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STEC PAMPHLET - 23

HAZARDS FOR NON-IONISING RADIATION & SAFE WORKING PRACTICES

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PREFACE

This document enumerates hazards of electromagnetic radiation of non-ionisation type, mainly, microwaves and lasers on human beings. All safety officers and other responsible persons working in Defence must be aware of the existence of potential electromagnetic radiation hazards and their effects on the performance of humans and various field equipment.

This document gives guidelines and safe working practices to be followed by personnel involved in design, manufacture or operation of the systems that produce or may be subjected to these radiation hazards. Taking into account the adverse biological effects of these radiations, international bodies have issued guidelines on limits of exposure to them. These guidelines give an insight into severity of various types of hazards and possible consequences of excessive radiation exposure to these radiations. To ensure safety of personnel, a worker should follow the instructions contained in this pamphlet.

It is hoped that users will find this revised STEC Pamphlet 2025 simpler, easier to understand and implement, thereby promoting the safe storage and transportation of military explosive. This publication supersedes STEC Pamphlet, 2017 on the subject.

PART – 1

INTRODUCTION

GENERAL

1. Non-ionising radiation emit photon with energy less than 12.4 eV (wavelength, λ = 100 nm and frequency ν = 3x1015) and are not capable of producing ionisation in a biological system. Microwave and laser radiations are most important from the point of view of their use in defence. Microwaves or radiofrequency electromagnetic fields are utilised not only in radars for surveillance, fire control and navigation but also in weapon guidance, communications, electronic counter measures etc. Similarly, lasers are used in satellite communication, weapon guidance, surveying, holography, symbol recognition etc. These non-ionising radiations are unperceived by any of the human senses unless their intensity becomes so great that it is felt as heat and at that intensity sufficient damage to the human system occurs. International Commission on Non-ionising Radiation Protection (ICNIRP) of International Radiation Protection Association (IRPA) has issued guidelines on limits of exposure for these radiations taking into account the adverse biological effects of these radiations. Several International bodies like American National Standards Institute (ANSI), Occupational Safety & Health Administration (OSHA), American Conference of Government & Industrial Hygienists (ACGIH) and National Radiological Protection Board (NRPB) have also established the guidelines for safe working practices.

2. Electromagnetic radiation, (“EMR”), is a form of energy composed of both electric and magnetic field components, which travels through space at the speed of light. The electric and magnetic field components are perpendicular to each other, and to the direction of travel or propagation (Fig. 1). The electric (“E”) and magnetic (“H”) fields vary sinusoid ally in both time and space. The rate at which the fields vary is called their frequency, and the distance travelled during one complete sinusoidal cycle is called their wavelength. EMR includes a wide variety of radiation forms including radio and television signals, microwaves, infra-red, ultraviolet, X-rays, etc. While all of these obey the same fundamental physical laws, they differ markedly in their physical properties due to their different wavelengths. Fig. 2 gives the complete electromagnetic spectrum with frequency bands and their characteristics name and Fig. 3 gives the standard radar’s frequency bands.

3. The frequency and wavelength of EMR in space are mathematically related: the frequency times wavelength equals the speed of light i.e. 300 million meters per second. The units of frequency, which is a measure of the number of times the electric and magnetic fields completes a full cycle each second, is expressed in Hertz (“Hz”) after Heinrich Hertz, a 19th century physicist who worked on electromagnetic phenomena. The many different frequency bands commonly used in communication and industrial applications are often referred to by names and letters. Some of these names and letters are given in Table 1.

SCOPE

4. This pamphlet deals with microwave radiation and laser radiation, which are dealt in separate parts: Part-I deals with the "Hazards from microwave radiation" and Part-II gives "Hazards from laser radiation". The guidelines on limits of exposure from these radiations and safe working practices to be followed by an individual worker or planner are also given. These guidelines give the reader an insight into severity of various types of hazards or possible consequences of excessive exposure to these radiations.

PART – 2

HAZARDS FROM MICROWAVE RADIATION

GENERAL

5. Natural sources of non-ionizing electromagnetic radiation include the sun and the other bodies in space and typically pose no risk to the human body as the levels are very low. Hazardous levels of EMR typically arise from man-made sources such as radio transmitters, microwave ovens, or industrial process equipment. The radiofrequency electromagnetic radiation covers the frequency range from 100 kHz to 300 GHz. The part of the frequency range 300 MHz to 300 GHz is often referred to as microwave radiation (MW). This part deals with the hazards from radiofrequency electromagnetic radiation, which includes microwave radiation also.

