensitivity to damage was discovered between the most hazardous wavelength of 0.442 ?m and the less hazardous wavelength, 0.633 ?m for an exposure duration of 1000 seconds. All of these studies reported ophthalmoscopically visible and also histologically damaged tissue as a result of long term exposure to visible light. In some experiments, very large areas of the retina were exposed with different wavelengths of the argon laser for four hours. The data points corroborated the limits for thresholds reported earlier by Dr. Ham. The tests used a spot size smaller than the 500 ?m spot used in Ham's earlier studies and also showed far more emphatically a difference between the delayed appearance of the photochemical lesion and the nearly immediate appearance of thermal injury. The fact that a photochemical lesion takes up to 24 or even 48 hours to appear perhaps explains why earlier studies looking for thermal injury could form no consistent picture of the photochemical effect. Along those lines, retinal exposure to the near infrared output of high repetition rate gallium-arsenide diode laser pulses for 30 seconds have also shown similar delayed effects. The mechanism for this type of damage is not well understood, but it may be related to the repetitive pulsing at several kilohertz pulse repetition rates characteristic of these laser types. Wavelength dependent functional effects were also demonstrated as early as 1971. The studies showed permanent loss of blue color vision as a result of blue light exposure. These levels were the basis for the long term intrabeam "safe" laser exposure criteria (approximately 1 uW/cm(2)). 3. LONG-TERM EXPOSURE TO DIFFUSED LASER LIGHT: Certain adverse effects of a vision function nature have been demonstrated in behavior studies with trained monkeys to evaluate visual acuity changes in an effort to determine if a distinction exists between visible lesions and functional loss. The data suggests both adverse and long term irreversible changes of retinal function, particularly to color vision and small angle acuity, resulting from large field DIFFUSE REFLECTION EXPOSURES to visible argon laser light. These effects occur at retinal irradiance levels in the magnitude of 10(-7) W/cm(2), well below the present safety limits. The data also suggests that the effects are dependent on the speckle pattern which is characteristic of diffused laser light. When the speckle was removed by vibrating diffusers in the laser beam projection optics, the effect was not noticed in associated experiments. It is important to note that all of the functional changes have been found only for very large fields of view. Indeed, almost by definition, they could not really be tested for point source exposure conditions. Only diffused laser sources will produce significant speckle pattern. 4. EYE MOVEMENT: The safety limits for long term exposures to a point source are difficult to compare with calculations for the dwell time on the retina of a scanning presentation. The studies on so-called saccadic or micronystagmic eye movements have shown that a point source will never remain for extended periods in one spot of the retina unless the eye has been anesthetized. Exposures to welding arcs by individuals purposely staring at such point sources give a clue as to the size of the retinal area that might be exposed over a period of a few minutes. Some studies had found that a welding arc produced a geometrical retinal image size of perhaps 20 ?m, which corresponds to the spot size commonly encountered for intrabeam viewing of a laser. However, the lesion size resulting from several minutes fixation exceeded 100 ?m. From the present studies of photochemical damage mechanisms it is clear that the expanded lesion resulted from eye movement. In other words, due to eye movements, the point source was scanned over an area larger than the point source image. Hence for an accumulated dose concept for photochemical damage, it is unrealistic to assume that the point source threshold achieved in an animal experiment, where the eye movements are stabilized by anesthetic or mechanical limitation, is directly applicable to the human exposure conditions.

G. EXPOSURE LIMITS

1. LONG TERM CW EXPOSURES (ANSI CORRECTION FACTOR CB): The Federal Laser Product Performance (CDRH) Standard assumes only a simple linearly additive biological effect for exposure durations to visible light between 10 and 10(4) seconds (2.8 hours). The cumulative radiant energy level that the CDRH standard accepts as the level that will not cause a biological effect is 3.85 mJ. Hence for a 10 second total accumulated exposure, this corresponds to a power, entering a 7 mm aperture of 385 ?W (0.385 mW), and for a total accumulated exposure of 10(4) seconds to 3 x 10(4) seconds, this corresponds to 0.385 ?W. The ANSI-Z136 and CDRH allowable exposure limits for CW lasers (Class I limits) are essentially identical for wavelengths between 400 and 550 nm. The ANSI limits are, however, more relaxed for wavelengths between 0.550 and 1.4 ?m. ANSI recognizes a decreased biological hazard in the red and infrared end of the spectrum that is not recognized by the CDRH. The ANSI-Z136 Maximum Permissible Exposure (MPE) level for a very long term exposure by a helium-neon laser is, in fact, seventeen times greater than the CDRH standard. In the 1976 revision, ANSI-Z136 introduced the correction factor CB, such that: C(B) = 10(15) (LAMBDA -0.550) where:

C(B) = 1.0 in the range 0.400-0.550 ?m

(blue light)

LAMBDA = Laser wavelength (?m).

This correction factor has a value of 17.5 at the 633 nm HeNe laser wavelength, and, thus, permitted a radiant exposure of 185 mJ/cm(2) accumulated exposure. This applies for periods of T(1) = 453 to 10(4) seconds, and 17.5 W/cm(2) (7 ?W in a 7 mm limiting aperture) for continuous operation of very long exposure durations exceeding 10(4) seconds. The comparable exposure for an argon laser at 0.488 to 0.514 ?m would be 1.0 ?W/cm(2) (0.4 ?W in a 7 mm limiting aperture). 2. REPETITIVELY PULSED EXPOSURES: Current laser safety standards (ANSI Z-136) require a decrease in the maximum permissible exposure (MPE) for scanned or repetitive pulse radiation as compared to continuous wave radiation for pulse repetition frequencies (PRF) in the general range of 1-15 KHz. For reasons that are not yet well understood, scanned or repetitively pulsed radiation with repetition rates less than 15 KHz have lower retinal damage threshold levels than CW radiation of comparable power. As has been mentioned previously, one important distinction between ANSI-Z136 and CDRH laser limits is that although both assume a 7 mm aperture, the ANSI standard has further restrictions regarding the exposures which occur with a repetitively pulsed or a scanning laser beam.

(Table III-4. Summary: Maximum Permissible Exposure Limits, see printed copy)

Typical scanning laser beams have a dwell time across the pupil of the eye of the order of a few microseconds. CDRH assumes that if a single scan exposure does not exceed the limits established for a microsecond duration single pulse laser, and that if the multiple scans in linear addition do not exceed the Class I limit, then the device presents no ocular hazard (i.e., it is Class I for one emission duration). However, the ANSI Z-136 Standard, has a reduction factor of the threshold for each of the single pulses based on biological data that is yet well explained by any theory. The CDRH standard does not recognize this repetitively pulsed correction factor. However, some experts envision the possibility of a repetitively pulsed laser which is Class I by the CDRH standard and perhaps Class II or even Class IIIB by the ANSI-Z-136 standard. If this is true, injury may result after an exposure of only a few seconds. The ANSI standard requires that multiple pulse (scanning) lasers operating from 1 to 15,000 Hz have a correction to the single pulse MPE. The correction factor is determined by taking the fourth root of the total number of pulses in a pulse train. Then, the correction factor is calculated such that the MPE radiant exposure or integrated radiance of an individual pulse within the train is reduced by a factor N(-1/4) as follows: MPE(multiple pulse) = [N(-1/4)] x MPE(single pulse) Where: N = number of pulses in the train MPE(single pulse) = MPE applicable to a single pulse of the pulse length. The choice of "on-time" to determine the total number of pulses is one of the variables that often leads to some confusion. This "on time" is chosen to be some appropriate time factor, typically ranging from 10 to 1000 seconds. The ANSI standard does indicate, however, that 10 seconds is a valid time for invisible (NIR) radiation. The allowable exposures given in all of the present safety standards attempt to follow as closely as possible, the actual biological data obtained with the different lasers. The ANSI-Z-136 standard probably gives the best fit with the real biological hazards. In this regard, it should be again noted that the upper limit for Class I Helium Neon lasers in the Federal Laser Standard is seventeen times less than the present ANSI-Z-136 (1980) standard. In 1973, the two standards were almost identical, but by 1976 the ANSI limits for lasers operating in the red and near-infrared regions of the optical spectrum were relaxed considerably because of new biological data that was unavailable in 1973.

H. MAXIMUM PERMISSIBLE EXPOSURE LIMITS:

A summary of Maximum Permissible Exposure (MPE) limits for direct ocular exposures for some of the more common lasers is given in Table III-3. For further information on MPE values, refer to the Z-136.1 "Safe Use of Lasers" Standard of the American National Standards Institute.

A summary of Maximum Permissible Exposure (MPE) limits for direct ocular exposures for some of the more common lasers is given below in Table 17-4. For further information on MPE values, refer to the ANSI Z-136.1 "Safe Use of Lasers" Standard.

The information in Table III-4 provides the MPE value for different lasers operating for different overall exposure times. The times chosen were:

. 0.25 SECOND: The human aversion time for a bright light stimulus. (e.g.: the "blink reflex"). Thus, this becomes the "first line of defense" for unexpected exposure to some lasers and is the basis of the Class II concept. . 10 SECONDS: The time period chosen by the ANSI Z-136.1 committees that represents the optimum "worst case" time period for ocular exposures to infrared (principally near-infrared) laser sources. It was argued that natural eye motions dominate for periods longer than 10 seconds. . 600 SECONDS: The time period chosen by the ANSI Z-136.1 committees that represents a typical "worst case" time period for viewing visible diffuse reflections during tasks such as alignment. . 30,000 SECONDS:

The time period that represents a full one-day (8 hour) occupational exposure. This results from of computing the number of seconds in 8 hours; e.g.: 8 hrs/day x 60 min/hr x 60 s/min = 28,800 s. Rounded off, it becomes 30,000 seconds.

The "safety" exposure limits (MPE's) in Table III-4 are expressed in irradiance terms (W/cm(2)) that would be measured at the cornea. Note that they vary by wavelength and exposure time.

I. ASSOCIATED (NON-BEAM) LASER HAZARDS:

In some laser operations, particularly in the research laboratory, other aspects may require consideration.

1. INDUSTRIAL HYGIENE CONSIDERATIONS: Potential hazards associated with compressed gases, cryogenic materials, toxic and carcinogenic materials and noise should be considered. Adequate ventilation shall be installed to reduce noxious or potentially hazardous fumes and vapors, produced by laser welding, cutting and other target interactions, to levels below the appropriate threshold limit values, e.g., American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLV's). [Additional references can be found in Appendix F: "Special Considerations" of ANSI Z136.1 (1986)]. 2. EXPLOSION HAZARDS: High pressure arc lamps and filament lamps or laser welding equipment shall be enclosed in housings which can withstand the maximum pressures resulting from lamp explosion or disintegration. The laser target and elements of the optical train which may shatter during laser operation shall also be enclosed. 3. OTHER NON-BEAM OPTICAL RADIATION HAZARDS: This relates to optical beam hazards other than laser beam hazards. Ultraviolet radiation emitted from laser discharge tubes, pumping lamps and laser welding plasmas shall be suitably shielded to reduce exposure to levels below the ANSI Z-136.1 (extended source) and/or ACGIH - TLV's. 4. COLLATERAL RADIATION: Radiation, other than laser radiation, associated with the operation of a laser or laser system, e.g., radiofrequency (RF) energy associated with some plasma tubes, x-ray emission associated with the high voltage power supplies used with excimer lasers, shall be maintained below the applicable protection guides. The appropriate protection guide for RF and microwave energy is that given in the American National Standard "Safety levels with respect to human exposure to radio frequency electromagnetic fields, 300 kHz to 100 GHz," ANSI C95.1; the appropriate protection guides for exposure to X-ray emission is found in the Department of Labor Occupational Safety and Health Standards, 29 CFR Part 1910.96 and the applicable State Codes. Lasers and laser systems which, by design, would be expected to generate appreciable levels of collateral radiation, should be monitored. 5. ELECTRICAL HAZARDS: The intended application of the laser equipment determines the method of electrical installation and connection to the power supply circuit (for example, conduit versus flexible cord). All equipment shall be installed in accordance with the National Electrical Code and the Occupational Safety and Health Act. [Additional specific recommendations can be found in Section 7.4 of ANSI Z136.1 (1986)]. 6. FLAMMABILITY OF LASER BEAM ENCLOSURES: Enclosure of Class IV laser beams and terminations of some focussed Class IIIB lasers, can result in potential fire hazards if the enclosure materials are exposed to irradiances exceeding (Equation, see printed copy). Plastic materials are not precluded as an enclosed material but their use and

potential for flammability and toxic fume release following direct exposure should be considered. Flame resistant materials and commercially available products specifically designed for laser enclosures should also be considered.

IV. LASER STANDARDS:

A. OVERVIEW OF STANDARDS:

In the United States the are four major activities concerned with regulations regarding safety of laser systems. These organizations are the American National Standards Institute (ANSI), the Center for Devices and Radiological Health (CDRH), the Occupational Safety and Health Administration (OSHA), and the various state governments.

ANSI is an organization for which expert volunteers participate on committees to set industry consensus standards in various fields. ANSI has provided the basis for numerous existing federal standards as-well-as the more recent Suggested State Regulations for Lasers (SSRL). The ANSI-Z-136.1 (1986) standard provides requirements and recommendations for the safe use of lasers with which the personnel who operate, maintain and service lasers must be familiar.

The CDRH is a regulatory bureau within the Federal Food and Drug Administration of the Department of Human Services. It has been chartered by Congress to standardize the manufacture of laser products. The laser products manufactured after August 2, 1976 which have been entered into interstate commerce must comply with these regulations.

In addition, CDRH also has the responsibility for enforcing compliance with the Medical Devices Legislation. All medical laser manufacturers must obtain either pre-market approval (PMA) or clearance (510K) of their laser surgical devices through the CDRH. It should also be noted that FDA sanctions the exploratory use of lasers for specific procedures through a process known as an Investigational Device Exemption (IDE). Approval of an IDE permits the limited use of a laser expressly for the purpose of conducting an investigation of the laser's "safety and effectiveness." Once an IDE has been done and the CDRH clears the device, the manufacturer may then actively market the laser for that specific medical/surgical procedure.

(Table IV-1. Summary of Current State Laser Regulations, see printed copy)
(Table IV-2. Tabulation of FDA/CDRH Requirements for Laser Products, see printed copy)
(Table IV-2. Tabulation of FDA/CDRH Requirements for Laser Products (Continued), see printed copy)

Laser regulations within the various states vary considerably from state to state and are generally concerned with the registration of lasers and the licensing of operators and institutions. This is summarized in Table IV-1. At present, physicians and medical lasers generally are exempt from most state requirements.

The complexity of state laser regulations may change in the future pending adoption by states of the "Suggested State Regulation for Lasers" which is currently being promulgated by the Conference of Radiation Control Program Directors.

The regulatory administration of the U.S. Department of Labor with the responsibility of assuring a safe work place is vested in the Occupational Safety and Health Administration (OSHA). At this time, OSHA does not have an all encompassing and comprehensive laser standard. There is an OSHA standard which covers the use of lasers in the construction field only (29 CFR 1910).

However, there have been OSHA citations issued relative to lasers using the authority vested under the "general duty clause" of Public Law 91-596; the Occupational Safety and Health Act of 1970. In these cases, the OSHA inspectors have asked the employers to revise their reportedly unsafe work-place using the recommendations and requirements of such industry consensus standards as the ANSI Z-136.1 Standard.

B. BACKGROUND OF LASER STANDARDS:

The initial development of laser safety standards began during the mid-1960's as new biological data was made available. Revisions occurred and the various standards reached their present state during the period of 1973-1986. In 1972 two primary group in the United States were developing laser standards. One was a consensus group of industry, university and governmental experts on lasers, laser biological effects and safety, who developed standard Z-136.1 (1973) under the auspices of the American National Standards Institute (ANSI) in New York City. This committee created the concept of classifying lasers according to a scheme of graded risk of exposure and risk of injury evolved.

Due to the large variety of lasers, difficulties of laser measurements, and the complexities of laser hazard evaluation, the committee felt that the scheme of not more than five classes of graded risk would help laser users to determine hazards. If hazards were known, then proper safety controls could be applied according to the classification. The different control measures were also graded according to this classification scheme. Hence, a user with a high risk laser (Class IV) would follow more stringent control measures than would apply to a low risk laser (Class II).

During this same period the Bureau of Radiological Health within the Food and Drug Administration developed regulations limited to performance requirements that apply to manufacturers. In 1982, the Bureau of Radiological Health was merged with the Bureau of Medical Devices and renamed the National Center of Devices and Radiological Health (NCDRH). The name was shortened soon thereafter to simply the Center of Devices and Radiological Health (CDRH). In addition to lasers, the CDRH also has regulatory responsibility for the Medical Devices Legislation.

The basic law under which gave the CDRH regulatory authority over lasers was the Radiation Control for Health and Safety Act of 1968 (PL-90-602). The act empowered the CDRH to set standards of performance for electronic products that emitted radiation. This is the same public law that applies to X-rays, ultrasonic devices, microwave ovens, etc..

Most of the CDRH's regulations pertains to very specific applications of a particular type of source of electromagnetic radiation. For instance, they do not have a standard for all microwave devices, but they do have a standard for microwave cooking ovens. Similarly, they have specific standards for X-ray emission from your color TV sets, X-ray emission from diagnostic X-ray units, etc.

In the case of lasers, however because of the precedent of the ANSI approach (which included all possible laser applications), the CDRH chose to try to adapt the basic concept of ANSI and formulate a set of performance and labeling requirements based on a classification scheme according to the level of laser radiation accessible during operation.

This was obviously a bold approach to undertake for a large class of products which were relatively new or unknown at the time that the standard was written. It is, therefore, not surprising that there have been some difficulties both in basic concepts and in interpretation of the standard since many have evolved since the standard was initially written. The standard has been amended twice since its initial issuance.

To summarize then, the CDRH Laser Product Performance regulates the manufacturer and the commercial laser products, not the user. The standard does not contain specific design specifications, but is a conceptual, performance standard which the designer of laser product must consider. The intent is to insure laser product safety from the manufacturer's standpoint only, as the CDRH does not "regulate the user" of electronic products. In addition, the CDRH laser standard applies to all laser products that are sold or otherwise transferred to users.

The ANSI-Z-136 standard is "For the Safe Use of Lasers" and is available for voluntary adoption by users of equipment. Although the Z-136.1 Standard in not "a law" it has had direct impact on all laser standards worldwide.

