Laser Safety Guide

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Laser Standards

In the United States there 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.

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-136.1 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.

Under the requirements of the Federal Laser Product Performance Standard: Title 21 of the Code of Federal Regulations; Part 1000; [parts: 1040.10 and 1040.11], 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. 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.

It is the responsibility of the owner/operator of a laser to effect the classification designation in cases where the laser or laser system classification is not provided or where the class level has changed because of alterations to the laser or laser system.

Laser Classification

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

The laser hazard classes are given as:

Class I: Cannot emit laser radiation at known hazard levels (typically CW: 0.4 μwatts 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 μW. 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 and 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.

Laser Hazard Evaluation

Laser Environmental Factors:

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

- The laser or laser system's ability to injure personnel.
- The environment in which the laser is used.
- 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 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:

- Number of lasers or laser systems.

- Degree of isolation (laboratory, production floor).
- Probability of the presence of uninformed, unprotected transient personnel.
- Permanence of beam path(s).
- Permanence of specularly reflecting objects in or near the beam path.
- The use of optics (e.g., lenses, microscopes, optical fibers).

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 should be assigned to a person with the requisite authority and responsibility, namely the Laser Safety Officer (LSO).

The LSO should 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 should 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 should be a designated LSO.

Standard Operating Procedure:

One of the most important control measures is the written standard operating procedure (SOP). The key to an effective SOP is the participation 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.

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. The following are considerations regarding operating personnel and those who may be exposed:

- General level of training and experience of the laser user(s), (that is, whether part time employees, scientists, etc.).

- Awareness of onlookers that potentially hazardous laser radiation may be present, and of relevant safety precautions.

- Degree of training in laser safety of all individuals involved in the laser operation.

- Reliability of individuals to follow control procedures.

- Number and location of individuals relative to the primary beam or reflections, and the potential for accidental exposure.

- Other hazards not due to laser radiation which may cause the individuals to react unexpectedly, or which influence the choice of personnel protective equipment.

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:

- Power or energy output.
- Beam diameter.

- Beam divergence.

- Pulse repetition frequency (prf).

- Wavelength.

- Beam path including reflections.

- Beam profile.

- Maximum anticipated exposure duration

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 (e.g., 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.

Control Measures

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.

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.

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:

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.

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, 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.

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. 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 to11.3 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.

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:

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). 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).

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). This sign is only posted during time when service is in progress.

Operated by Qualified and Authorized Personnel: This includes appropriate training of the individuals in aspects of laser safety training.

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.

Class IV Laser Controls - General Requirements:

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

- Supervised directly by an individual knowledgeable in laser safety.
- Require approved entry of any non-involved personnel.
- Terminate all potentially hazardous beams in a beam stop of an appropriate material.
- Use diffusely reflecting materials near the beam, where appropriate.
- Personnel within the laser controlled area are provided with appropriate laser protective eyewear.
- Secure and locate the laser such that the beam path is above or below eye level in any standing or seated position.
- 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.
- Require storage or disabling of lasers when not in use.

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:

- All personnel entering a Class IV area shall be adequately trained and provided proper laser protective eyewear.

- All personnel shall follow all applicable administrative and procedural controls.

- All Class IV area/entryway controls shall allow both rapid entrance and exit under all conditions.

- 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:

- 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.

- 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.

- 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.

Administrative and Procedural Controls:

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.

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.

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.

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.

Laser protective eyewear 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.

Engineering Control Measures for the Four Laser Classes:

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.

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.).

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.

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.

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.

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).

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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 µm 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 μm 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.

Selecting Laser Eyewear:

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.

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.

Laser Output Factors:

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.

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 µm may emit about 2 watts at the green wavelength while the Nd:YAG laser itself (operating at 1.064 µm 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 µm 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").

Because of the logarithmic factor, a filter attenuating a beam by a factor of 1,000 (or10(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.

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.

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.

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.

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.

Plastic - Versus - Glass:

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.

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.

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.

Laser Training:

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.

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.

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.

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.

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.

ACCESSIBLE EMISSION 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 µm).

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 µm (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 whichdoes 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 μm. These wavelengths are often broken up into regions: IR-A (0.7-1.4 μm), IR-B (1.4-3.0 μm) and IR-C (3.0-1000 μm).

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 distributedacross 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 (approximately10-12 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 toobservers.

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 actionoccurs.

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 μm) 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.