BIOLOGICAL EFFECTS OF MICROWAVE RADIATION

6. The biological effects of microwave radiation can be viewed as the net result of radiant energy absorption and direct interference with biophysical, biochemical and bioelectrical consider the interaction of the electric and magnetic components of the electromagnetic waves with biological tissues. The magnetic permeability of the tissues can be taken as nearly 1 i.e. they are practically transparent to magnetic field and there is no absorption of energy as a result of magnetic interactions. The interaction of the electric component produces oscillation of free charges or ions and rotation of dipole molecules. This increased kinetic energy is rapidly converted to heat and the interaction process is thermal. Another effect of microwaves is due to direct action of electric field with tissues leading to altered cell membrane permeability and the process is non-thermal or athermal.

7. Biological effects of microwaves covers a wide range i.e. thermal sensation, cellular effects, effects on the eye, testes, hearing, blood & immune system, reproductive system, cardiovascular system, neuron-endocrine system, nervous system and behavior. Most of the observed effects are primarily caused by heating. On exposure to microwaves, body temperature of irradiated animal starts increasing. This stimulates thermo-regulatory processes which try to maintain thermal equilibrium, but eventually, due to thermoregulatory insufficiency, a critical temperature is reached and death occurs. The intensity of hyperthermia is affected by a number of parameters like (i) biological specificity of the species, (ii) power density, (iii) environmental conditions, (iv) nature of microwave radiation viz. pulsed or continuous and (v) size of the target in relation to the wavelength. Some of these effects are discussed below:-

   (a) **Thermal sensation**. The threshold of thermal sensation varies with the frequency of microwaves. One can feel the warmth in a few seconds of exposure to microwave radiation with power density of 130 Wm^{-2} at a frequency of 10 GHz. But at lower frequencies much larger power densities are required because energy is absorbed preferentially in deeper seated tissues.

(b) **Ocular effects**. The threshold exposure for cataract formation is about 1800 Wm^{-2} applied for periods of more than one hour, which corresponds to specific absorption rate of 30 Wkg^{-1} Whether long-term exposure to low levels of microwave radiation can lead to cataract formation in human subjects is still debatable, although a few workers have reported statistically significant increase in cataract due to thickening of lens posterior capsule, a defect which is difficult to be differentiated from senile cataract due to ageing.

(c) **Hearing effect**. Some people exposed to pulsed microwave radiation are able to perceive a buzzing or clicking sound to pulsed repetition frequency at a relatively small power density (as low as 0.1 $mWcm^{-2}$). This energy is capable of increasing the tissue temperature by only 5x 10^{-60}C. The electromagnetic radiation causes rapid temperature increase which causes thermo-elastic expansion of the brain tissue, creating an acoustic pressure that is detected in the cochlea of ear. This may be responsible for some of the observed behavioral changes in animals exposed to microwave radiation.

(d) **Hematological& Immune system**. Effects on the hematological and immune systems have been observed at the average SAR > 0.5 W/kg. Chronic exposure to continuous as well as pulsed microwaves at 300 MHz at 50-70 Wm^{-2} daily for 3 hours led to an increase in lymphocyte counts in exposed animals, which return to normal levels on cessation of exposure.

(e) **Effect on genetics and fetal development**. No serious effect on genetics is observed at power densities below 100 Wm^{-2}. At higher power densities low sperm count in males and decreased fertility in females have been reported. Irradiation at early stages of pregnancy to RF exposure above 2 W/kg may lead to a decreased fetal weight.

(f) **Behavioral effects**. Behavioral disruption occurs at the RF energy deposition rates between 25% to 50% of the resting metabolic rate of the animal and these changes are reversible with time. RF radiation has been shown to alter the effect of drugs which can influence the central nervous system. Retarded learning has been observed in rats exposed to 2.45 GHz pulsed radiation at a whole body average SAR of 0.6 W/kg.

(g) **Carcinogenic effects**. Long-term low-level microwave radiation exposure has been found to cause no statistically significant increase in neo plastic lesions in rats. However, microwave exposure at 2450 MHz SARs, from 2 to 8 W/kg of mice treated with a chemical carcinogen applied either to the skin or to the mammary gland resulted in an accelerated tumor development. The various studies shows that microwave radiation may not be a cancer initiator but a cancer promoter.