C. STANDARDS VERSUS REALITY:

When the potential hazard from any real product is considered, there is always a distinction between the real hazard and that which may be implied by the regulations and standards. The writers of standards and regulations are always forced to make general statements which will inevitably have exceptions. Complete accuracy is often sacrificed for simplicity. For example, notwithstanding the complexity of the CDRH regulations, the classification limits still do not, in all cases, fit the reality of current biological knowledge.

For example, corrections for repetitively pulsed lasers have not been incorporated into the CDRH standard although this has been a part of the ANSI and other international standards for more than a decade.

This may be related to the elaborate requirements for the review and comment revision process for CDRH regulation which is slow and cumbersome or to the lack of sufficient biological data to support the issue.

In contrast, the revision process for an ANSI Standard is considerably less cumbersome, which is reflected in the fact that a massive revision was adopted and published in 1976, only two years after the original publication. A second massive revision was completed in 1980 by the ANSI committee to correct previous difficulties, particularly in organization as well as compatibility with the CDRH standard. A third complete revision was finished in 1986 and led to the publication of the fourth edition (ANSI Z-136.1-1986) in the early part of 1986. Work is now underway for major revisions and a new edition for 1991-1992 period.

The CDRH laser standard has undergone only two minor revisions since it was first released. Some changes were proposed in November, 1980 and finally approved in August, 1985 to become effective, in most part, by September 1986.

At present, the manufacturer of a laser product is faced with two concerns:

1. Assurance that the laser products that are manufactured are indeed reasonably safe both from an ethical standpoint and also to avoid legal liability. 2. The compliance requirements of the Federal Laser Product Performance Standard.

To some extent, in certain cases, there is a third consideration. The necessity to avoid unwarranted fear and concern by the user about the safety of the product.

D. U.S. FEDERAL LASER PRODUCT PERFORMANCE STANDARD (FLPPS):

A requirement of compliance with U.S. regulations is required by organizations/personnel involved in the design, fabrication and manufacture of laser products. This is applicable to lasers or laser systems to be sold by a company within or imported inside the U.S. It can also apply in some cases when a laser or laser system is transferred within a company for internal use within the U.S.

The compliance procedure requires implementation of the procedures and requirements as set forth in the U.S. Federal Laser Product Performance Standard: Title 21 of the Code of Federal Regulations; Part 1000; [parts: 1040.10 and 1040.11].

This also pertains to commercial laser products that are placed into commerce by a company either directly, after modification, and/or after being incorporated into a laser product.

The FLPPS regulates the manufacturer and the performance of the product by specifying performance features:

. Protective housing . Protective housing warning labels and logotype labels . Safety interlocks . Emission indicator . Remote interlock connector . Key control . Beam attenuator . Specification on control locations . Viewing optic limitations . Scanning beam safeguards . Manual reset on beam cutoff

The laser manufacturer establishes the required specifications, and is responsible for compliance with federal CDRH laser product requirements. The laser product will encompass one of the following categories:

- Internally developed by a organization within a company. - Obtained from an organization within a company. - Obtained from an outside manufacturer and repackaged for resale. - Obtained from an outside manufacturer, incorporated into another product and repackaged for resale.

Under the requirements of the FLPPS, the manufacturer is required to classify the laser as either a Class I, Class II, Class IIA, Class IIIA, Class IIIB or Class IV laser product certify by means of a label on the product, and submit an initial report demonstrating compliance with all requirements (performance features) of the standard. These requirements are detailed in Table IV-2.

E. REPORTING GUIDELINES (FLPPS):

The COMPLIANCE GUIDE FOR LASER PRODUCTS, which is available from CDRH, summarizes the requirements of the U.S. Federal Laser Product Performance Standard which a Manufacturer should use to ensure that the laser product complies with the CDRH regulations (performance requirements, labeling, reporting, classification, etc.) The Compliance Guide is available from The Center for Devices and Radiological Health (CDRH), Food and Drug Administration (FDA). This guide should also be consulted prior to the completion of Initial, Model Change, or Annual Reports by personnel responsible for these reports (product engineers, designers, developers, etc.)

An Initial or Model Change Report shall be prepared, for each laser product or product family, by the responsible personnel for the location which is manufacturing the product and submitted to the FDA prior to introducing the laser product into commerce.

An Annual Report for all manufactured laser products is also required by the FDA. All locations which manufacture lasers that are introduced directly into commerce must report to FDA/CDRH all lasers manufactured from July 1 of any year to June 30 of the next.

V. LASER CLASSIFICATIONS

A. INTRODUCTION:

The basis for the classifications in this document are:

1. The ANSI Z-136.1 and ANSI Z-136.2 Standards of the American National Standards Institute (ANSI). 2. The U.S. Federal Laser Product Performance Standard (FLPPS): Title 21 of the Code of Federal Regulations; Part 1000; [Parts 1040.10 and 1040.11, as applicable].

The intent of laser hazard classification is to provide warning to users by identifying the potential hazards associated with the corresponding levels of accessible laser radiation through the use of labels and instruction. It also serves as a basis for defining appropriate control measures and medical surveillance.

Lasers and laser systems received from manufacturers shall be classified and appropriately labeled by the manufacturer. However, the classification may change whenever the laser or laser system is modified to accomplish a given task.

Also, the Laser Safety Officer (LSO) shall effect the classification designation in cases where the laser or laser system classification is not provided or where the class level may change because of alterations to the laser or laser system.

It should be mentioned that the U.S. Federal Government does not "approve" laser systems. The manufacturer of the laser system first classifies the laser and then certifies that it meets all performance requirements of the Federal Laser Product Performance Standard (FLPPS).

Therefore, all lasers and laser systems that are manufactured by a company, or purchased by a company and relabeled and placed into commerce, or incorporated into a system and placed into commerce, shall be classified in accordance with the FLPPS. The classification shall be confirmed by the LSO at the laser installation.

B. LASER HAZARD CLASSES:

Virtually all of the U.S. and international standards divide all lasers into four major hazard categories called the laser hazard classifications.

The basis of the classification scheme is the ability of the primary or reflected primary beam to cause biological damage to the eye or skin during intended use.

The criteria is established

(TABLE V-1. Laser Classifications: Summary of Hazards, see printed copy)

relative to the Maximum Permissible Exposure (MPE) levels that are accessible during operation of the laser.

Lasers and laser systems are assigned one of four broad Classes (I to IV) and Optical Fiber Communications Systems (OFCS) are assigned one of four service groups (SG1, SG2, SG3a, SG3b) depending on the potential for causing biological damage.

The laser hazard classes are summarized in Table V-1 and are given as:

. CLASS I: cannot emit laser radiation at known hazard levels (typically CW: 0.4 ?watts at visible wavelengths). Users of a Class I laser products are generally exempt from radiation hazard controls during operation and maintenance (but not necessarily during service).

Since lasers are not classified on beam access during service, most all Class I industrial lasers will consist of a higher class (high power) laser enclosed in a properly interlocked and labeled protective enclosure. In some cases, the enclosure may be a room (walk-in protective housing) which requires a means to prevent operation when operators are inside the room.

. CLASS II: low power visible lasers which emit above Class I levels but emitting a radiant power not above 1 mW. The concept is that the human aversion reaction to bright light will protect a person.

NOTE: Class IIA is a special designation that is based upon a 1000 second exposure and applies only to lasers that are "not intended for viewing" such as a supermarket laser scanner. The upper power limit of Class IIA is 4.0 ?W. These are products whose emission does not exceed the Class I limit for an emission duration of 1000 seconds.

. CLASS IIIA: intermediate power lasers (CW: 1-5 mW). Only hazardous for intrabeam viewing. Some limited controls are usually recommended.

NOTE: There are different labeling requirements for Class IIIA lasers with a beam irradiance that does not exceed 2.5 mW/cm(2) (Caution logotype) and those where the beam irradiance does exceed 2.5 mW/cm(2) (Danger logotype).

. CLASS IIIB: moderate power lasers (CW: 5-500 mW, pulsed: 10 J/cm(2) - or the diffuse reflection limit, which ever is lower). In general, Class IIIB lasers will not be a fire hazard nor are not generally capable of producing a hazardous diffuse reflection except for conditions of intentional staring done at distances close to the diffuser. Specific controls are recommended. . CLASS IV: High power lasers (cw: 500 mW) are hazardous to view under any condition (directly or diffusely scattered) and are a potential fire hazard and a skin hazard. Significant controls are required of Class IV laser facilities.

EMBEDDED LASER: A Class II, Class III, or Class IV laser or laser system contained in a protective housing and operated in a lower classification (Class I, Class II or Class III). Specific control measures may be required to maintain the lower classification.

C. OPTICAL FIBER COMMUNICATION SYSTEMS (OFCS):

Optical Fiber Communication Systems (OFCS) and the associated optical test sets use semiconductor lasers or LED transmitters that emit energy at wavelengths typically greater than 700 nm into the lightguide fiber optic cables.

All OFCS are designed to operate with the beam totally enclosed within the fiber optic and associated equipment and, therefore, are always considered as Class I in normal operation. The only risk for exposure would occur during installation and service when lightguide cables are disconnected or during an infrequent accidental cable break.

Optical Fiber Communication Systems (OFCS) are assigned into one of four service group designations: SG1, SG2, SG3a, SG3b, depending on the potential for an accessible beam to cause biological damage. The service group designations relate to the potential for ocular hazards to occur only during accessible beam conditions. This would normally occur only during periods of service to a OFCS. Such designations apply only during periods of service in one of the following four service groups (SG):

. SERVICE GROUP 1: An OFCS that is SG1 has a total output power that is less than the Accessible Emission Limit (AEL) for Class I and there is no risk of exceeding the Maximum Permissible Exposure (MPE) when viewing the end of a fiber with a microscope, an eye-loupe or with the unaided eye. . SERVICE GROUP 2: An OFCS is SG2 only if wavelengths between 400 and 700 nm are emitted and is potentially hazardous if viewed for more than 0.25 s. (Note: at present, there are virtually no OFCS that operate in this wavelength range.) . SERVICE GROUP 3A: A SG 3A OFCS is not hazardous when viewed with the unaided eye and is hazardous only when viewed with a microscope or an eye-loupe. . SERVICE GROUP 3B: OFCS which meet none of the above criteria are designated as SG 3B.

NOTE: OFCS where the total power is at or above 0.5W do not meet the criteria for optical fiber service group designation. In this case, the OFCS are treated as a standard laser system.

D. LASER CLASSIFICATION MEASUREMENTS:

The measurement and test parameters for purposes of laser classification are outlined in detail in 21 CFR Part 1040. For convenience, they are summarized below:

Tests on lasers and laser systems, for purposes of classification, shall be made during operation, maintenance or service as appropriate:

. Under those conditions and procedures which maximize the accessible emission levels, including start-up, stabilized emission, and shut-down of the laser or laser system; . With all controls and adjustments listed in the operation, maintenance, and service instruction adjusted in combination to result in the maximum accessible emission level of radiation; and, . For the case of laser diodes, with the device biased to operate at the output power levels specified in the data sheet for the intended use.

At points in space to which human access is possible in the configuration which is necessary to determine compliance with each requirement, e.g., if operation may require removal of portions of the protective housing e.g., disconnection of an optical connector for OFCS, and defeat of safety interlocks, measurements shall be made at accessible points with the measuring instrument detector positioned and so oriented with respect to the laser or laser system as to result in the maximum detection of radiation by the instrument.

Accessible emission levels of laser and collateral radiation shall be based upon the following measurements (or their equivalent) as appropriate:

For laser products intended to be used in a locale where the emitted laser radiation is unlikely to be viewed with optical instruments, the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 millimeters and within a circular solid angle of acceptance of 10(-3) steradians with collimating optics of 5 diopters or less (i.e., a maximum distance of 20 cm). A 50 millimeter diameter aperture stop with the same collimating optics and acceptance angle shall be used for all other laser products. For scanned laser radiation, the direction of the solid angle of acceptance shall change as needed to maximize detectable radiation, with an angular speed of up to 5 radians/second. A 50 millimeter diameter aperture stop with the same collimating optics and acceptance angle stated above shall be used for all other laser products.

The irradiance (W/cm(2)) or radiant exposure (J/cm(2)) equivalent to the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 millimeters and, for irradiance, within a circular solid angle of acceptance of 10(-3) steradian with collimating optics of 5 diopters or less, divided by the area of the aperture stop (cm(2)).

The radiance (W/cm(2) sr) equivalent to the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 millimeters and within a circular solid angle of acceptance of 10(-5) steradians with collimating optics of 5 diopters or less, divided by that solid angle (sr) and by the area of the aperture stop (cm(2)).

For diode lasers coupled to an optical fiber, the radiant power (W) or radiant energy (J) detectable through a circular aperture stop having a diameter of 7 mm can be calculated from the output power measured at the connector (closed system) and the numerical aperture (for a multimode fiber) or the mode-field diameter (for a single mode fiber). This procedure, described in ANSI Z- 136.2, provides a conservative estimate, i.e., yields values slightly in excess of the corresponding measured values.

VI. LASER HAZARD EVALUATION

A. LASER ENVIRONMENTAL FACTORS:

Three aspects of the application of a laser or laser system influence the total hazard evaluation:

1. The laser or laser system's ability to injure personnel 2. The environment in which the laser is used 3. The personnel who may use or be exposed to the beam

All three aspects must be considered in order to establish control measures commensurate with the potential hazard.

The environment in which the laser is used may vary with each application. It is extremely important, however, that the environment in which the laser is used be considered in order to determine whether or not the control measures in are adequate, or if some are unnecessary. For example, the controls for a laser robotic system used on a production floor would be expected to be considerably different from those used in a research laboratory. As a minimum, the following shall be considered:

1. Number of lasers or laser systems 2. Degree of isolation (laboratory, production floor) 3. Probability of the presence of uninformed, unprotected transient personnel 4. Permanence of beam path(s) 5. Permanence of specularly reflecting objects in or near the beam path 6. The use of optics (e.g., lenses, microscopes, optical fibers).

B. LASER SAFETY OFFICER (LSO):

The conditions under which the laser is used, the level of safety training of individuals using the laser and other environmental and personnel factors are important considerations in determining the full extent of safety requirements. Since such situations require informed judgments by responsible persons, major responsibility for such judgments has been assigned to a person with the requisite authority and responsibility, namely the Laser Safety Officer (LSO).

The LSO shall have the authority and responsibility to monitor and enforce the control of laser hazards, and to effect the knowledgeable evaluation and control of laser hazards. This shall be done at each location or administrative area where Class III or Class IV lasers or laser systems are used or manufactured.

Designation of an LSO is generally not required for operation of a Class II or Class IIIA laser or laser system. Designation of an LSO is generally not required if maintenance and service are limited to Class I and Class II laser systems which do not contain embedded lasers of a Class higher than Class II. If service is performed on a laser product having an embedded Class IIIA, Class IIIB, or Class IV laser, there shall be a designated LSO.

Depending on the number and classification of lasers and laser systems, within a location or administrative area, the position of LSO may not be a fulltime assignment.

C. STANDARD OPERATING PROCEDURE:

One of the most important, but often least used, control measure is the requirement to develop a written Standard Operating Procedure (SOP). The key to an effective

SOP is the participation, during its preparation, of all individuals (including the LSO) that will operate, maintain, monitor, and/or service the equipment. A good starting point for an SOP would be the instructions for safe operation suggested by the manufacturer; however these may not always be appropriate for a specific application due to special use conditions.

An SOP is considered as an administrative/procedural control and is required for all Class IV lasers and laser systems. An SOP is recommended for Class IIIB lasers, especially those CW lasers operating above 200 mW in an open configuration.

D. LASER PERSONNEL:

The personnel who may be in the vicinity of a laser and its emitted beam(s) and the operator can influence the total hazard evaluation. Hence, they can influence the decision to adopt additional control measures not specifically required for the class of laser being employed. The type of personnel influences the total hazard evaluation. It must be kept in mind that for certain lasers or laser systems (for example, some Class IIIA lasers used for alignment tasks), the principal hazard control rests with the operator; that it is his or her responsibility not to aim the laser at personnel or flat mirrorlike surfaces. If individuals unable to read or understand warning labels are exposed to potentially hazardous laser radiation, the evaluation of the hazard is affected and control measures may require appropriate modification. The following are considerations regarding operating personnel and those who may be exposed:

1. Maturity of judgment of the laser user(s). 2. General level of training and experience of the laser user(s), (that is, whether part time employees, scientists, etc.). 3. Awareness of onlookers that potentially hazardous laser radiation may be present, and of relevant safety precautions. 4. Degree of training in laser safety of all individuals involved in the laser operation. 5. Reliability of individuals to follow control procedures. 6. Number and location of individuals relative to the primary beam or reflections, and the potential for accidental exposure. 7. Other hazards not due to laser radiation which may cause the individuals to react unexpectedly, or which influence the choice of personnel protective equipment.

E. THE NOMINAL HAZARD ZONE:

The Nominal Hazard Zone (NHZ) associated with Class IIIB and Class IV lasers shall also be determined. The NHZ describes the space within which the level of direct, reflected, or scattered radiation during normal operation exceeds the appropriate MPE's and is determined from the following characteristics of the laser: 1. Power or energy output 2. Beam diameter 3. Beam divergence 4. Pulse repetition frequency (prf) 5. Wavelength 6. Beam path including reflections 7. Beam profile 8. Maximum anticipated exposure duration

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NOTE: Examples of NHZ calculations are given in the appendix of ANSI Z136.1 (1986). In addition, computer software is also available to assist in the computations for NHZ, protective eyewear optical densities and other aspects of laser hazard analysis. --

It is often necessary in some applications where open beams are required (vis: industrial processing, laser robotics) to define the area where the possibility exists for potentially hazardous exposure. This is done by determining the Nominal Hazard Zone (NHZ) which is, by definition, described by the space within which the level of direct, reflected or scattered radiation exceeds the level of the applicable MPE. Consequently, persons outside the NHZ boundary would be exposed below the MPE level and are considered to be in a "safe" location. The NHZ boundary may be defined by direct (intrabeam) beams, diffusely scattered laser beams as-well-as beams transmitted from fiber optics and/or through lens trains... etc. In other words, the NHZ perimeter is the envelope of MPE exposure levels from any specific laser installation geometry.

The purpose of an NHZ evaluation is to define that region where control measures are required. Thus, as the scope of laser uses has expanded, the classic method of controlling lasers by enclosing them in an interlocked room has become limiting and, in many instances, can be an expensive over-reaction to the real hazards present.

1. INTRABEAM NOMINAL HAZARD ZONE: If the value of the irradiance at a distance (R) away from the laser is maintained at (or below) the MPE, then the distance is considered the intrabeam NHZ range (RI.B. NHZ) or "safe range" value. This may be expressed in terms of the laser parameters as follows (see Figure VI-1): (Figure VI-1, see printed copy)

Eq. 1:

(Equation 1. see printed copy) For example, consider the case of a 300 watt Class IV (open beam) industrial Nd:YAG laser materials processing system with a beam divergence of 2.5 milliradian and an exit beam diameter of 0.4cm. Using EQUATION 1 and assuming the long term (8 hour) "worst case" MPE of 1.6 mW/cm(2), we find that: R(I.B.) NHZ = (Equation, see printed copy) Thus, one would have to be nearly two kilometers away from this laser before the beam would spread to a size large enough that it would reduce the laser beam irradiance to the MPE level of 1.6 x 10(-3) W/cm(2). This distance is certainly larger than an industrial facility, hence controls would be needed to both confine the hazard and protect those in the space. 2. DIFFUSE REFLECTIONS: In practice, most slightly rough non-glossary surfaces act as diffusing surfaces to incident laser beams. A diffusing "rough" surface acts as a plane of very small scattering sites that reflect the beam in a radially symmetric manner. The roughness of the surface is such that the scattering sites are larger than the laser wavelength. Consequently the reflected radiant intensity expressed as power per unit solid angle (W/sr), denoted by I(theta), is dependent upon incident intensity (I(o)) and the cosine of the viewing angle (theta) (both measured from the normal to the surface) by the relationship:

Eq. 2:

(Equation 2. see printed copy) This relationship is known as LAMBERT'S COSINE LAW and a surface behaving in this manner is generally referred to as a Lambertian surface. This relationship DEFINES an ideal plane diffuse reflector. It should be stressed that "rough" surfaces do not always act as diffuse reflectors at ALL WAVELENGTHS. For example, brushed aluminum (which is partially diffuse for visible wavelength laser radiation) is a good specular (mirror-like) reflector for far-infrared wavelength lasers such as the CO(2) laser (10.6 ?m). However, if the metal surface is melting (such as during a laser welding process) the laser beam back reflected from the weld puddle will usually obey a cosine scattering relationship. Additionally, most slightly "rough" surfaces may still have some properties that also contribute some specular reflection component. This may occur with just a few percent of the incident radiation specularly reflected and the remainder diffusely reflected. This behavior is generally the rule, and not the exception, for most common surfaces. As a result, a constant power distribution of the reflected radiation is not exactly radially symmetric, but will skews toward the specularly reflected component. A laser beam reflected from a diffuser is often expressed in radiant energy units which combine the reflected radiant power (or energy) with the geometry of a solid angle "cone" and the reflected "source" area. This is referred to as the radiance (L) of a plane diffuse Lambertian surface and is related to the irradiance incident on the surface by the equation:

Eq. 3:

(Equation 3, see printed copy) This allows us to calculate the radiance of a diffusely reflected laser beam while knowing only the irradiance incident upon the surface and the reflectivity of the surface. For example, let's assume that a 1 mW HeNe "aiming laser" beam is directed a distance of 10 meters across the room onto a 100% diffusely reflecting wall. The irradiance on the wall will be 1.1 mW/cm(2). Assuming the reflectivity of the surface to be 100% (rho = 1.0), we find from Equation 3 that the radiance of the reflected beam L = 0.35 x 10(-)3 W/cm(2)sr. For comparative purposes, consider that staring directly at a standard 100 watt frosted light bulb at close range is equivalent to viewing a diffuse light source with a radiance of about 40 mW/cm(2)sr. Hence the diffuse reflection of a 1 mW HeNe laser directed onto a wall 10 meters away is over 100 times less "bright" than viewing a 100 watt diffused light bulb! Hence diffuse viewing of low power laser light can offer no more hazard (and maybe less) than more conventional light sources. The dividing point between hazardous and non hazardous diffuse reflections with cw lasers is generally considered to be 0.5 watt (the dividing point between cw Class IIIB and Class IV lasers). 3. INVERSE SQUARE LAW: The reflected irradiance (E) or radiant exposure (H) from a Lambertian surface at some distant point is inversely related to the square of the distance (r) from the surface. This describes diffuse reflections from a point source. This is expressed by the following equa tion for CW sources:

Eq. 4a:

(Equation 4a, see printed copy) Where E(r, theta) expresses the irradiance at the distance (r) and angle (theta) in units of W/cm(2). For pulsed lasers the power term PHI, is replaced by pulse energy (Q(p)) and the expression becomes:

Eq. 4b:

(Equation 4b, see printed copy) where H(r, theta) expresses the radiant exposure (J/cm(2)). The inverse square relationship with distance holds as long as the distance (r) is much greater than the spot diameter D(L). Consequently, a diffuse surface acts as a distance-dependent attenuator that permits indirect viewing of some low powered laser beams when the reflecting spot is small. Obviously, if the laser power is sufficient (ie: 0.5 watts), even a diffuse reflection is hazardous to view. This is an important consideration for those working with high powered visible or near infrared Class IV lasers where specific control methods are required for safe use. 4. DIFFUSE REFLECTION NOMINAL HAZARD ZONE: There are some instances where it is useful to calculate the distance away from a "point source" diffuse reflector at which a specific irradiance occurs. Solving the inverse square law for distance, we find that the diffuse reflection nominal hazard zone (R(D.R.NHZ)) can be written (see Figure VI-2): (Figure VI-2, see printed copy)

Eq. 5:

(Equation 5, see printed copy) For example, assume 45 degree (cos theta = cos (450) = 0.707) viewing of a 50 W xenon fluoride excimer UV laser directed onto a surface with a 75% reflectance at the 0.351 ?m wavelength. At what distance does the long term (3x10(4) sec.) MPE irradiance of 33.3 ?W/cm(2) occur? Solving Equation 5 and inserting numerical values, we find that: (Equation, see printed copy) Thus, one needs to be over five meters away for a "safe" exposure to the backscattered UV excimer laser beam in this example. Similarly, it can be shown that the maximum NHZ range for a 100% diffuse reflection from a 300 watt Nd:YAG laser (MPE=1.6x10(-3) W/cm(2)) will be 244 cm or about 8 feet! 5. EXTENDED SOURCE DIFFUSE REFLECTIONS: In cases where the laser creates large sized spots on the diffuse target (relative to the viewing distance), the diffuse surface is said to create an "extended source" relative to the eye. In this case, the retinal image size of the focused laser light will usually exceed 100 ?m and the viewer can resolve the details of the diffuse target source. Such larger area retinal images are of special concern because the threshold for biologic damage for the larger retinal images is at least TEN TIMES LOWER than for point source images. Also significant is the fact that in this case the resulting retinal irradiance produced while viewing an extended source can be shown to be INDEPENDENT of the distance between the source and viewer. Therefore, as one moves away from the source, the focused retinal spot becomes smaller but the retinal irradiance remains constant. In general, the condition applies up to that point where the source can still be resolved by the viewer. Beyond that point, the retinal image size no longer changes with distance and the point source diffuse relationships apply. In practice, the evaluation of the point source/extended source dilemma has been addressed in the ANSI Z-136 standard by requiring an evaluation of the Angle subtense angle (alpha) between the viewer and the extended source target. For Lambertian (diffuse) viewing, this angle is also a measure of the resultant retinal image size (dr = f alpha); where f is the focal length of the eye, approximately 17 mm. Thus alpha may be expressed in terms of the so called viewing angle (theta (v)) and the extended source diameter (D(L)) by the relationship:

Eq. 6:

(Equation 6, see printed copy) The cut-off between point source and extended source occurs at the "minimum" viewing angle, called alpha (MIN), which corresponds to the MAXIMUM viewing distance (R(MAX)) for which extended source MPE values apply. In this case, the MPE's are expressed in radiance units and R(MAX) is given by:

Eq. 7:

(Equation 7, see printed copy) For example, the ANSI Z-136 standard indicates that in the time frame from 10(3) to 3x10(4) seconds, the extended source MPE for visible and near infrared frequencies is given by the following expression for the radiance (L(p)):

Eq. 8:

MPE = 0.64 x C(A) (W/cm(2)/sr) Where C(A) = 5 is the near infrared correction factor in the wavelength range from 1.051 to 1.400 ?m. Assume, for example, a CW 300 watt Nd:YAG laser is directed onto a 100% diffusely reflecting wall through a short focal length lens so-as-to produce a spot diameter on the wall of 10 inches (DL = 25.4 cm). The ANSI Z-136.1 standard indicates that an minimum of 24 milliradians applies. Thus, using equation 7, the extended source criteria will apply for a distance of (Equation, see printed copy) Beyond that distance, point source criteria apply. The applicable MPE can be determined from equation 8 above. Substituting and using the value of C(A) = 5.0, the extended source MPE = (0.64) x (5) = 3.2 W/cm(2)/sr. The radiance of the reflected beam in the example above can be determined using Equation 3. Substituting, (Equation, see printed copy) or approximately 17 times lower than the MPE level. Hence, the reflected beam would be "safe" to view, provided the large spot diameter was maintained. A similar computation can show that the reflected radiance will just reach the MPE value when the spot diameter is reduced to 6.2 cm. In this case, the extended source condition would apply for a distance up to 2.6 meters normal to the reflecting surface. Spot sizes less than 6.2 cm will produce an extended source viewing hazard region (L MPE) which will extend out into 2 pi steradian zone surrounding the reflecting point. This is a very serious viewing condition since the viewing angle can be from anywhere in the area around the reflecting point. In addition, a very large retinal image is produced which can result in a large retinal damage area. 6. LENS ON THE LASER NOMINAL HAZARD ZONE: Most industrial laser uses incorporate a lens as the final component in the beam path. This not only provides the increased irradiance in the focal plane of the lens to do the work intended of the laser, but it also causes the beam to spread with an angle usually many times larger than the inherent laser beam divergence in the space beyond the focal plane. Consequently, the MPE irradiance is reached in a distance much less than the intrabeam NHZ. This can be referred to as the lens on the laser nominal hazard zone range (RL.L.NHZ) as given by:

Eq. 9:

(Equation 9, see printed copy) Where f(0) is the lens focal length and b is the diameter of the beam as it strikes the lens, Figure VI-3. (Figure VI-3, see printed copy) For example, consider a 3000 watt CO(2) laser with a 5 inch focal length lens in place. Assume the beam size at the lens is 1 inch. Thus, substituting into Equation 9, we have: (Equation, see printed copy) Thus, in the direction defined by the cone of laser light directed through the lens, the hazard zone extends up to a distance of 9.8 meters, at which point the beam has expanded to a diameter: (Equation, see printed copy)

7. FIBER-OPTIC ON LASER NOMINAL HAZARD ZONE:

In a manner similar to the lens-on-laser condition, a fiber optic attached in the beam path also provides a beam expanding element that shrinks the hazard range depending upon the characteristics of the fiber. For a typical multimode fiber used for some industrial Nd:YAG applications (Figure VI-4), the fiber optic NHZ range (R(F.O.NHZ)) is given by: (Figure VI-4, see printed copy)

Eq. 10:

(Equation 10, see printed copy) For example, for a multimode fiber optic with a numerical aperture: NA = 0.20 attached to a 300 watt Nd:YAG laser, the nominal hazard zone range can be computed as: (Equation, see printed copy) The fiber optic hazard range is roughly equivalent the hazard range for a 300 watt Nd:YAG laser system with a 3.5 mm beam size and a 15 mm focal length lens in the beam path. This is reasonable since a fiber optic is optically equivalent to a short focus lens in the beam path.

F. INTRABEAM OPTICAL DENSITY DETERMINATION:

Based upon these typical exposure conditions, the optical density required for suitable filtration can be determined. Optical density is a logarithmic function defined by the equation:

Eq. 11:

(Equation 11, see printed copy)

Based upon the worst case exposure conditions outlined above, one can determine the optical density recommended to provide adequate eye protection for this laser. For example, the minimum optical density at the 1.06 ?m Nd:YAG laser wavelength for a 10 second direct intrabeam exposure to the 100 watt maximum laser output can be determined as follows:

Where: PHI = 100 Watts MPE = 5.06 mW/cm(2) (10 second criteria) d = 7 mm (worst case pupil size)

Computing the worst case exposure H(o):

(Two Equations, see printed copy)

Substituting into Equation 11, we have:

(Equation, see printed copy)

An extremely conservative approach would be to choose an 8 hour (occupational) exposure. In this case, the optical density at 1.06 ?m is increased to OD = 5.2 for a 100 watt intrabeam exposure because the 8-hour (30,000 seconds) MPE is reduced to 1.6 x10(-3) W/cm(2).

The OD values for a number of common laser types are given in Table VI-1.

G. SURGICAL FIBER OD HAZARD ANALYSIS:

A hazard analysis of a typical Nd:YAG surgical laser with a fiber optic hand-piece attachment could be based upon the following parameters:

- Laser power: 100 Watts (maximum/CW); - Beam divergence: 210 milliradian (12 degrees from fiber tip); - Exposure time: 10 seconds (maximum); Wavelength: 1.06 ?m

Using these parameters, a mathematical hazard analysis can be done to estimate the general region around the surgical site where hazardous exposures may be possible. Although, the following analysis is based upon one specific unit, it is representative of Nd:YAG surgical lasers. This analysis is based upon the maximum permissible exposure (MPE) criteria of the ANSI Z-136.1 standard.

The "worst case" MPE value for a direct intrabeam Nd:YAG laser exposure of 10 seconds is 50.6 millijoules/cm(2). The MPE for a 10 second diffuse reflection of this laser is 10(8) Joules/cm(2) sr. contained within an apparent visual angle (alpha min) which is not smaller than 24 milliradians. The 10 second MPE value for skin exposure is 10.5 Joules/cm(2).

To estimate a diffuse reflection from the site, one can estimate, using the inverse square law, an approximate scattering distance of 40 cm from the beam (on the tissues) to the eye. Using the ANSI Z-136.1 point source criteria (because the focused beam acts as a point source), the irradiance at the eye will be 19.9 mW/cm(2). This produces a radiant exposure of nearly 200 mJ/cm(2) during a ten second exposure.

The optical density required for safe viewing of the diffuse reflection off tissues is substantially reduced from the 100 watt intrabeam case. Using a 40 cm "viewing distance", and assuming a "point source condition, the required optical density at 1.06 ?m would be OD = 0.6 for a 10 second exposure and OD = 1.1 for an 8 hour (occupational) exposure.

(Table VI-1, Optical Densities for Protective Eyewear for Various Laser Types, see printed copy)

The "worst case" conditions suggest than an optical density ranging from 0.6 to 5.2

depending upon viewing time and conditions.

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VII. CONTROL MEASURES: --

A. CONTROL MEASURES - OVERVIEW:

Control measures shall be devised to reduce the possibility of exposure of the eye and skin to hazardous laser radiation and to other hazards associated with the operation of lasers and laser systems. This applies during normal operation and maintenance by users, as well as by Manufacturers during the manufacture, testing, alignment, servicing, etc. of lasers and laser systems.

There are four basic categories of controls useful in laser environments. These are engineering controls, personal protective equipment, administrative and procedural controls, and special controls. The controls to be reviewed here are based upon the recommendations of the ANSI Z-136.1 standard.

The controls specified by the ANSI Z-136.1 standard have been rather universally adopted by industry, medicine and government as the "user requirements" of lasers. In general, the controls are rather easily implemented by the LSO of the facility. A summary of controls is given in Table VII-1.

For all users of lasers and laser systems, it is recommended that the minimum radiation level be used for the required application. If levels higher than the MPE are required, it is recommended that such higher powered lasers be "embedded" in a Class I laser system configuration whenever feasible.

(Table VII-1. Summary: Laser Protection Control Measures Recommended by ANSI Z-136.1 (1986), see printed copy)

Designs for lasers, laser systems, and the associated work areas shall be predicated upon the classification of the laser or lasers used. Generally, all purchased systems will be classified by the manufacturer in accordance with the Federal Standard. However, it is the responsibility of the LSO to confirm the classification and recommend or approve all control measures prior to laser equipment or facility use.

Important in all controls is the distinction between the functions OF OPERATION, MAINTENANCE AND SERVICE. First, laser systems are classified on the basis of level of the laser radiation accessible during operation. Maintenance is defined as those tasks specified in the user instructions for assuring the performance of the product and may include such tasks as routine cleaning or replenishment of expendables. Service functions are usually performed with far less frequency than maintenance functions (vis: replacing the laser resonator mirrors, repair of faulty components) and often will require access to the laser beam by those performing the service functions. Service functions should be clearly delineated as such in the product's manuals.

B. LASER SAFETY OFFICER:

The LSO has the authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards. The LSO administers the overall laser safety program where the duties include, but are not limited to items such as confirming the classification of lasers, effecting (or doing) the NHZ evaluation, assuring that the proper control measures are in place and approving substitute controls, approving SOP's, recommend and/or approve eyewear and other protective equipment, special appropriate signs and labels, approve overall facility controls, effect proper laser safety training as needed, effect medical surveillance and designate the laser/incidental personnel categories.

The LSO should receive detailed training including an understanding of lasers, laser bioeffects, exposure limits, classifications, NHZ computations, control measures (including area controls, eyewear, barriers ...etc.) and medical surveillance.

In many industrial situations, the LSO will be a parttime activity, depending on number of lasers and general laser activity. The individual is often in the corporate industrial hygiene department or may be a laser engineer with safety responsibility. Some corporations implement an internal laser policy and effect safety practices based upon the ANSI Z-136.1 standard as-well-as their own corporate safety requirements.

C. BEAM PATH CONTROLS:

There are some uses of Class IIIB and IV Class IV lasers where the entire beam path may be totally enclosed, other uses where the beam path is confined by design to significantly limit access and yet other uses where the beam path is totally open.