(h) **Relationship of the physical size to wavelength**. The maximum absorption in adult man of 1.7 meters occurs at about 70-80 MHz and this frequency is referred to as resonant frequency for man. At this frequency, the power absorbed is a few times greater than that obtained by multiplying the surface area of the body cross-section by the incident power density. For a man standing in contact with RF ground, the resonant frequency shifts to about 30-40 MHz and specific absorption rate (SAR) increases by about a factor of two. At low frequencies below the resonance, the penetration (skiing) depth is greater than the body dimensions. At frequencies higher than about 10 GHz, the skin depth is of the order of a few cm. only. Non-uniform distribution of absorbed power may lead to formation of 'hot spots' and may cause a variety of secondary interactions. The formation of hot spots in brain and lung in the frequency region 400-2000 MHz or even up to 300 MHz is possible and may explain the occurrence of headache in microwave radiation workers.

POWER DENSITY MEASUREMENT

8. The radiation from an antenna has to be worked out for different regions, i.e. Near-field region and far-field region. The near-field region or Fresnel region extends out to a distance or 2-3 wavelengths from the antenna and in this region the E and H field have not established their correct phase relationship. The far-field region extends beyond the near-field region to infinity. The power density at a distance, d is give by

$$S = \frac{P_t\, G}{4\,\Pi\, d^2}$$

Where S = Power density at a given point in mW/cm^2
G = Transmitted antenna maximum far-field gain
P_t = Average power transmitted in mW fed to the antenna
d = Distance for antenna

The equation does not include the effects of ground reflection. For vertical polarization the grazing angle φ is limited as follows:

at 100 MHz $\varphi = 1^0$ where H_t = antenna height above ground
at 500 MHz $\varphi = 5^0$ where H_p = height of point P from ground
$\varphi = \tan^{-1} [(H_t + H_p)]$ where z = distance of point P from antenna
As frequency increases, the allowable grazing angle increases.

9. In the Fresnel region antenna gain and pattern are no longer constant, with both parameters being functions of the distance from the antenna. On-axis power densities for special antenna structures may be calculated using reference RADHAZ documents or equipment manuals.

(i) As an example to work out the microwave power density at a distance of 10 m on the x-axis of the antenna of a radar having a peak power output of 35 kW (35×10^6 mw), gain 26 db ($10^{2.6}$) and frequency range 9375 ± 30 MHz can be computed by using the above formula as under:

$$S = \frac{35 \times 10^6 \times 10^{2.6}}{} = 11.1\ mW/cm^2$$

$$4 \pi (10 \times 10^3)^2$$

(ii) Alternately, one can work out the distance at which the microwave power density is 5 mW/cm^2, the exposure limit for occupational workers. Some typical values of distance along the center of the beam for different radar systems are as under:

(a) For a 2 MW Search Radar the field strength of 10 mW/cm^2 extends to a distance of 65 m.

(b) For 5 MW Height Finder Radar the field strength of 10 mW/cm^2 extends to a distance of 144 m at -20 tilt.

(c) For a 500 kW Search Radar the field strength of 10 mW/cm^2 extends to a distance of 152 m.

(d) In radars using the V-beam techniques the fields strength of 10 mW/cm^2 extends to a distance of 61 m along the center of the beam. However, the field strength of 10 mW/cm^2, when the antenna is placed on a 3 m ramp, extends to only 6.2 m, at a height of 2.1 m above the ground.

EXPOSURE LIMITS FOR RF RADIATION

10. Exposure limits are the limits of radiation exposure at which an individual is protected against direct physical hazards as well as adverse biological effects. The exposure limits are given by International Non-ionizing Radiation Protection Committee of the international Radiation Protection Association (IRPA/INRIC) for occupational workers and members of the public. American National Standards Institute (ANSI) and National Radiological Protection Board (NRPB) of UK have also given exposure limits for occupational workers and members of the public separately. The occupationally exposed workers are adults exposed under controlled conditions, and who are trained to be aware of potential risks and to take appropriated precautions. The duration of exposure is limited to the duration of the working day which is normally assumed to be 8 hour per day. The general public consists individuals of all age groups including pregnant women, children and infants; they are not aware of any exposure and may be unwilling to take risks (however slight) associated with exposure. The general public can be exposed 24 hours per day and they are not expected to take precautions against RF shocks and burns. Hence the exposure limits should be low enough so that RF shocks cannot occur.

OCCUPATIONAL

11. Occupational exposure to RF radiation at frequencies below and up to 10 MHz should not exceed the levels of unperturbed RMS electric and magnetic field strengths as given in Table2, when the squares of the electric and magnetic field strengths are averaged over any 6-min period during the working day, provided that the body to ground current does not

exceed 200 mA, and hazards to RF burns are eliminated as per recommendations given paragraph 16.