In each case, the controls required will vary as follows:

1. ENCLOSED (TOTAL) BEAM PATH: Perhaps the most common form of a Class I laser system is a high power laser that has been totally enclosed (embedded) inside a protective enclosure equipped with appropriate interlocks and/or labels on all removable panels or access doors. Beam access is prevented, therefore, during operation and maintenance. Such a completely enclosed system, if properly labeled and properly safeguarded with a protective housing interlocks (and all other applicable engineering controls), will fulfill all requirements for a Class I laser and may be operated in the enclosed manner WITH NO ADDITIONAL CONTROLS for the operator. It should be noted that during periods of service or maintenance, controls appropriate to the class of the embedded laser may be required (perhaps on a temporary basis) when the beam enclosures are removed and beam access is possible. Beam access during maintenance or service procedures will not alter the Class I status of the laser during operation. 2. LIMITED OPEN BEAM PATH: It is becoming quite commonplace, particularly with some industrial materials processing lasers, to have an enclosure that surrounds the area around the laser focusing optics and encloses the immediate area of the workstation almost completely. Often, a computer controlled positioning table is located within this enclosure; there is often a gap of less than one-quarter of an inch between the bottom of the enclosure and the top of the material to be laser processed. Such a design provides the needed mobility relative to the stationary laser. Such a system would not meet, perhaps, the stringent "human access" requirements of the FLPPS for a Class I laser, but the real laser hazards are well confined. Such a design provides what can be called a limited open beam path. In this situation, the ANSI Z-136.1 standard recommends that the LSO shall effect a laser hazard analysis and establish the extent of the NHZ. In many system designs, (such as described above), the NHZ will be extremely limited and procedural controls (rather than elaborate engineering controls) will be sufficient. Such an installation will require a detailed standard operating procedure (SOP). Training is also needed for the system operator commensurate with the class of the embedded laser. Protective equipment (eye protection, temporary barriers, clothing and/or gloves, respirators ..etc) would be recommended, for example, only if the hazard analysis indicated a need or if the SOP required periods of beam access such as during setup or infrequent maintenance activities. Temporary protective measures for service is handled in a manner similar to service of any embedded Class IV laser. 3. TOTALLY UNENCLOSED BEAM PATH: There are several specific applications areas where high power (Class IIIB and Class IV) lasers are used in an unenclosed beam condition. This would include for example, open industrial processing systems (often incorporating robotic delivery), laser research laboratory installations, surgical installations...etc. Such laser uses will require that a complete hazard analysis and NHZ assessment be effected by the LSO. Then, the controls implemented will reflect the magnitude and extent of hazards associated with the accessible beam. For example, some 100 watt Nd:YAG laser processing systems may require beam access controls during use. As summarized in Table VII-2, the intrabeam (direct) hazard extends from 792 to 1410 meters, depending upon whether a 10 second or 8 hour MPE criteria is used in the NHZ calculation. Similarly, with a lens on the laser, the hazard exists over a range from 6.3 to 11.3 meters. The diffuse reflection zone is, however, markedly smaller; it ranges from 0.8 to 1.4 meters. None-the-less, this analysis suggests that operating personnel

and support staff close to the laser would still need laser eye protection, even for diffuse reflections. If, however, the LSO provides a detailed procedural control to limit the "beam on" condition only to situations where the lens was in place and the beam was only focussed onto the workpiece, then the extent of potential hazard would be limited to diffuse reflections and, in a "worst case" scenario, to the specular reflections of the focussed beam. This implies a maximum hazard region that extends no greater than about 30 feet. This certainly would project outside a typical laser processing area; hence the LSO would be proper in requiring either a barrier be placed just inside the entrance way so as to prevent an unlikely stray beam from going out a doorway, or requiring a means of entryway interlocking. Similar analysis are also given in Table VII-2 for a 500 Watt CO(2) and a 5 Watt argon laser. Note that the NHZ's do not vary for the CO(2) laser (because the MPE values are nearly identical for 10 second and 8 hour criteria). Also note that the diffuse reflection NHZ's are very small except for the 8 hour criteria for the argon laser. In most cases, 0.25 seconds be used with visible lasers unless intentional staring is possible.

(Table VII-2. NHZ distance values for various Lasers, see printed copy)

D. LASER CONTROLLED AREA:

When the entire beam path from a Class IIIB or Class IV laser is not sufficiently enclosed and/or baffled such that access to radiation above the MPE is possible, a "laser controlled area" is required. During periods of service, a controlled area may be established on a temporary basis. The controlled area will encompass the NHZ.

Those controls required for both Class IIIB and Class IV installations are as follows:

1. POSTING WITH APPROPRIATE LASER WARNING SIGNS: CLASS IIIA (BEAM IRRADIANCE 2.5 mW/cm(2)), CLASS IIIB AND CLASS IV LASERS: Require the DANGER sign format: white background, red laser symbol with black outline and black lettering, Figure VII-1. Note that under ANSI Z-136.1 criteria, area posting is required only for Class IIIB and Class IV lasers. CLASS II OR CLASS IIIA AREAS (IF THE LSO CHOOSES TO POST): All signs (and labels) associated with these lasers (when beam irradiance for Class IIIA does not exceed 2.5 mW/cm(2)) uses the CAUTION format: yellow background, black symbol and letters, Figure VII-2. During times of service and other times when a temporary laser controlled area is established, a NOTICE sign format is required: white background, red laser symbol with blue field and black lettering, Figure VII-3. This sign is only posted during time when service is in progress. 2. OPERATED BY QUALIFIED AND AUTHORIZED PERSONNEL: This includes appropriate training of the individuals in aspects of laser safety. (See Section IX: Training.) 3. TRANSMISSION FROM INDOOR CONTROLLED AREA: The beams shall not, under any circumstances, be transmitted from an indoor laser controlled area unless for specific purposes (such as testing). In such cases, the operator and the LSO must assure that the beam path is limited to controlled air space.

E. CLASS IV LASER CONTROLS - GENERAL REQUIREMENTS:

Those items recommended for Class IIIB but required for Class IV lasers are as follows:

1. Supervised directly by of an individual knowledgeable in laser safety. 2. Require approved entry of any non-involved personnel. 3. Terminate all potentially hazardous beams in a beam stop of an appropriate material. 4. Use diffusely reflecting materials near the beam, where appropriate. 5. Personnel within the laser controlled area are provided with appropriate laser protective eyewear. 6. Secure and locate the laser such that the beam path is above or below eye level in any standing or seated position. 7. Have all windows, doorways, open portals...etc. from an indoor facility covered or restricted so-as-to reduce transmitted beams below appropriate ocular MPE level. 8. Require storage or disabling of lasers when not in use.

F. ENTRYWAY CONTROL MEASURES (CLASS IV):

In addition, there are specific controls required at the entryway to a Class IV laser controlled area. These can be summarized as follows:

1. All personnel entering a Class IV area shall be adequately trained and provided proper laser protective eyewear. 2. All personnel shall follow all applicable administrative and procedural controls. 3. All Class IV area/entryway controls shall allow both rapid entrance and exit under all conditions. 4. The controlled area shall have a clearly marked "Panic Button" (disconnect switch) that allows rapid deactivation of the laser. In addition, Class IV areas also require some form of area-entryway controls. In the past, doorway interlocking was customary for Class IV installations. Now, the ANSI Z-136.1 (1986) standard provides three options that allow the LSO to provide an entryway control suited for the installation. The options include: a. NON-DEFEATABLE ENTRYWAY CONTROLS: A non-defeatable control, such as a magnetic switch built into the entryway door which actuates a "beam off" condition when the door is opened is one option. In this case, training is required only for persons regularly working in the laser area. b. DEFEATABLE ENTRYWAY CONTROLS: Defeatable controls may be used at an entryway, for example, during long term testing in a laser area. In this case the controls may be temporarily by- passed if it is clearly evident that there is no hazard at the point of entry. Training is required for all personnel who frequently require area entry. c. PROCEDURAL ENTRYWAY CONTROLS: A blocking barrier, or screen, or curtain which can block or filter the laser beam at the entryway may be used inside the controlled area to prevent the laser light from exiting the area at levels above the applicable MPE level. In this case, a warning light or sound is required outside the entryway that operates when the laser is energized and operating. All personnel who work in the facility shall be appropriately trained. (See Section IX: Training)

(Table VII-3. Administrative and Procedural Control Measures for the Four Laser Classes: ANSI Z-136.1(1986), see printed copy)

G. ADMINISTRATIVE AND PROCEDURAL CONTROLS:

Administrative and Procedural Control Measures are summarized in Table VII-3 and detailed below:

1. STANDARD OPERATING PROCEDURES: One of the more important of the so-called administrative and procedural controls is the written Standard Operating Procedure (SOP). The ANSI Z-136.1 standard requires an SOP for a Class IV laser and recommends SOP's for Class IIIB lasers. The key to an effective SOP is the involvement of those individuals that

operate, maintain and service the equipment in the preparation along with guidance from the LSO. Most laser equipment is provided with instructions for safe operation by the manufacturer, however sometimes these are not well suited to a specific application due to special use conditions. 2. ALIGNMENT PROCEDURES: One of the highest rate of laser eye accidents occurs during alignment tasks. Such procedures must be done with extreme caution. A written SOP is recommended for all recurring alignment tasks. 3. LIMITATIONS ON SPECTATORS: Persons unnecessary to the laser operation should be kept away. For those who do enter the laser area, appropriate eye protection and instruction is recommended. 4. PROTECTIVE EQUIPMENT: Protective equipment for laser safety generally means eye protection in the form of goggles or spectacles, clothing and barriers and other devices designed for laser protection. a. LASER PROTECTIVE EYEWEAR: This includes special prescription eyewear using high optical density filter materials or reflective coatings (or a combination of both) to reduce the potential ocular exposure below MPE limits. Some applications, such as use of high power excimer lasers operating in the ultraviolet, may also dictate the use of a skin cover if chronic (repeated) exposures are anticipated at exposure levels at or near the MPE limits for skin. In general, it is recommended that other controls be employed rather than reliance specifically on the use of protective eyewear. This argument is predicated on the fact that so many accidents have occurred when eyewear was available but not worn. There are many reasons cited for this, but the most common is that laser protective eyewear is often dark, uncomfortable to wear and limits vision.

(Table VII-4. Engineering Control Measures for the Four Laser Classes: ANSI Z-136/1 (1986), see printed copy)

See Section VIII for details of laser protective eyewear. b. LASER BARRIERS AND PROTECTIVE CURTAINS: Area control can be effected in some cases using special barriers which have been specifically designed to withstand either direct and/or diffusely scattered beams. In this case, the barrier will exhibit a Barrier Threshold Limit (BTL) for beam penetration through the barrier during some specified exposure time (typically 60 seconds). The barrier is located at a distance from the laser source so that the BTL is not exceeded in the "worst case" exposure scenario. Currently available laser barriers exhibit BTL's ranging from 10 W/cm(2) to 350 W/cm(2) for different laser wavelengths and power levels. An analysis is usually required (done in a manner similar to the NHZ evaluations described previously) that establishes the recommended barrier type and installation distances for a given laser. Important in the design is the factor of flammability of the barrier. It is essential that the barrier not support combustion and be consumed by flames following an exposure.

H. ENGINEERING CONTROLS:

The most universal controls are so-called engineering controls (see Table VII- 4). Usually, these are items built into the laser equipment that provide for safety. In most instances, these will be included on the equipment provided by the laser manufacturer as so-called "performance requirements" mandated by the FLPPS. Specifics on some of the more important engineering controls recommended in the

ANSI Z-136.1 standard are detailed as follows:

1. PROTECTIVE HOUSING: A Laser shall have an enclosure around the laser which limits access laser radiation at or below the applicable MPE level. A protective housing is required for all classes of lasers, except of course, at the beam aperture. In some cases, the walls of a properly enclosed room area can be considered as the protective housing for an open beam laser. Such a "walk in" enclosure can also be a CDRH Class I provided that controls preclude operation with personnel within the room (vis: pressure sensitive floor mat switches, IR sensors, door interlocks..etc.). 2. MASTER SWITCH CONTROL: All Class IV lasers and laser systems require a master switch control. The switch can be operated by a key or computer code. When disabled (key or code removed), the laser is not capable of operation. Only authorized system operators are to be permitted access to the key or code. Inclusion of the master switch control on Class IIIB lasers and laser systems is also recommended but not required. 3. OPTICAL VIEWING SYSTEM SAFETY: Interlocks, filters or attenuators are to be incorporated in conjunction with beam shutters when optical viewing systems such as telescopes, microscopes, viewing ports or screens are used to view the beam or beam reflection area. For example, an electrical interlock could prevent laser system operation when a beam shutter is removed from the optical system viewing path. Such optical filter interlocks are required for all but Class I lasers. 4. BEAM STOP OR ATTENUATOR: Class IV lasers require a permanently attached beam stop or attenuator which can reduce the output emission to a level at or below the appropriate MPE level when the laser system is on "standby." Such an beam stop or attenuator is also recommended for Class IIIA and Class IIIB lasers. 5. LASER ACTIVATION WARNING SYSTEM: An audible tone or bell and/or visual warning (such as a flashing light) is recommended as an area control for Class IIIB laser operation. Such a warning system is mandatory for Class IV lasers. Such warning devices are to be activated upon system start up and are to be uniquely identified with the laser operation. Verbal "countdown" commands are an acceptable audible warning and should be a part of the standard operating procedures (SOP). 6. SERVICE ACCESS PANELS: The ANSI Z-136.1 standard requires that any portion of the protective housing that is intended to be removed only by service personnel and permit direct access to an embedded Class IIIB or Class IV laser will have either an interlock or require that a tool is used in the removal process. If an interlock is used and is defeatable, a warning label indicating this fact is required on the housing near the interlock. The design shall not allow replacement of a removed panel with the interlock in the defeated condition. 7. PROTECTIVE HOUSING INTERLOCK REQUIREMENTS: Interlocks which cause beam termination or reduction of the beam to MPE levels must be provided on all panels intended to be opened during operation and maintenance of all Class IIIA, Class IIIB and Class IV lasers. The interlocks are typically electrically connected to a beam shutter and, upon removal or displacement of the panel, closes the shutter and eliminates the possibility of hazardous exposures. For embedded Class IIIB and Class IV lasers only, the interlocks are to be "failsafe". This usually means dual redundant electrical series connected interlocks are associated with each removable panel. Adjustments or procedures during service on the laser shall not cause the safety interlocks to become inoperative or the laser radiation outside a Class I laser protective housing to exceed the MPE limits, unless a temporary laser controlled area is established. 8. REMOTE INTERLOCK CONNECTOR: All Class IV lasers or laser systems are to be provided with a remote interlock connector to allow electrical connections to an emergency master disconnect ("Button panic button") interlock

or to room, door or fixture interlocks. When open circuited, the interlock shall cause the accessible laser radiation to be maintained below the appropriate MPE level. The remote interlock connector is also recommended for Class IIIB lasers.

I. SAFETY PROCEDURES - GENERAL BASIC PRECAUTIONS:

The LSO shall be notified of the purchase of any laser, regardless of the class. Such notification should include the classification, media, output power or pulse energy, wavelength, repetition rate (if applicable), special attachments (frequency doublers...etc.), beam size at the laser aperture, beam divergence and users.

No attempt shall be made to place any shiny or glossy object into the laser beam other than that for which the equipment is specifically designed.

Eye protection devices which are designed for protection against radiation from a specific laser system shall be used when engineering controls are inadequate to eliminate the possibility of potentially hazardous eye exposure (i.e., whenever levels of accessible emission exceed the appropriate MPE levels.) This generally applies only to Class IIIB and Class IV lasers. All laser protective eyewear shall be clearly labeled with optical density values and wavelengths for which protection is afforded.

Skin protection can best be achieved through engineering controls. If the potential exists for damaging skin exposure, particularly for ultraviolet lasers (200-400 nm), then skin covers and or "sun screen" creams are recommended.

. HANDS - Most gloves will provide some protection against laser radiation. Tightly woven fabrics and opaque gloves provide the best protection. . ARMS - A laboratory jacket or coat can provide protection for the arms. For Class IV lasers, consideration should be given to flame resistant materials. 1. CLASS I, CLASS II AND CLASS IIIA LASERS: Accident data on laser usage has shown that Class I, Class II Class IIA and Class IIIA lasers are normally not considered hazardous from a radiation standpoint unless illogically used.

DIRECT EXPOSURE on the eye by a beam of laser light should always be avoided with any laser, no matter how low the power. -- ----------------

2. CLASS IIIB LASERS: Laser beams shall be contained whenever possible. When uncontained beams are used, the following precautions shall be taken: . A Class IIIB warning sign shall be placed at all entrances to the area when the laser beam is operating and access must require authorization of persons responsible for the area. . The laser beam shall be terminated at the limit of its useful distance. A dull black (highly absorbing/low reflectance) surface is recommended for visible frequency lasers and beam traps or terminators with total absorbers appropriate to the wavelength for UV and IR lasers. . Specularly reflecting

surfaces in or near the beam path shall be minimized. . The area shall be well lighted to constrict pupils. . A standard operating procedure is suggested for all Class IIIB lasers including emergency procedures. . The laser shall be positioned and the beam contained such that the beam does not exit the immediate area of use. 3. CLASS IV LASERS: The same requirements as for Class IIIB lasers shall be followed. In addition, the following safeguards are required: . A total hazards review shall be conducted before a high power laser is used. This shall include evaluation of Nominal Hazard Zones (NHZ), measurements (if deemed necessary and other such analytical techniques. . Devices shall be located in an area designated specifically for laser operations (laser controlled area). Access during operation must require authorization of the person responsible for the area. In conditions where the beam path is not completely enclosed, access shall be limited. . An entryway control shall be used. This may include: - A non defeatable entryway interlock at the doorway, or - A defeatable entryway interlock at the doorway; or - Procedural entryway controls including a warning light immediately outside the room. One form of such a warning light could indicate conditions of enabled laser (high voltage on), laser on (beam on) and area clear (no high voltage or beam on). Such measures shall permit rapid egress by the laser personnel at all times and admittance to the area under emergency conditions. . A control-disconnect switch or equivalent device shall be available near the exit for deactivating the laser. . A notice outside the area shall indicate the meaning of the blinking light. . Care must be taken to insure that the hands, arms, or other parts of the body do not intersect the beam. . The system must have provision(s) for quickly disengaging the laser power source from the electrical main during emergency. . The beam shall be terminated by a highly absorbent beam trap of fire resistant material. . For infrared lasers, since the radiation is invisible, areas which are exposed to reflections of the beam shall be protected by fully enclosing the beam and target area. . Ultraviolet laser beam radiation shall require a beam shield which attenuates the radiation to acceptable levels. . A countdown procedure shall be used to signify the firing of single pulse laser types (eg.: Q-switch) to ensure all present are aware of the time of the operation. . The use of laser protective eyewear is mandatory with Class IV lasers. Protective eyewear shall be fabricated of plastic or glass absorption filters appropriate for the laser. All laser protective eyewear shall be clearly labeled with optical density values and wavelengths for which protection is afforded.

J. ENGINEERING CONTROL MEASURES:

Engineering control measures (items incorporated into the laser or laser system by the Manufacturer or designed into the installation by the user) shall be given primary consideration in instituting a control measure program for limiting access to laser radiation. These are summarized in Table VII-4.

If engineering controls are impractical or inadequate, administrative and procedural controls and personnel protective equipment approved by the LSO shall be used. If, during periods of service to a laser or laser system, the level of accessible emission exceeds the applicable MPE, temporary control measures may be instituted, as deemed appropriate by the LSO.

1. LASER USE WITHOUT PROTECTIVE HOUSING (ALL CLASSES): In some circumstances, such as during the manufacture of lasers, and during research and development, operation of an unenclosed laser or laser system may become necessary. In such cases, the LSO shall determine the hazard and ensure that controls are instituted appropriate to the class of maximum accessible emission to ensure safe operation. Such controls may include but are not limited to: . Access restriction. . Eye protection. . Area controls. . Barriers, shrouds, beam stops, etc. . Administrative and procedural controls. . Education and training. 2. LASER CONTROLLED AREAS: The following control measures apply to Laser Controlled Areas containing Class IIIB and Class IV lasers and laser systems. (Laser laboratories containing Class IIIB and Class IV lasers or laser systems are considered laser controlled areas.) . Laser devices shall be isolated in an area designed solely for laser operations. Access to such an area shall require appropriate authorization. . Special emphasis shall be placed on control of the path of the laser beam. . All persons using such lasers or laser systems shall be duly informed about the potential hazards of laser operations. . Only authorized personnel shall operate laser systems. . Visitors shall not be permitted into the laser-controlled area unless appropriate supervisory approval has been obtained and protective measures taken. . Alignment of laser optical systems (mirrors, lenses, beam deflectors, etc.) shall be performed in such a manner that the primary beam or specular reflections cannot expose the eye to a level above the appropriate intrabeam MPE. . Whenever possible, the entire beam path, including the interaction area, that is, the area in which irradiation of materials by the primary or secondary beam occurs, should be enclosed. Enclosures should be equipped with interlocks so that the laser system will not operate unless such enclosures are properly installed. . For pulsed systems, interlocks shall be designed so as to prevent firing of the laser by dumping the stored energy into a dummy load. For cw lasers, the interlocks shall turn off the power supply or interrupt the beam by means of shutters. Interlocks shall not allow automatic reenergizing of the power supply but shall be designed so that after tripping the interlock, the power supply or shutter must be reset manually. . Eye protection devices which are designed for protection against radiation from a specific laser system shall be used when engineering and procedural controls are inadequate to eliminate potentially hazardous exposures. . Whenever possible, the laser system should be fired and monitored only from remote positions. . An alarm system (e.g., an audible sound or a warning light which is visible through protective eyewear) or a verbal "countdown" command should be used prior to activation. . The audible system may consist of a bell or chime which commences when a pulsed laser power supply is charged for operation, for example, during the charging of capacitor banks. Systems should be used in which a warning will sound intermittently during the charging procedure (pulsed systems) and continuously when fully charged. . In order to safely operate a Class IV laser or laser system, a laser warning system shall be installed. - A laser activation warning light assembly shall be installed outside the entrance to each laser room facility containing a Class IV laser or laser system. - In lieu of a blinking entryway warning, the entryway light assembly may alternatively be interfaced to the laser in such a manner that a light will indicate when the laser is not operational (high voltage off) and by an additional light when the laser is powered up (high voltage applied) but not operating and by an additional (flashing) light when the laser is operating. - A laser warning sign shall be posted both inside and outside the laser controlled area. . Under conditions where the entire beam path is not enclosed, safety latches or interlocks shall be used to prevent unexpected entry into laser controlled areas.

Such measures shall be designed to allow both rapid egress by the laser personnel at all times, and admittance to the laser controlled area in an emergency condition. For such emergency conditions, a "panic button" (control-disconnect switch or equivalent device) shall be available for deactivating the laser. . Under conditions where the entire beam path is not completely enclosed, access to the laser controlled area shall be limited only to persons wearing proper laser protective eyewear when the laser is capable of emission. In this case all other optical paths (for example, windows) from the facility shall be covered or restricted in such a way as to reduce the transmitted intensity of the laser radiation to levels at or below the MPE for direct irradiation of the eye. Specularly reflecting surfaces which are not required when using the laser shall be removed from the beam path. 3. TEMPORARY LASER CONTROLLED AREA: Should overriding interlocks become necessary for special training, or during service, or maintenance, and access to Class IIIB or Class IV lasers is possible, a temporary laser controlled area shall be devised, following specific procedures approved by the LSO. These procedures shall outline all safety requirements necessary during such operation. Such temporary laser controlled areas, which by nature will not have the built in protective features, as defined above for a laser controlled area, shall nevertheless provide all of the safety requirements for all personnel, both within and without the temporary laser controlled area during periods of operation with the interlocks defeated.

K. OPTICAL FIBER (LIGHTWAVE) COMMUNICATION SYSTEMS (OFCS):

Under normal operation such systems are completely enclosed (Class I) with the optical fiber and optical connectors forming the enclosure. Under installation or service conditions, or when an accidental break in the cable occurs, the system can no longer be considered enclosed. If engineering controls limit the accessible emission to levels below the applicable MPE (irradiance), no controls are necessary. If the accessible emission is above the MPE, the following requirements shall apply:

. Only authorized trained personnel shall be permitted to perform service on lightwave transmission systems if access to laser emission is required. . Only authorized trained personnel shall be permitted to use the laser test equipment (Optical Loss Test Set, Optical Time Domain Reflectometer, etc.) during installation and/or service. . All unauthorized personnel shall be excluded from the immediate area of access to laser radiation during service and installation when there is a possibility that the system may become energized. The immediate area shall be considered a temporary laser controlled area. . Staring into the end of any broken, severed or unterminated optical fiber or cable shall be avoided. . The end of any broken, severed or unterminated optical fiber shall not be viewed with unfiltered optical instruments (microscopes, telescopes, etc.) An exception to this is the use of indirect image converters such as an infrared image converter or closed circuit television system for verification that a fiber is not energized. . During a splicing operation (either installation or service) if it is required that the ends of the fiber be examined with an eye-loupe for a satisfactory cut, only an eye-loupe containing an appropriate filter shall be used. If a fusion splicer is used, rigid adherence to the appropriate operating safety procedures shall be done. (Figure VII-1. DANGER Sign, see printed copy) (Figure VII-2. CAUTION Sign, see printed copy) (Figure VII-3. NOTICE Sign, see printed copy)

VIII. PERSONAL PROTECTIVE EQUIPMENT: ---

A. PROTECTIVE EQUIPMENT - OVERVIEW:

Protective equipment for laser safety generally means eye protection in the form of goggles or spectacles, this includes special prescription eyewear using high optical density filter materials or reflective coatings (or a combination of both) to reduce the potential ocular exposure below MPE limits. Some applications, such as use of high power excimer lasers operating in the ultraviolet, may also dictate the use of a skin cover if chronic (repeated) exposures are anticipated at exposure levels at or near the MPE limits for skin.

In general, it is recommended that other controls be employed rather than reliance specifically on the use of protective eyewear. This argument is predicated on the fact that so many accidents have occurred when eyewear was available but not worn. There are many reasons cited for this, but the most common is that laser protective eyewear is often dark, uncomfortable to wear and limits vision.

1. PROTECTIVE CLOTHING: Where personnel may be exposed to levels of radiation that clearly exceed the MPE for the skin, particularly in the ultraviolet, the LSO shall recommend or approve the use of protective clothing. Where personnel may be subject to chronic skin exposure from scattered ultraviolet radiation, as may occur during excimer laser processing, skin protection should be provided even at levels below the MPE for the skin. Consideration should also be given to the use of fire resistant material when using Class IV lasers. 2. LASER BARRIERS AND PROTECTIVE CURTAINS: Area control can be effected in some cases using special barriers which have been specifically designed to withstand either direct and/or diffusely scattered beams. In this case, the barrier will exhibit a Barrier Threshold Limit (BTL) for beam penetration through the barrier during some specified exposure time (typically 60 seconds). The barrier is located at a distance from the laser source so that the BTL is not exceeded in the "worst case" exposure scenario. Currently available laser barriers exhibit BTL's ranging from 10 W/cm(2) to 350 W/cm(2) for different laser wavelengths and power levels. An analysis is usually required (done similarly to the NHZ evaluations) that establishes there commended barrier type and installation distances for a given laser. Important in the design is the factor of flammability of the barrier. It is essential that the barrier not support combustion and be consumed by flames following an exposure. 3. PROTECTIVE VIEWING WINDOWS: All viewing portals, optics, windows or display screens included as a part of the laser or laser installation shall incorporate some means to attenuate the laser radiation transmitted through the windows to levels below the appropriate MPE levels. This would include, for example, a "viewing window" into the laser facility. The filtration requirements would be based upon the level of laser radiation that would occur at the window in a typical "worst case" condition in a manner identical to the eyewear evaluation. 4. OTHER PERSONNEL PROTECTIVE EQUIPMENT: Respirators

and hearing protection may be required whenever engineering controls cannot provide protection from harmful ancillary environment.

B. LASER PROTECTIVE EYEWEAR:

A wide variety of commercially available optical absorbing filter materials (glass and plastics) and various coated reflecting "filters" (dielectric and holographic) are available for laser eye protection. Some are available with spectacle lenses ground to prescription specifications. Protection for multiple laser wavelengths is becoming more common in the research environment as more applications involve several laser types. In this case, dual filters are often the design of choice; frequently mounted in a "flip-up" style goggle or spectacle frame.

The spectral absorption of the filter at the laser wavelength determines the percentage of the beam absorbed by the protective filter. If properly designed, the filter will reduce the "worst case" exposure of the beam to the MPE level. In general, the stronger the filter's absorption ability, the higher the laser power for which the filter provides protection. This is specified by the filter "optical density" (OD) as is detailed below.

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.

Historically, the most common eye protection has been the use of special colored glass absorbing filters. These are generally the most effective in resisting damage from general use as-well-as from exposure to intense laser sources.

Unfortunately, not all absorbing glass filters used for laser protection can be easily annealed (thermally hardened) and, consequently, do not provide adequate impact resistance. In some goggle designs, however, impact resistant plastic filters (polycarbonate) can be used together with non-hardened glass filters in a goggle design where the plastic is placed in front and behind of the non-hardened laser filter glass.

In some tests, glass filter plates have cracked and shattered following intense Q-switched pulsed laser exposures. In some instances, the shattering occurred after one-quarter to one-half hour had elapsed following the exposure. Also, at least one glass filter type has been shown to photobleach when exposed to the short pulses of a Q-switched laser.

The advantage of using reflective coatings is that they can be designed to selectively reflect a given wavelength while transmitting as much of the remaining visible spectrum as possible. However, some angular dependence the of spectral attenuation factor may be present.

The advantages of using absorbing plastic filters materials are greater impact resistance, lighter weight, and convenience of molding the eyeprotection into comfortable shapes. The disadvantages are that they are more readily scratched and the filters often "age" poorly in that the organic dyes used as absorbers are more readily affected by heat and/or ultraviolet radiation which cause the filter to significantly darken. In addition, as will be discussed, the plastic materials generally display a lower threshold for laser beam penetration.

It should be stressed that there are few known materials that can withstand laser exposures which exceed 10(5) W/cm(2) since the electric fields associated with the beam will exceed the bonding forces of matter. Most materials will begin to degrade at levels far below these field strength levels due to thermal or shock effects.

Typical CO(2) laser eyewear products are often made from polycarbonate plastics. These materials are light in weight, relatively inexpensive, and have a high optical density at the 10.6 ?m CO(2) wavelength.

It should be noted that such plastic protective eyewear has a penetration threshold level (PTL) of about 5 W/cm(2). It has been shown that for an "arms length" distance of 50 centimeters, the maximum allowed laser beam power limit for a raw beam exposure condition on such plastic eyeprotectors should be less than 20 watts. If beam expansion is present (such as occurs beyond the focus of a simple lens), the power limit is increased to about 200 watts; well above the levels generally experienced without optical enhancement. The upper power limitation for use with plastic eyewear when exposed by a diffuse reflection at 50 cm is well above the power available in commercially available CO(2) lasers.

Therefore plastic eyewear should be acceptable for most laser use situations. It should be strongly noted, however, that the use of plastic eyewear becomes questionable when exposure conditions are closer than "arms length" from the laser and/or under conditions of a direct "raw beam" exposure above a 20 watt level. Such exposures are not likely in most laser facilities; especially for support staff standing at a some distance from the laser. A 20 watt "raw beam" exposure would be far more likely to occur during servicing to the laser equipment or to the operator of a open (Class IV) laser while working at close distances where the irradiance could easily exceed the 5 W/cm(2) limit.

While direct raw beam exposure onto eyewear is certainly not recommended under any normal condition, it does occur. At least one intrabeam eye accident with thermal puncture of plastic laser eyewear has been reported with a Nd:Yag laser in a research laboratory.

Those using CO(2) laser devices should be reminded that materials which do not appear specular (mirror-like) to the eye may be specular at the 10.6 ?m far infrared wavelength, e.g., brushed metal surfaces and enamel-metal surfaces. The beam should not be directed near any such surface, particularly if flat. Where possible, optical elements which have convex surfaces to diverge the beam should be used in or near the beam path.

C. SELECTING LASER EYEWEAR:

For all personnel using Class IIIB and Class IV lasers, whether in the production facility, research lab, out-patient clinic or surgical environment must be informed to make the correct and optimum choice of laser protective eyewear.

This means, in general, the need for a more complete understanding of such topics as:

. The specific wavelength(s) of the laser emission. . Exposure time of anticipated or "worst case" exposure. . The output parameters of the laser(s) in use. This includes the average laser power or pulse energy, pulse lengths and pulse repetition characteristics (if applicable). . Worst case ocular exposure levels: either irradiance (W/cm(2)) or radiant exposure (J/cm(2)) of the laser beam. . The "safe" exposure criteria or Maximum Permissible Exposure (MPE) for each laser. . In some cases, aspects of the viewing condition (e.g. point source or extended source). . Reflection factors from targets at the laser wavelength. . Optical density (OD) of eyewear at laser output wavelength based above factors. . Visible light transmission requirements. . Radiant exposure or irradiance at which laser safety eyewear damage occurs. . Need for prescription glasses. . Comfort and fit. . Degradation of absorbing media. .

Strength of materials (resistance to shock). . Need for peripheral vision. . Specifications of the protective devices commercially available.

It should be stressed that laser hazards can also include hazards associated with electrical power supplies, flammable or toxic chemicals and materials, fuel hazards, respiratory hazards from laser induced fumes and vapors, and noise hazards. These factors should also be considered in selection of protective equipment; especially eyewear. These conditions may result in hazards from laser related operation (flash tubes, chemicals, fumes, etc.). Consult ANSI Z-87.1: The American National Standard Practice for Occupational and Educational Eye and Face Protection, as-well-as ANSI Z136.1.

It should be noted also that a separate edition of the ANSI standard that pertains only to medical lasers is also available. This edition is ANSI Z136.3 (1988), and is entitled: "Safe Use of Lasers in Health Care Facilities". This standard addresses the MPE requirements, NHZ specifications, training needs and equipment features, eye and skin protection needs, beam measurement requirements, fume and toxic gas control, equipment and facility audits as-well-as all other appropriate area controls and procedural needs for medical laser usage.

D. SELECTION CRITERIA:

The basic requirements for protective eyewear as proposed in the ANSI Z-136.1 standard can be summarized as follows:

. Protective eyewear shall be worn whenever operational conditions may result in potential eye hazard. . The attenuation (optical density) of the laser protective eyewear at each laser wavelength shall be specified by the LSO. . All laser protective eyewear shall be clearly labeled with the optical density value and wavelength for which protection is afforded. . Protective eyewear should be comfortable, have adequate visibility (luminous transmission) and prevent hazardous peripheral radiation. . Periodic inspection shall be made of protective eye wear to insure the maintenance of satisfactory filtration ability. This shall include inspection of the filter material for pitting, crazing,cracking, etc. and inspection of the goggle frame for mechanical integrity and light leaks.

The laser parameters of wavelength and exposure time are the most important in determining the maximum permissible exposure (MPE) levels for a specific laser. The ANSI Z-136.1 standard provides charts and tables that allow determination of such levels.

E. LASER OUTPUT FACTORS:

As the laser industry has grown and matured, more lasers have become available with even more complex outputs. Now such exotic terms as: super-pulsed, Q-switched, mode-locked, femtoseconds, Excimers...etc. are used to describe the laser performance. In addition, more safety equipment suppliers provide different types of eye protection; and we hear arguments about alignment versus full protection, plastic versus glass, "laser safe" frames versus untested frames ...etc. The eye protection selection process has become more complex as the industry has grown.

The different modes of operation of a laser are distinguished by the rate at which energy is emitted. These include such factors as CW, normal pulse mode, repetitively pulsed, Q-switched and mode-locked. (See Glossary, Appendix A)

These lasers are by no means representative of the vast number of different lasers which are manufactured. It is evident that even these most common laser types produce a wide range of output levels and specific beam characteristics which are dependent in a complex way upon the particular laser media and the manner in which it is operated. This makes a general broad comparison of all laser devices a difficult, if not impossible task, especially for safety eye protection specifications.

For pulsed lasers, the peak power characteristics are all important, and typically, the output specifications are expressed in terms of the pulse energy (Joules) for a given pulse length (seconds). When the output beam is repetitively pulsed, the output beam specifications are usually expressed in terms of average power (Watts), pulse repetition rate (Hertz or pulses-per-second), and single pulse duration (seconds). In addition, the peak power (Watts) of the individual pulse is also often specified.