12. Occupational exposure to frequencies above 10 MHz should not exceed a SAR of 0.4 W/kg when averaged over any 6-min period and over the whole body, provided that in extremities (hands, wrists, feet and ankles) 2 W per 0.1 kg shall not exceeded and that 1 W per 0.1 kg shall not be exceeded in any other part of the body. These limits apply to whole body exposure either from continuous or modulated electromagnetic fields from one or more sources, averaged over any 6-min period during the working day (8 hours per 24 hours).

13. In case of the near filed, a complex phase relationship between the magnetic and electric field components exists, it is possible that exposure may be predominantly from one of these components, and in extreme cases from the magnetic or electric field alone. The limits for magnetic and electric field strengths indicated in Table 2 for frequencies above 10 MHz may be exceeded for the case of near field exposure, provided that:

$$5/6(E^2/120\pi) + 1/6(120\pi H^2) \leq P_{eq},$$

where E is the field strength (V/m), H is the magnetic field strength (A/m), and P_{eq} is the equivalent plane wave power density limit (W/m^2) from Table 2, and the SAR limits of occupational exposure, averaged over any 6-min period, are not exceeded. The above formula may be applied in practical situations to the case of near field exposure in the frequency range from 10 MHz to 30 MHz, in rare instances up to 100 MHz.

GENERAL PUBLIC

14. Exposures of the general public to RF radiation at frequencies below and up to 10 MHz should not exceed the levels of unperturbed root mean square (RMS) electric and magnetic field strength given in Table 3, provided that any hazards of RF burns are eliminated according to the recommendations given in paragraph 16.

15. Exposures of the general public to frequencies above 10 MHz should not exceed a SAR of 0.08 W/kg when averaged over the whole body and over any 6-min period. These limits apply to whole body exposure from either continuous or modulated electromagnetic fields from one or more sources, averaged over any 6-min period during the 24-hour day.

RF SHOCKS AND BURNS

16. RF shocks would normally produce effects ranging from inconvenience to severe burns to tissue, situations could arise where such shocks and burns result in accident situations having more serious consequences. It is not feasible to predict or prescribe protection strategies against RF burns since much depends on actual configurations and conditions. RF shocks and burns can result from touching ungrounded metal objects that have been charged up by the field from contact of a charged up body with a grounded metal object. Ifthe current at the point of contact exceeds 100 mA, there is a risk of burns. The maximum induced and

contact radiofrequency currents for occupational workers and members of general public are given in Table 4.

SAFE WORKING PRACTICES FOR RF RADIATION

17. Every effort should be made to protect personnel from harmful exposure to RF radiation and it is mainly achieved by keeping the personnel clear of hazardous intensity levels and following certain precautions, which are given below:-

(a) Area in which RF power density in excess of 1 mW/cm^2 is suspected or detected will be considered potentially hazardous area. These areas should be appropriately posted by with warning signs. Periods of exposure in these areas should be kept to an absolute minimum to commensurate with proper maintenance and operations.

(b) Where test procedures require free space radiation, the radiating device should be positioned to avoid directing the energy beam towards inhabited areas, or other personnel groupings. In the positioning of such radiating devices, care should be taken to avoid reflecting structures either the primary beam or secondary lobes in such a manner as not to expose personnel in adjacent areas.

(c) The practice of discharging, under test, the RF output of high power generators which produce average power levels of 1 mW/cm^2, or more, into the surrounding areas should be discouraged. Dummy loads, or other absorptive materials should be used to absorb the energy output of such equipments while being operated or tested.

(d) Visual inspection of open ends of waveguides, feed horns and any opening emitting RF electromagnetic energy should not be made unless the equipment is secured for the purpose of such inspection.

(e) Aircraft employing high-power radars should be oriented so that if the radar is energised, the beam is directed away (or into absorbent chambers) from personnel working areas.

(f) The elevation of radar antennas should be above working zones and there should be provision of appropriate interlocks on antenna elevation and azimuth so as to prevent pointing antenna at populated areas.

(g) The antenna should be located in a fenced area to ensure safe levels outside the fenced areas.

(h) All RF radiation workers should be familiarized with the local safety procedures or codes of safe practice.

(i) Surveys should be conducted in all installations or on all devices likely to emit RF radiation above accepted levels. The survey reports should be retained and includes details of the exposure conditions, and in cases where exposure limits are exceeded, indications of ways and means for reducing levels. Recommendations for reduction of exposures to acceptable limits should be implemented as soon as possible.