Depending upon design, the beams will, in general, be delivered in a single pulse, in a series of repetitive pulses, or as a continuous wave (CW) level of radiant power.

The major parameters needed when selecting laser protective eyewear are listed below:

WAVELENGTH(S): The wavelength(s) of laser radiation limits the type of eye protection chosen to only that type which reduce the power level at a particular wavelength(s) from reaching the eye at hazardous levels. 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 example, a frequency doubled Nd:YAG operating at 0.532 ?m may emit about 2 watts at the green wavelength while the Nd:YAG laser itself (operating at 1.064 ?m in the near infrared) emits 50 watts. But some safety filters which strongly absorb the 0.532 m wavelength may absorb essentially nothing at the 1.064 ?m wavelength. This is big problem for dye lasers which have a variable or tunable wavelength ability. In such cases, the eyewear can only be specified over a narrow band of wavelengths where the therapy is to be done.

OPTICAL DENSITY: 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 and is not used. As a result, laser protective eyewear filters are specified in terms of the logarithmic units of Optical Density (usually referred to as "OD"). The optical density (OD) of a specific filter at a given laser wavelength is related by the equation:

(Equation, see printed copy)

where H(o) is the anticipated "worst case" exposure (usually directly out of the laser) and is expressed in the units of W/cm(2) or J/cm(2) depending upon whether the laser in question is CW, repetitively pulsed or single pulse. The MPE is expressed in the identical units as the MPE limit.

It should be noted that since the MPE values are distributed over the pupil diameter (limiting aperture), the calculation for H(o) for beams smaller than the limiting aperture requires that the limiting aperture be used instead of the smaller beam size. That is, the calculation is made as though the beam were spread over the limiting aperture. (See example below.)

Because of the logarithmic factor, 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 together is essentially the linear sum of two individual optical densities.

LASER BEAM INTENSITY: The maximum laser beam power (Watts) or pulse energy (Joules). In some cases, the beam size is needed where pulsed lasers are expressed in radiant exposure units of Joules/cm(2) and CW lasers in terms of beam irradiance in Watts/cm(2).

VISIBLE TRANSMITTANCE OF EYEWEAR: Since the object of laser protective eyewear is to filter out the laser wavelengths while transmitting as much of the visible light as possible, the visible (or luminous) transmittance should as high as possible. A low visible transmittance (usually measured in percent) creates problems of eye fatigue and may require an increase in ambient lighting. However, adequate optical density at the laser wavelengths should not be sacrificed for improved visible transmittance.

There can be, in some instances, significant differences between the luminous transmission of different filter types for a given laser. In one instance, a specific (green) plastic filter for Nd:YAG lasers has less than 35% visible transmittance while several corresponding glass filters (with only a slight tint) can yield luminous transmissions above 85%. In both cases, adequate OD's are provided for filtration of the Nd:YAG beam. It is simply more difficult to see through the darker green plastic filters and the clearer glass filter is better suited.

Low visible transmittance has been repeatedly linked with the common practice of "cheating" (i.e., removing the laser eyewear in order to see the area where the beam will hit). This has obvious impact on laser accidents.

LASER FILTER DAMAGE LEVEL: (Maximum Irradiance). At some specific beam intensity, the filter material which absorbs the laser radiation can be damaged. Plastic materials have damage thresholds much lower than glass filters and glass (by itself) is lower than a dielectric coated glass. The damage threshold is especially important for those who work closely to the beam interaction site where there is a much higher probability to receive a direct exposure. Typical damage thresholds for CW lasers fall between 400 and 1000 watts/cm(2) for dielectric coated glass, 100 to

300 watts/cm(2) for uncoated glass and 1 to 10 watts/cm(2) for plastics.

The German eye protection standard (DIN 58 215), for example, requires that both the filter and frame be designed to withstand an exposure of 10 seconds (CW or PRF 10 hz) or 100 pulses (prf hz) without a loss of rated optical density. A similar test exposure criteria is not specifically required by the ANSI Z-136.1 standard, although the standard does indicate that the radiant exposure or irradiance and the corresponding time factors at which damage occurs (penetration), including transient bleaching, is a important factor in determining the appropriate eyewear to be used.

However, unless the eyewear is designed to meet the German DIN standard requirements, damage threshold limits may be difficult to identify and evaluate.

A 1979 FDA study EVALUATION OF COMMERCIALLY AVAILABLE LASER PROTECTIVE EYEWEAR (HEW Publication (FDA) 79-8086) reported limited testing of laser protective eyewear available at that time. For example, tests were reported for Q- switched rubylaser exposures (0.694 ?m) on various manufacturer's protective eyewear. The plasticlaser protective eyewear displayed damage thresholds (surface pitting) ranging from 3.8 to 18 J/cm(2) while glass filters required a radiant exposure ranging from 93 to 1620 J/cm(2).

Detailed damage threshold data for protective eyewear of more recent vintage is not readily available.

F. OPTICAL DENSITY DETERMINATION:

Two major factors are required to establish the OD; namely the laser output level and the MPE value for that laser wavelength and at the specified exposure time.

For CW lasers, exposure times can be selected as short as the "blink reflex" time (0.25 second) for some visible lasers; to 10 seconds for some infrared lasers; 600 seconds for viewing diffuse reflections (when they do not act as extended sources). The maximum "worst case" would be an 8 hour (30,000 seconds) exposure that is considered as a maximum daily "occupational" exposure. For pulsed lasers, the individual pulse time is needed and the pulse repetition rate. the MPE value is determined using the ANSI standards. For "worst case" conditions, the beam is considered to be confined to a size of a dark adapted pupil (7 mm). As an example of a single pulse laser, consider the case of an 80 milliJoule single-pulse (50 nanosecond), Q-switched Nd:YAG laser emitted in a 2 mm beam diameter. This would be a Class IV laser and reference to the ANSI Z-136.1 (1986) standard yields an MPE value for a single pulse of: MPE = 5.0 J/cm(2).

The OD is calculated by first determining the value of H(o). From the parameters above, one calculates first the worst case exposure spread over the 7 mm limiting aperture (not the 2 mm beam diameter). The laser beam "area" may be calculated using the equation for a circle as follows:

(Equations, see printed copy)

Thus a filter with OD = 4.6 would provide adequate protection for one pulse from this laser.

A wide variety of commercially-available optical filter glass (and plastics) are available for laser eye protection. Some are available in eye-spectacles ground to prescription specifications. One filter-type may be applicable to more than one wavelength. Some filters have a high optical density below a certain "cut-off" wavelength, usually limiting overall visibility.

Consequently, protection devices must be selected based upon the specific operational characteristics of the laser being used. One cannot always be assured that the protective device which may be applicable for one laser will apply to another laser of the same media.

For example, the eyewear OD requirement for a repetitively pulsed, Q-switched Nd:YAG

(Table VIII-1. OD Requirements for ND:YAG Lasers of Different Output Specifications, see printed copy)

ophthalmic laser WILL NOT BE THE SAME as selected for a 100 watt CW surgical system or, for that matter, for a 15 watt CW Nd:YAG featuring a diffusing probe on a fiber optic delivery. Each unit contains a Nd:YAG laser but each should receive a separate evaluation for optimum laser eye protection because of the system performance differences. See Table VIII-1.

It should be clear that there would be significant difficulty in providing a "one fix -

cures all" approach for eyewear selection. The advantages introduced by a broad spectrum of available laser sources is, of itself, a disadvantage when attempting to provide a uniform "all purpose" laser safety code.

G. EYE PROTECTION FOR SUPPORT STAFF AND SPECTATORS:

Is eye protection needed for the ancillary staff? The answer is YES! In most cases, there can be the possibility of hazardous diffuse reflections and even a diffuse reflection off the wall can exceed the safe exposure limit. If a power less than 500 milliwatts is considered to be a "safe level" to view as a diffuse reflection long-term, and the laser emits 1000 milliwatts, then the potential exposure is well above the safe level, and the beam on the wall could be potentially hazardous to view. The common sense solution is to simply require the use of eye protection.

H. FLASHBACK FILTERS FOR VIEWING SYSTEMS:

Reflections of argon and neodymium laser radiation back through a microscope or endoscope (flash-back) must be attenuated with protective filters built into the optical systems viewer. For example, studies have shown that the reflections back through the laser catheter were of the order of 2 mW for a specular reflection flashback returning through an endoscope PER WATT OF POWER incident at the distal end of the fiber-optic delivery system used with a Nd:YAG laser; and less than 1mW per watt for the argon laser systems.

Thus, filtration would be required to protect the user's eye from injury during viewing. Computations can show that filters having an optical density of 5.4 would be required at the argon laser wavelengths (assuming a 10 W maximum power) to provide protection as well as comfortable viewing during extended exposures. An optical density of at least 2.1 would be required at the Nd:YAG wavelength assuming 100 watts maximum power.

I. SELECTION PROCESS:

Selection of laser eyewear first requires an analytical review of a specific laser's output parameters and selection of the proper maximum permissible exposure limit from the ANSI standard. From this information, the required filter optical density can then be specified using the equation for OD given earlier.

Some will find the logarithmic optical density computation to be beyond their scope of expertise. Those individuals may need to seek assistance from those more experienced in such mathematics or, perhaps, utilize existing computer software programs that are designed to easily provide the answers needed.

1. ALIGNMENT EYEWEAR: The ultimate choice of eyewear is then made by first making the decision whether "worst case" (so-called full protection) requirements must be met or whether alignment eyewear is needed. Experience has shown that laser eye accidents more frequently occur during such alignment procedures. A common theme in such laser eye accident has been that AVAILABLE EYE PROTECTION HAS NOT BEEN WORN. There have been numerous accidents reported involving individuals who had eye protection within reach but didn't have it on. The reason stated was that during "alignment" they need to see the beam! Certainly a reasonable request. The problem centers on the fact that "full protection" eyewear is usually designed to virtually eliminate the possibility of seeing the beam. Thus a diffuse reflection cannot be seen during an alignment process. As a result, the eyewear is removed to accomplish the alignment task. So called "alignment" eyewear is designed to allow a safe level of laser light to be transmitted through the filter. This requires viewing only diffuse reflections of the beam (scattered light) and never the direct beam. Usually the alignment eyewear does afford some limited-time protection for a direct beam case but it is never intended for such viewing. Visibility through the filter of the normal ambient light (luminous transmission) can sometimes be improved if the laser eyewear filters are designed for the task. For example, optical alignment with a modestly powerful cw laser can be done using a filter type that reduces the laser power transmitted through the filter from a diffuse reflection to not only a "safe" level but also a level that is "comfortable" to view. This might be required during alignment of an optical system by a technician using a diffusely reflecting target "to see the beam" during the task. In these cases, the MPE used in the optical density determinations can be based upon an exposure time of 600 seconds. Often the design allows an optical density significantly lower than would be required using an 8 hour MPE criteria. This usually results in a filter of greater overall luminous transmission, hence superior visibility while wearing the eyewear. Since the option during alignment processes is to "cheat" and not wear protective eyewear, in essence, alignment eyewear provides an alternative to no eyewear at all. Clearly a superior alternative considering the accident records! 2. PLASTIC - VERSUS - GLASS? Then the concern of plastic versus glass must be considered. This is essentially the question of determining the conditions in which the eyewear is to be used. Namely, is the user to be located in an area where the exposure could exceed the damage threshold (PTL) of the eyewear or is it to be used by ancillary personnel typically at a sufficient distance from the beam interaction site that the PTL requirement is lower. Obviously cost can play a major role. Laser protective eyewear is not inexpensive. Units can range from about $90.00 for some plastic "goggle" units to over $500.00 for some special coated glass units. Many laser medical facilities purchase a "mix" of units. It should be stressed that the choice of which eyewear to provide should not be based only upon the cost but upon the PROTECTION REQUIREMENT of the individual considering the possibilities for worst case exposure. The more laser resistant units are normally provided to those regular laser personnel who work close to the beam and the less laser resistant are supplied to those who normally work at a distance from the interaction

site. Laser service personnel are usually supplied the more laser resistant eye protection since their activity will bring them in regular close proximity with the beam. The final choice in the selection process will be the choice in filter types. In some instances there will be a number of possibilities available. In these cases, factors such as room light transmission (luminous transmission) may be the deciding factor. Obviously the higher the luminous transmission the better one can see to do the task. Many times the final choice will be a trade off between all of the above factors. One may be willing to accept lower luminous transmission but purchase a less expensive eye protector while maintaining the required optical density level. It should go without saying that one should never choose a filter with an inadequate OD rating but one could choose a filter with less white light transmission and have a functional protector. Additionally, one can consider a "mix" of protectors predicated upon the fact that the protection requirement is not always the same for all laser workers. This approach, however, does impose the need for training for those using the eyewear.

J. SUMMARY:

Reviewing numerous laser accident conditions has shown that having laser eyewear is not the major problem. The major problem is having the laser personnel wear available eyewear.

How does one reinforce the wearing safety eyewear? In any Class IV laser environment the use of eye protection should be a procedural requirement. If laser protective eyewear has been deemed as mandatory for a given procedure, then:

LASER EYEWEAR MUST BE ON BEFORE THE LASER CAN BE TURNED ON! ---

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The person who has specific laser safety responsibility of turning on the laser and making sure all the safety features are operational during the process must also be responsible for proper laser eye protection.

One positive aspect that comes from a frequent evaluation of a laser safety program is keeping the level of hazard awareness so high that the personnel wear protective eyewear automatically.

The eyewear selection process first requires basic laser parameter understanding and some fundamental mathematical skills. The decision process is then reduced to an interrelated combination of task analysis, economics and vendor choice.

IX. LASER TRAINING ---

RECOMMENDED LASER TRAINING REQUIREMENTS: The LSO shall insure that all employees assigned to service, maintain, install, adjust, and operate laser equipment be appropriately qualified and trained. The training program should be designed appropriate to the Class of laser radiation accessible during the required task(s) of the personnel. Laser area supervisors shall maintain the names of all persons trained and date of training and inform the LSO of training completions and requirements.

A. CLASS I TRAINING:

Class I training can be limited, in general, to information contained in the operation/maintenance manuals of the laser Manufacturer. No additional operator training is necessary provided the Class I status is maintained.

B. CLASS II, CLASS IIA AND CLASS IIIA TRAINING:

Class II, Class IIA and Class IIIA training can include information contained in the operation/maintenance manuals of the laser Manufacturer and, where appropriate, additional basic safety guide literature of a general topic nature. Short, concise audio-visual programs can also enhance understanding of hazards in some use scenarios especially where Class II, Class IIA or Class IIIA laser systems are subject to frequent operator changes.

C. CLASS IIIB AND CLASS IV TRAINING:

Class IIIB and Class IV training is recommended for those working with Class IIIB and Class IV lasers, including operators, maintenance personnel, service persons as-well-as those on the technical support staff, technicians, ..etc. The training should provide a complete understanding of the requirements of a safe laser environment and include discussion of the hazards, safety devices required, procedures related to operating the equipment, warning sign requirements and description of medical surveillance practices. Emphasis should be placed on practical, safe laser techniques and procedures as well as safety devices that provide an overall safe environment.

D. LASER SAFETY OFFICER TRAINING:

Laser Safety Officer training is required for the facility LSO. This can be a comprehensive multi-day course which covers the all key aspects of laser safety and a indepth review of the appropriate standards, OSHA requirements, and needs for state and local compliance, as appropriate. A topical outline of such a training program is given in Table IX-1.

E. UPDATE TRAINING REQUIREMENTS:

Update training requirements have been shown to be appropriate, especially for research and service personnel where beam alignment is a frequent work requirement. For example, one published account by an individual who lost the sight of one eye when protective eyewear was not used, concluded: "But more important than the actual event is the idea that this incident could have been avoided. Don't let it happen to you or a co-worker. Take time to assess safety conditions, and do it again in 6 months or a year; additional hazards arise in an ever-changing research environment. Safety deserves your thoughtful considerations, now, before your accident."

F. TAILORED TRAINING SESSIONS:

There often will be a need to tailor the laser safety training session for each of the different groups that use lasers in the facility. Often the type of laser(s) and locations will impact the content of the training program. For example, the hazards and controls recommended for the far-infrared CO(2) lasers are usually different than those for a near-infrared Nd:YAG laser or a visible Argon Ion laser or an ultraviolet Excimer laser. Where possible, the specific course content should be designed for the lasers and personnel in the environment.

APPENDIX A. GLOSSARY OF LASER TERMS

ABSORB To transform radiant energy into a different form, with a resultant rise in temperature.

ABSORPTION Transformation of radiant energy to a different form of energy by the interaction of matter, depending on temperature and wavelength.

ABSORPTION COEFFICIENT Factor describing light's ability to be absorbed per unit of path length.

ACCESSIBLE EMISSION LEVEL The magnitude of accessible laser (or collateral) radiation of a specific wavelength or emission duration at a particular point as measured by appropriate methods and devices. Also means radiation to which human access is possible in accordance with the definitions of the laser's hazard classification.

ACCESSIBLE EMISSION The maximum accessible emission level.

LIMIT (AEL) permitted within a particularly class. In ANSI Z- 136.1, AEL is determined as the product of Accessible Emission Maximum Permissible Exposure limit (MPE) and the area of the limiting aperture (7mm for visible and near infrared lasers).

ACTIVE MEDIUM Collection of atoms or molecules capable of undergoing stimulated emission at a given wavelength.

AFOCAL Literally, "without a focal length"; an optical system with its object and image point at infinity.

AIMING BEAM A laser (or other light source) used as a guide light. Used coaxially with infrared or other invisible light may also be a reduced level of the actual laser used for surgery or for other applications.

AMPLIFICATION The growth of the radiation field in the laser resonator cavity. As the light wave bounces back and forth between the cavity mirrors, it is amplified by stimulated emission on each pass through the active medium.

AMPLITUDE The maximum value of the electro-magnetic wave, measured from the mean to the extreme; simply stated: the height of the wave.

ANGLE OF INCIDENCE See Incident Ray

ANGSTROM UNIT A unit of measure of wavelength dual to 10(-10) meter, 0.1 nanometer, or 10(-4) micrometer, no longer widely used nor recognized in the SI system of units.

ANODE An electrical element in laser excitation which attracts electrons from a cathode.

APERTURE An opening through which radiation can pass.

APPARENT VISUAL ANGLE The angular subtense of the source as calculated from the source size and distance from the eye. It is not the beam divergence of the source.

AR COATINGS Antireflection coatings used on optical components to suppress unwanted reflections.

ARGON A gas used as a laser medium. It emits blue/green light primarily at 448 and 515 nm.

ARTICULATED ARM CO(2) laser beam delivery device consisting of a series of hollow tubes and mirrors interconnected in such a manner as to maintain alignment of the laser beam along the path of the arm.

ATTENUATION The decrease in energy (or power) as a beam passes through an absorbing or scattering medium.

AUTOCOLLIMATOR A single instrument combining the functions of a telescope and a collimator to detect small angular displacements of a mirror by means of its own collimated light.

AVERAGE POWER The total energy imparted during exposure divided by the exposure duration.

AVERSION RESPONSE Movement of the eyelid or the head to avoid an exposure to a noxious stimulant, bright light. It can occur within 0.25 seconds, and it includes the blink reflex time.

AXIAL-FLOW LASER A laser in which an axial flow of gas is maintained through the tube to replace those gas molecules depleted by the electrical discharge used to excite the gas molecules to the lasing. See gas discharge laser.

AXICON LENS A conical lens which, when followed by a conventional lens, can focus laser light to a ring shape.

AXIS, OPTICAL AXIS The optical centerline for a lens system; the line passing through the centers of curvature of the optical surfaces of a lens.

BEAM A collection of rays that may be parallel, convergent, or divergent.

BEAM BENDER A hardware assembly containing an optical device, such as a mirror, capable of changing the direction of a laser beam; used to repoint the beam, and in "folded," compact laser systems.

BEAM DIAMETER The distance between diametrically opposed points in the cross section of a circular beam where the intensity is reduced by a factor of e(-1) (0.368) of the level (for safety standards). The value is normally chosen at e(-2) (0.135) of the peak level for manufacturing specifications.

BEAM DIVERGENCE Angle of beam spread measured in radians more milliradians (1 milliradian = 3.4 minutes-of-arc or approximately 1 mil). For small angles where the cord is approximately equal to the arc, the beam divergence can be closely approximated by the ratio of the cord length (beam diameter) divided by the distance (range) from the laser aperture.

BEAM EXPANDER An optical device that increases beam diameter while decreasing beam divergence (spread). In its simplest form consists of two lenses, the first to diverge the beam and the second to re-collimate it. Also called an upcollimator.

BEAM SPLITTER An optical device using controlled reflection to produce two beams from a single incident beam.

BLINK REFLEX See aversion response.

BREWSTER WINDOWS The transmissive end (or both ends) of the laser tube, made of transparent optical material and set at Brewster's angle in gas lasers to achieve zero reflective loss for one axis of plane polarized light. They are non-standard on industrial lasers, but a must if polarization is desired.

BRIGHTNESS The visual sensation of the luminous intensity of a light source. The brightness of a laser beam is most closely associated with the radio-metric concept of radiance.

C.I.E. Abbreviation for Commission International de l'Eclairage, the French translation for: International Commission on Illumination.

CALORIMETER An instrument which measures the energy, usually as heat generated by absorption of the laser beam.

CARBON DIOXIDE Molecule used as a laser medium. Emits far energy at 10,600 nm (10.6 ?m).

CATHODE A negatively charged electrical element providing electrons for an electrical discharge.

CLOSED INSTALLATION Any location where lasers are used which will be closed to unprotected personnel during laser operation.

CO(2) LASER A widely used laser in which the primary lasing medium is carbon dioxide gas. The output wavelength is 10.6 ?m (10600 nm) in the far infrared spectrum. It can be operated in either CW or pulsed.

COAXIAL GAS A shield of inert gas flowing over the target material to prevent plasma oxidation and absorption, blow away debris, and control heat reaction. The gas jet has the same axis as the beam,so the two can be aimed together.

COHERENCE A term describing light as waves which are in phase in both time and space. Monochromaticity and low divergence are two properties of coherent light.

COLLIMATED LIGHT Light rays that are parallel. Collimated light is emitted by many lasers. Diverging light may be collimated by a lens or other device.

COLLIMATION Ability of the laser beam to not spread significantly (low divergence) with distance.

COMBINER MIRROR The mirror in a laser which combines two or more wavelengths into a coaxial beam.

CONTINUOUS MODE The duration of laser exposure is controlled by the user (by foot or hand switch).

CONTINUOUS WAVE (CW) Constant, steady-state delivery of laser power.

CONTROLLED AREA An locale where the activity of those within are subject to control and supervision for the purpose of laser radiation hazard protection.

CONVERGENCE The bending of light rays toward each other, as by a positive (convex) lens.

CORRECTED LENS A compound lens that is made measurably free of aberrations through the careful selection of its dimensions and materials.

CRYSTAL A solid with a regular array of atoms. Sapphire (Ruby Laser) and YAG (Nd:YAG laser) are two crystalline materials used as laser sources.

CURRENT REGULATION Laser system regulation in which discharge current is kept constant.

CURRENT SATURATION The maximum flow of electric current in a conductor; in a laser, the point at which further electrical input will not increase laser output.

CW Abbreviation for continuous wave; the continuous-emission mode of a laser as opposed to pulsed operation.

DEPTH OF FIELD The working range of the beam in or near the focal plane of a lens; a function of wavelength, diameter of the unfocused beam, and focal length of the lens.

DEPTH OF FOCUS The distance over which the focused laser spot has a constant diameter and thus constant irradiance.

DICHROIC FILTER Filter that allows selective transmission of colors desired wavelengths.

DIFFRACTION Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

DIFFUSE REFLECTION Takes place when different parts of a beam incident on a surface are reflected over a wide range of angles in accordance with Lambert's Law. The intensity will fall-off as the inverse of the square of the distance away from the surface and also obey a Cosine Law of reflection.

DIFFUSER An optical device or material that homogenizes the output of light causing a very smooth, scattered, even distribution over the area affected. The intensity will obey Lambert's law (see Diffuse Reflection).

DIVERGENCE The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser radiant exposure or irradiance is e(-1) or e(-2) of the maximum value, depending upon which criteria is used.

DOSIMETRY Measurement of the power, energy, irradiance or radiant exposure of light delivered are two crystalline materials used as laser to tissue.

DRIFT All undesirable variations in output either amplitude or frequency).

ANGULAR DRIFT Any unintended change in direction of the beam before, during, and after warmup; measured in mrad.

DUTY CYCLE Ratio of total "on" duration to total exposure duration for a repetitively pulsed laser.

ELECTRIC VECTOR The electric field associated with a light wave which has both direction and amplitude.

ELECTROMAGNETIC RADIATION The propagation of varying electric and magnetic fields through space at the velocity of light.

ELECTROMAGNETIC SPECTRUM The range of frequencies and wavelengths emitted by atomic systems. The total spectrum includes radiowaves as well as short cosmic rays. Wavelengths cover a range from 1 hz to perhaps as high as 1020 hz.

ELECTROMAGNETIC WAVE A disturbance which propagates outward from an electric charge that oscillates or is accelerated. Includes radio waves; X-rays; gamma rays; and infrared, ultraviolet, and visible light.

ELECTRON Negatively charged particle of an atom.

EMBEDDED LASER A laser with an assigned class number higher than the inherent capability of the laser system in which it is incorporated, where the systems lower classification is appropriate to the engineering features limiting accessible emission.

EMERGENT BEAM DIAMETER Diameter of the laser beam at the exit aperture of the system in centimeters (cm) defined at e(-1) or e(-2) irradiance points.

EMISSION Act of giving off radiant energy by an atom or molecule.

EMISSIVITY The ratio of the radiant energy emitted by a any source to that emitted by a blackbody at the same temperature.

EMITTANCE The rate at which emission occurs.

ENCLOSED LASER DEVICE Any laser or laser system located within an enclosure which does not permit hazardous optical radiation emission from the enclosure. The laser inside is termed an "embedded laser."

ENERGY The product of power (watts) and duration (seconds). One watt second = one Joule.

ENERGY (Q) The capacity for doing work. Energy is commonly used to express the output from pulsed lasers and it is generally measured in Joules (J). The product of power (watts) and duration (seconds). One watt second = one Joule.

ENERGY SOURCE High voltage electricity, radiowaves, flashes of light, or another laser used to excite the laser medium.

ENHANCED PULSING Electronic modulation of a laser beam to produce high peak power at the initial stage of the pulse. This allows rapid vaporization of the material without heating the surrounding area. Such pulses are many times the peak power of the CW mode (also called "Superpulse").

ETALON A Fabry-Perot interferometer with a fixed air gap separation. Such a device also serves as a basic laser resonant cavity.

EXCIMER "EXCITED DIMER." A gas mixture used as the active medium in a family of lasers emitting ultraviolet light.

EXCITATION Energizing a material into a state of population inversion.

EXCITED STATE Atom with an electron in a higher energy level than it normally occupies.

EXEMPTED LASER PRODUCT In the U.S., a laser device exempted by the U.S. Food and Drug Administration from all or some of the requirements of 21 CFR 1040.

EXTENDED SOURCE An extended source of radiation can be resolved into a geometrical image in contrast with a point source of radiation, which cannot be resolved into a geometrical image. A light source whose diameter subtends a relatively large angle from an observer.

F-NUMBER The focal length of lens divided by its usable diameter. In the case of a laser the usable diameter is the diameter of the laser beam or a smaller aperture which restricts a laser beam.

FABRY-PEROT INTERFEROMETER Two plane, parallel partially reflective optically flat mirrors placed with a small air gap separation (1-20 mm) so as to produce interference between the light waves (interference fringes) transmitted with multiple reflections through the plate.

FAILSAFE INTERLOCK An interlock where the failure of a single mechanical or electrical component of the interlock will cause the system to go into, or remain in, a safe mode.

FEMTOSECONDS 10(-15) seconds.

FIBEROPTICS A system of flexible quartz or glass fibers with internal reflective surfaces that pass light through thousands of glancing (total internal) reflections.

FLASHLAMP A tube typically filled with Krypton or Xenon. Produces a high intensity

white light in short duration pulses.
FLUORESCENCE The emission of light of a particular wavelength resulting from absorption of energy typically from light of shorter wavelengths.
FLUX The radiant, or luminous, power of a light beam; the time rate of the flow of radiant energy across a given surface.
FOCAL LENGTH Distance between the center of a lens and the point on the optical axis to which parallel rays of light are converged by the laser.
FOCAL POINT That distance from the focusing lens where the laser beam has the smallest diameter.
FOCUS As a noun, the point where rays of light meet which have been reflected by a mirror or refracted by a lens, giving rise to an image of the source. As a verb, to adjust focal length for the clearest image and smallest spot size.
FOLDED RESONATOR Construction in which the interior optical path is bent by mirrors; permit compact packaging of a long laser cavity.
FREQUENCY The number of light waves passing a fixed point in a given unit of time, or the number of complete vibrations in that period.
GAIN Another term for amplification.
GAS DISCHARGE LASER A laser containing a gaseous lasing medium in a glass tube in which a constant flow of gas replenishes the molecules depleted by the electricity or chemicals used for excitation.
GAS LASER A type of laser in which the laser action takes place in a gas medium.
GATED PULSE A discontinuous burst of laser light, made by timing (gating) a continuous wave output - usually in fractions of a second.
GAUSSIAN CURVE NORMAL Statistical curve showing a peak with even distribution on either side. May either be a sharp peak with steep sides, or a blunt peak with shallower sides. Used to show power distribution in a beam. The concept is important in controlling the geometry of the laser impact.
GROUND STATE Lowest energy level of an atom.
HALF-POWER POINT The value on either the leading or trailing edge of a laser pulse at which the power is one-half of its maximum value.

HEAT SINK A substance or device used to dissipate or absorb unwanted heat energy.

HELIUM-NEON (HeNe) LASER A laser in which the active medium is a mixture of helium and neon. Its wavelength is usually in the visible range. Used widely for alignment, recording, printing, and measuring.

HERTZ (Hz) Unit of frequency in the International System of Units (SI), abbreviated Hz; replaces cps for cycles per second.

HOLOGRAM A photographic film or plate containing interference patterns created by the coherence of laser light. A three dimensional image may be reconstructed from a hologram. Here are transmission, reflection or integral holograms.

IMAGE The optical reproduction of an object, produced by a lens or mirror. A typical positive lens converges rays to form a "real" image which can be photographed. A negative lens spreads rays to form a "virtual" image which can't be projected.

INCIDENT LIGHT A ray of light that falls on the surface of a lens or any other object. The "angle of incidence" is the angle made by the ray with a perpendicular to the surface.

INFRARED RADIATION (IR) Invisible Electromagnetic radiation with wavelengths which lie within the range of 0.70 to 1000 ?m. These wavelengths are often broken up into regions: IR-A (0.7-1.4 ?m), IR-B (1.4-3.0 ?m) and IR-C (3.0-1000 ?m).

INTEGRATED RADIANCE Product of the exposure duration times the radiance. Also known as pulsed radiance.

INTENSITY The magnitude of radiant energy.

INTRABEAM VIEWING The viewing condition whereby the eye is exposed to all or part of a direct laser beam or a specular reflection.

ION LASER A type of laser employing a very high discharge current, passing down a small bore to ionize a noble gas such as argon or krypton.

IONIZING RADIATION Radiation commonly associated with X-Ray or other high energy electro-magnetic radiation which will cause DNA damage with no direct, immediate thermal effect. Contrasts with non-ionizing radiation of lasers.

IRRADIANCE (E) Radiant flux (radiant power) per unit area incident upon a given surface. Units: Watts per square centimeter. (Sometimes referred to as power density, although not exactly correct).

IRRADIATION Exposure to radiant energy, such as heat, X-rays, or light.

JOULE (J) A unit of energy (1 watt-second) used to describe the rate of energy delivery. It is equal to one watt-second or 0.239 calorie.

JOULE/cm(2) A unit of radiant exposure used in measuring the amount of energy incident upon a unit area.

KTP Potassium Titanyl Phosphate. A crystal used to change the wavelength of a Nd:YAG laser from 1060 nm (infrared) to nm (green).

LAMBERTIAN SURFACE An ideal diffuse surface whose emitted or reflected radiance (brightness) is dependent on the viewing angle.

LASER An acronym for light amplification by stimulated emission of radiation. A laser is a cavity, with mirrors at the ends, filled with material such as crystal, glass, liquid, gas or dye. A device which produces an intense beam of light with the unique properties of coherency, collimation and monochromaticity.

LASER ACCESSORIES The hardware and options available for lasers, such as secondary gases, Brewster windows, Q-switches and electronic shutters.

LASER CONTROLLED AREA See CONTROLLED AREA.

LASER DEVICE Either a laser or a laser system.

LASER MEDIUM (Active Medium) material used to emit the laser light and for which the laser is named.

LASER OSCILLATION The buildup of the coherent wave between laser cavity end mirrors producing standing waves.

LASER PRODUCT A legal term in the U.S. See 21 CFR 1040.10, a laser or laser system or any other product that incorporates or is intended to incorporate a laser or a laser system.

LASER ROD A solid-state, rod-shaped lasing medium in which ion excitation is caused by a source of intense light, such as a flashlamp. Various materials are used for the rod, the earliest of which was synthetic ruby crystal.

LASER SAFETY OFFICER (LSO) One who has authority to monitor and enforce measure to the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

LASER SYSTEM An assembly of electrical, mechanical and optical components which includes a laser. Under the Federal Standard, a laser in combination with its power supply (energy source).

LEADING EDGE SPIKE The initial pulse in a series of pulsed laser emissions, often useful in starting a reaction at the target surface. The trailing edge of the laser power is used to maintain the reaction after the initial burst of energy.

LENS A curved piece of optically transparent material which depending on its shape is used to either converge or diverge light.

LIGHT The range of electromagnetic radiation frequencies detected by the eye, or the wavelength range from about 400 to 760 nanometers. The term is sometimes used loosely to include radiation beyond visible limits.

LIGHT REGULATION A form of power regulation in which output power is monitored and maintained at a constant level by controlling discharge current.

LIMITING ANGULAR SUBTENSE The apparent visual angle which divides intrabeam viewing from extended-source viewing.

LIMITING APERTURE The maximum circular area over which radiance and radiant exposure can be averaged when determining safety hazards.

LIMITING EXPOSURE DURATION An exposure duration which is specifically limited by the design or intended use(s).

LONGITUDINAL OR AXIAL MODE Determines the wavelength bandwidth produced by a given laser system controlled by the distance between the two mirrors of the laser cavity. Individual longitudinal mode standing waves within a laser cavity.

LOSSY MEDIUM A medium which absorbs or scatters radiation passing through it.

MAINTENANCE Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system, which are to be performed by the user to ensure the intended performance of the product. It does not include operation or service as defined in this glossary.

MAXIMUM PERMISSIBLE EXPOSURE (MPE) The level of laser radiation to which person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

MENISCUS LENS A lens which has one side convex, the other concave.

METASTABLE STATE The state of an atom, just below a higher excited state, which an electron occupies momentarily before destabilizing and emitting light. The upper of the two lasing levels.

MICROMETER A unit of length in the International System of Units (SI) equal to one-millionth of a meter. Often referred to as a "micron".

MICRON An abbreviated expression for micrometer which is the unit of length equal to 1 millionth of a meter. See MICROMETER.

MICROPROCESSOR A digital chip (computer) that operates, controls and monitors some lasers.

MODE A term used to describe how the power of a laser beam is geometrically distributed across the cross-section of the beam. Also used to describe the operating mode of a laser such as continuous or pulsed laser.

MODE LOCKED A method of producing laser pulses in which short pulses (approximately 10-12 second) are produced and emitted in bursts or a continuous train.

MODULATION The ability to superimpose an external signal on the output beam of the laser as a control.

MONOCHROMATIC LIGHT Theoretically, light consisting of just one wavelength. No light is absolutely single frequency since it will have some bandwidth. Lasers provide the narrowest of bandwidths that can be achieved.

MULTIMODE Laser emission at several closely-spaced frequencies.

NANOMETER (nm) A unit of length in the International System of Units (SI) equal to one-billionth of a meter. Abbreviated nm - a measure of length. One nm equals 10(-9) meter, and is the usual measure of light wavelengths. Visible light ranges from about 400 nm in the purple to about 760 nm in the deep red.

NANOSECOND One billionth (10(-9)) of a second. Longer than a picosecond or femto-second, but shorter than a micro-second. Associated with Q-switched lasers.

Nd:GLASS LASER A solid-state laser of neodymium: glass offering high power in short pulses. A Nd doped glass rod used as a laser medium to produce 1064 nm light.

Nd:YAG LASER Neodymium:Yttrium Aluminum Garnet. A synthetic crystal used as a laser medium to produce 1064 nm light.

NEAR FIELD IMAGING A solid-state laser imaging technique offering control of spot size and hole geometry, adjustable working distance, uniform energy distribution, and a wide range of spot sizes.

NEMA Abbreviation for National Electrical Manufactures' Association, a group which defines and recommends safety standards for electrical equipment.

NEODYMIUM (Nd) The rare earth element that is the active element in Nd:YAG laser and Nd:Glass lasers.

NOISE Unwanted minor currents or voltages in an electrical system.

NOMINAL HAZARD ZONE (NHZ) The nominal hazard zone describes the space within which the level of the direct, reflected or scattered radiation during normal operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the appropriate MPE level.

NOMINAL OCULAR HAZARD DISTANCE (NOHD) The axial beam distance from the laser where the exposure or irradiance falls below the applicable exposure limit.

OBJECT The subject matter or figure imaged by, or seen through, an optical system.

OPACITY The condition of being non-transparent.

OPEN INSTALLATION Any location where lasers are used which will be open to operating personnel during laser operation and may or may not specifically restrict entry to observers.

OPERATION The performance of the laser or laser system over the full range of its intended functions (normal operation). It does not include maintenance or services as defined in this glossary.

OPTIC DISC The portion of the optic nerve within the eye which is formed by the meeting of all the retinal nerve fibers at the level of the retina.

OPTICAL CAVITY (Resonator) Space between the laser mirrors where lasing action occurs.

OPTICAL DENSITY A logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter.

OPTICAL FIBER A filament of quartz or other optical material capable of transmitting light along its length by multiple internal reflection and emitting it at the end.

OPTICAL PUMPING The excitation of the lasing medium by the application of light rather than electrical discharge.

OPTICAL RADIATION Ultraviolet, visible and infrared radiation (0.35-1.4 ?m) that falls in the region of transmittance of the human eye.

OPTICAL RESONATOR See Resonator.

OPTICALLY PUMPED LASERS A type of laser that derives energy from another light source such as a xenon or krypton flashlamp or other laser source.

OUTPUT COUPLER Partially reflective mirror in laser cavity which allows emission of laser light.

OUTPUT POWER The energy per second measured in watts emitted from the laser in the form of coherent light.

PHASE Waves are in phase with each other when all the troughs and peaks coincide and are "locked" together. The result is a reinforced wave in increased amplitude (brightness).

PHOTOCOAGULATION Use of the laser beam to heat tissue below vaporization temperatures with the principal objective being to stop bleeding and coagulate tissue.

PHOTOMETER An instrument which measures luminous intensity.

PHOTON In quantum theory, the elemental unit of light, having both wave and particle behavior. It has motion, but no mass or charge. The photon energy (E) is proportional to the EM wave frequency (v) by the relationship: E=hv; where h is Planck's constant (6.63 x l0(-34) Joule-sec).

PHOTOSENSITIZERS Chemical substances or medications which increase the

sensitivity of the skin or eye to irradiation by optical radiation, usually to UV.
PICOSECOND A period of time equal to 10-12 seconds.
PIGMENT EPITHELIUM A layer of cells at the back of the retina containing pigment granules.
PLASMA SHIELD The ability of plasma to shop transmission of laser light.
POCKEL'S CELL An electro-optical crystal used as a Q-switch.
POINT SOURCE Ideally, a source with infinitesimal dimensions. Practically, a source of radiation whose dimensions are small compared with the viewing distance.
POINTING ERRORS Beam movement and divergence, due to instability within the laser or other optical distortion.
POLARIZATION Restriction of the vibrations of the electromagnetic field to a single plane, rather that the innumerable planes rotating about the vector axis. Various forms of polarization include random, linear, vertical, horizontal, elliptical and circular.
POPULATION INVERSION A state in which a substance has been energized, or excited, so that more atoms or molecules are in a higher excited state than in a lower resting state. This is necessary prerequisite for laser action.
POWER The rate of energy delivery expressed in watts (joules per second). Thus: 1 Watt = 1 Joule x 1 Sec.
POWER METER An accessory used to measure laser beam power.
PRF Pulse Repetition Frequency. The number of pulses produced per second by a laser.
PROTECTIVE HOUSING A protective housing is a device designed to prevent access to radiant power or energy.
PULSE A discontinuous burst of laser, light or energy, as opposed to a continuous beam. A true pulse achieves higher peak powers than that attainable in a CW output.
PULSE DURATION The "on" time of a pulsed laser, it may be measured in terms of milliseconds, microsecond, or nanosecond as defined by half-peak-power points on

the leading and trailing edges of the pulse.
PULSE MODE Operation of a laser when the beam is intermittently on in fractions of a second.
PULSED LASER Laser which delivers energy in the form of a single or train of pulses.
PUMP To excite the lasing medium. See Optical Pumping or Pumping.
PUMPED MEDIUM Energized laser medium.
PUMPING Addition of energy (thermal, electrical, or optical) into the atomic population of the laser medium, necessary to produce a state of population inversion.
Q-SWITCH A device that has the effect of a shutter to control the laser resonator's ability to oscillate. Control allows one to spoil the resonator's "Q-factor", keeping it low to prevent lasing action. When a high level of energy is stored, the laser can emit a very high-peak-power pulse.
Q-SWITCHED LASER A laser which stores energy in the laser media to produce extremely short, extremely high intensity bursts of energy.
RADIAN A unit of angular measure equal to the angle subtended at the center of a circle by a chord whose length is equal to the radius of the circle.
RADIANCE Brightness; the radiant power per unit solid angle and per unit area of a radiating surface.
RADIANT ENERGY (Q) Energy in the form of electromagnetic waves usually expressed in units of Joules (watt-seconds).
RADIANT EXPOSURE (H) The total energy per unit area incident upon a given surface. It is used to express exposure to pulsed laser radiation in units of J/cm(2).
RADIANT FLUX RADIANT POWER - The time rate of flow of radiant energy. Units- watts. (One [1] watt = 1 Joule-per-second). The rate of emission of transmission of radiant energy.
RADIANT INTENSITY The radiant power expressed per unit solid angle about the direction of the light.
RADIANT POWER See Radiant flux.

RADIATION In the context of optics, electromagnetic energy is released; the process of releasing electromagnetic energy.

RADIOMETRY A branch of science which deals with the measurement of radiation.

RAYLEIGH SCATTERING Scattering of radiation in the course of its passage through a medium containing particles, the sizes of which are small compared with the wavelength of the radiation.

REFLECTANCE OR REFLECTIVITY The ratio of the reflected radiant power to the incident radiant power.

REFLECTION The return of radiant energy (incident light) by a surface, with no change in wavelength.

REFRACTION The change of direction of propagation of any wave, such as an electromagnetic wave, when it passes from one medium to another in which the wave velocity is different. The bending of incident rays as they pass from one medium to another (eg.: air to glass).

REPETITIVELY PULSED LASER A laser with multiple pulses of radiant energy occurring in sequence with a PRF greater than or equal to 1 Hz.

RESONATOR The mirrors (or reflectors) making up the laser cavity including the laser rod or tube. The mirrors reflect light back and forth to build up amplification.

ROTATING LENS A beam delivery lens designed to move in a circle and thus rotate the laser beam around a circle.

RUBY The first laser type; a crystal of sapphire (aluminum oxide) containing trace amounts of chromium oxide.

SCANNING LASER A laser having a time-varying direction, origin or pattern of propagation with respect to a stationary frame of reference.

SCINTILLATION This term is used to describe the rapid changes in irradiance levels in a cross section of a laser beam produced by atmospheric turbulence.

SECURED ENCLOSURE An enclosure. to which casual access is impeded by an appropriate means (e.g., door secured by lock, magnetically or electrically operated, latch, or by screws).

SEMICONDUCTOR LASER A type of laser which produces its output from semiconductor materials such as GaAs.

SERVICE Performance of adjustments, repair or procedures on a non routine basis, required to return the equipment to its intended state.

SOLID ANGLE The ratio of the area on the surface of a sphere to the square of the radius of that sphere. It is expressed in steradians (sr).

SOURCE The term source means either laser or laser-illuminated reflecting surface, i.e., source of light.

SPECTRAL RESPONSE The response of a device or material to monochromatic light as a function of wavelength.

SPECULAR REFLECTION A mirror-like reflection.

SPONTANEOUS EMISSION Decay of an excited atom to a ground or resting state by the random emission of one photon. The decay is determined by the lifetime of the excited state.

SPOT SIZE The mathematical measurement of the diameter of the laser beam.

STABILITY The ability of a laser system to resist changes in its operating characteristics. Temperature, electrical, dimensional and power stability are included.

STERADIAN (sr) The unit of measure for a solid angle.

STIMULATED EMISSION When an atom, ion or molecule capable of lasing is excited to a higher energy level by an electric charge or other means, it will spontaneously emit a photon as it decays to the normal ground state. If that photon passes near another atom of the same frequency, the second atom will be stimulated to emit a photon.

SUPERPULSE Electronic pulsing of the laser driving circuit to produce a pulsed output (250-1000 times per second), with peak powers per pulse higher than the maximum attainable in the continuous wave mode. Average powers of superpulse are always lower than the maximum in continuous wave. Process often used on CO(2) surgical lasers.

TEM Abbreviation for: Transverse Electro-Magnetic modes. Used to designate the cross-sectional shape of the beam.

TEM(oo) The lowest order mode possible with a bell-shaped (Gaussian) distribution of light across the laser beam.
THERMAL RELAXATION TIME The time to dissipate the heat absorbed during a laser pulse.
THRESHOLD The input level at which lasing begins during excitation of the laser medium.
TRANSMISSION Passage of electromagnetic radiation through a medium.
TRANSMITTANCE The ratio of transmitted radiant energy to incident radiant energy, or the fraction of light that passes through a medium.
TRANSVERSE ELECTROMAGNETIC MODE The radial distribution of intensity across a beam as it exits the optical cavity. See TEM.
TUNABLE LASER A laser system that can be "tuned" to emit laser light over a continuous range of wavelengths or frequencies.
TUNABLE DYE LASER A laser whose active medium is a liquid dye, pumped by another laser or flashlamps, to produce various colors of light. The color of light may be tuned by adjusting optical tuning elements and-or changing the dye used.
ULTRAVIOLET (UV) RADIATION Electromagnetic radiation with wavelengths between soft X-rays and visible violet light, often broken down into UV-A (315-400 nm), UV-B (280-315 nm), and UV-C (100-280 nm).
VAPORIZATION Conversion of a solid or liquid into a vapor.
VIGNETTING The loss of light through an optical element when the entire bundle of light rays does not pass through; an image or picture that shades off gradually into the background.
VISIBLE RADIATION (LIGHT) Electromagnetic radiation which can be detected by the human eye. It is commonly used to describe wavelengths which lie in the range between 400 nm and 700-780 nm.
WATT A unit of power (equivalent to one Joule per second) used to express laser power.
WATT/cm(2) A unit of irradiance used in measuring the amount of power per area of absorbing surface, or per area of CW laser beam.

WAVE An sinusoidal undulation or vibration; a form of movement by which all radiant electromagnetic energy travels.

WAVELENGTH The length of the light wave, usually measured from crest to crest, which determines its color. Common units of measurement are the micrometer (micron), the nanometer, and (earlier) the Angstrom unit.

WINDOW A piece of glass with plane parallel sides which admits light into or through an optical system and excludes dirt and moisture.

YAG Yttrium Aluminum Garnet; a widely used solid-state crystal which is composed of yttrium and aluminum oxides which is doped with a small amount of the rare-earth neodymium.

APPENDIX B. SUBJECT INDEX

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APPENDIX C. REFERENCES

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1. American National Standards Institute, 1986. AMERICAN NATIONAL STANDARD FOR THE SAFE USE OF LASERS: ANSI Z-136.1 (1986), Laser Institute of America: Orlando, FL.

2. Food and Drug Administration: PERFORMANCE STANDARD FOR LASER PRODUCTS, Center for Devices and Radiological Health, Food and Drug Administration (DHHS), Code of Federal Regulations (CFR), 50 (161): pp. 33682-33702, Tuesday, August 20, 1985.

3. American National Standards Institute, 1988. AMERICAN NATIONAL STANDARD FOR THE SAFE USE OF OPTICAL FIBER COMMUNICATION SYSTEMS UTILIZING LASER DIODE AND LED SOURCES: ANSI Z-136.2 (1988). Laser Institute of America: Orlando, Florida.

4. American National Standards Institute, 1988. AMERICAN NATIONAL STANDARD FOR THE SAFE USE LASERS IN THE HEALTH CARE ENVIRONMENT: ANSI Z-136.3 (1988). Laser Institute of America: Orlando, Florida.

5. Rockwell, R. J. 1986. LASER CONCEPTS, TISSUE INTERACTIONS, AND SAFETY PRACTICES. In: Complications of Laser Surgery of the Head and Neck, (M.P. Fried, J. H. Kelly and M. Strome, Editors). Year Book Medical Publisher, Inc.: Chicago, IL.

6. Rockwell, R.J. 1988. SAFETY PROCEDURES FOR Nd:YAG LASER SURGERY. In: Advances in Nd:YAG Laser Surgery. (S.N. Joffe and Y. Oguro, Editors). Springer Verlag: New York

7. Tolonen, S. L. 1987. LASER SAFETY IN THE OPERATING ROOM. In: Laser Applications in Neurosurgery. (R. Sawaya and J.M. Tew, Editors) State of The Art Reviews, Vol.2., No. 2. Haney & Belfus, Inc.: Philadelphia.

8. Rockwell, R.J., editor. 1987. LASER SAFETY IN SURGERY AND MEDICINE, (Second Edition) Rockwell Associates, Inc.: Cincinnati.

9. R. James Rockwell, Jr. 1986. FUNDAMENTALS OF INDUSTRIAL LASER

SAFETY. In: Industrial Laser Annual Handbook, edited by (M. Levitt and D. Belforte, Editors) pp. 131-148, Penn Well Books: Tulsa.
10. Laser Institute of America, Safety Information on Electrical Hazards, LASER NEWS, Laser Institute of America, 6(5): 8-14, 1984.
11. Rockstron, T. J., and Mazumber, J., 1987. SPECTROSCOPIC STUDIES OF PLASMA DURING CW LASER MATERIALS INTERACTION. J.APPL. PHYS. 61 (3):917-923.
12. Herziger, G., 1986. THE INFLUENCE OF LASER-INDUCED PLASMA ON LASER MATERIALS PROCESSING. In: Industrial Laser Annual Handbook. (M. Levitt and D. Belforte, Editors) Tulsa, Okla., Penn Well Books: Tulsa. pp. 108-115.
13. Doyle, Daryl and Kokasa, John, 1986. Laser Processing of Kevlar: Hazardous Chemical Bi-products, PROCEEDINGS OF ICALEO, Laser Institute of America: Orlando.
14. Doyle, D. J., and KoKosa, J. M. 1985. HAZARDOUS BY-PRODUCTS OF PLASTICS PROCESSING WITH CARBON DIOXIDE LASERS. In: Laser Welding, Machining and Materials Processing. (C. Albright, Editor.) Proceedings of ICALEO, IFS LTD.: Bedford, U.K., pp. 201-203.
15. Rockwell, R. James, Jr. and Moss, C.E. 1983. Optical Radiation Hazards of Laser Welding Processes Part I: Nd:YAG Laser, THE JOURNAL OF THE AMERICAN INDUSTRIAL HYGIENE ASSOCIATION. 44(8):572-579.
16. Rockwell, R. James, Jr. and Moss, C.E. 1989. Optical Radiation Hazards of Laser Welding Processes Part II: Carbon Dioxide Laser. THE JOURNAL OF THE AMERICAN INDUSTRIAL HYGIENE ASSOCIATION. 50(8)419-427.
17. Rockwell, R. James, Jr., Editor. 1989. LASER SAFETY TRAINING MANUAL. (6th Edition) Rockwell Associates, Inc.: Cincinnati.
18. R. James Rockwell, Jr. 1986. Analyzing Laser Hazards. LASERS AND APPLICATIONS, 5(5)97-103.
19. Sliney, David H. and Wolbarsht, Myron L. 1980 SAFETY WITH LASERS AND OTHER OPTICAL SOURCES. Plenum: New York.
20. Rockwell Laser Industries. LAZAN: LASER HAZARD ANALYSIS COMPUTER

PROGRAM. Rockwell Laser Industries: Cincinnati.
21. Rockwell, R. James, Jr. 1984. Ensuring Safety in Laser Robotics. LASERS AND APPLICATIONS, 3(11): 65-69.
22. National Institutes of Occupational Safety and Health, 1984. REQUEST FOR ASSISTANCE IN PREVENTING INJURY OF WORKERS BY ROBOTS. [DHHS(NIOSH) Publication No. 85-103], NIOSH: Cincinnati.
23. R. James Rockwell, Jr. 1986. Controlling Laser Hazards. LASERS AND APPLICATIONS, 5(9):93-99.
24. Laser Institute of America. 1989. GUIDE FOR THE SELECTION OF LASER EYE PROTECTION (2nd Edition), The Laser Institute of America: Toledo.
25. R. James Rockwell, Jr. 1989. Selecting Laser Eyewear, MEDICAL LASER BUYER'S GUIDE, Penn Well Books: Tulsa. pp: 84-92
26. Envall, K.R. and Murray, R., 1979. EVALUATION OF COMMERCIALLY AVAILABLE LASER PROTECTIVE EYEWEAR, DHEW Publication (FDA) 79- 8086.
27. R. James Rockwell, Jr. 1989. Laser Accidents: Are They All Reported and What Can Be Learned From Them? JOURNAL OF LASER APPLICATIONS, 53-57,.
28. Hardy, J.D., et al. 1956. Spectral Transmittance and Reflectance of Excised Human Skin. J. APPL. PHYSIOL. 9: 257-264.
29. Ham, W.T. Jr., Mueller, H.A., and Sliney, D.H. 1976. Retinal Sensitivity to Damage from Short Wavelength Light. NATURE. 260(5547):153-155.

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