(j) Ensure that operational procedures are such that the used of personnel protective devices (special eye/head protectors, clothing) is a last resort.

(k) Person with pace-makers or other metallic implants should not be allowed to enter RF field.

SITING OF RF EMITTING DEVICES

18. For siting a microwave emitting device, it is necessary to determine the use and occupancy of surrounding areas. The microwave devices should be sited away from populates area and in case it is not achievable, the elevation of the antenna should be such that people living nearby do not get any excessive radiation exposure. For the same reason, such devices should be away from high rise buildings. When a microwave emitting device like radar is located on the ground in an open space, the height of the antenna should be such that the person can walk around the permitted area of the site. For this, personal clearance height of 2.5 m is recommended. Safe routes for human access may be properly laid down and marked. There should be flash lights on the radiation antennas to warn the people and RF operators that the RF system is switched on. Following installation of RF system, analytical estimates of the distribution of e.m. fields should be verified by empirical measurements. Zones may be clearly marked with appropriate warning signs. Barriers may be used to restrict access to the areas where the RF field may exceed 1 mW/cm^2.

PART – 3

HAZARDS FROM LASER RADIATION

GENERAL

19. Lasers are used for alignment, welding, micro-machining, and sealing, spectrophotometer, interferometer, fiber optics communication systems, and surgical removal or repair procedures. In defence, lasers are used in satellite communication, weapon guidance, surveying, holography, symbol recognition etc. The biological effects of exposure to laser radiation depend upon the type of laser beam, the wavelength, the output power, the beam divergence, and the pulse repetition rate. The primary hazard from laser radiation is exposure to eyes and to a lesser extent to the skin.

BIOLOGICAL EFFECTS OF LASER RADIATION

20. The eye and skin are critical organs for laser radiation exposure. The type of effect, injury thresholds, and damage mechanisms vary significantly with wavelength. In general, the consequences of over-exposure are more serious than that of the skin. For understanding the biological effects, the optical radiation spectrum has been divided into seven spectral regions as shown in Table 5. The biological effects in different spectral regions are discussed below:

(a) Ultraviolet radiation (UVR) effects. Short wavelength UV-B and UV-C radiation is absorbed within the cornea and conjunctiva, whereas UV-A is absorbed largely in the lens. Exposure to "actinic" UV (UV-B and UV-C) laser radiation may lead to the acute effects of erythematic (reddening of the skin) and photo-keratitis (corneal inflammation) and conjunctivitis. UV-A thermal injury to the skin or to the lens and cornea has not been reported for exposure durations greater than 1ms. The peak sensitivity for photo-keratitis is around 270 nm with a decrease in action spectrum in either direction. The peak of erythematic action spectrum varies from 200 to 300 nm depending upon the definition of the degree of severity and the time of assessment of the effect. In the actinic-UV region, the cornea is not substantially more sensitive than untanned light pigmented skin; damage to the cornea is much more disabling (and painful) than injury to the skin. Although UV-A is absorbed more heavily in the lens, it is UV-B radiation which is primarily responsible for cataract formation.

(b) Visible and IR-A radiation. In the visible and IR-A regions (400-1400 nm) the retina is primarily affected. This is due the transparency of the ocular media and to the inherent focusing properties of the eye. The focusing properties in this spectral region render the retina much more susceptible to damage than any other part of the body. Most of the radiation that reaches retina is absorbed by the retinal pigmented epithelium and by underlying choroid (which supplies blood to much of the retina). The photo-pigments in the retina absorb only a small fraction of the incident radiation – perhaps less than 15 percent.

(c) Infrared radiation (IR-B and IR-C). In the IR-B and IR-C regions of the spectrum (> 1,4μm), the ocular media becomes opaque as a result of the strong absorption by the water component, a major constituent of all biological tissue. Thus the damage in this infrared region is primarily to the cornea, although lens damage has also been attributed to infrared radiation at wavelengths below 3 μm (IR-A and B). The infrared damage mechanism appears to be thermal, at least for exposure duration greater than 1 μs. For shorter pulse durations the mechanism may be thermo-mechanical. In the IR-C region, as in ultraviolet, the threshold for damage to the skin is comparable to that of the cornea. Nevertheless, the damage to the cornea will be of greater concern because of the adverse impact upon vision.

21. Biological effect will depend on Irradiance (W/m^2), radiant exposure (J/m^2), exposure duration and wavelength. These interactions can take four main forms: photochemical, thermal, thermo-acoustic and multiphoton-dependent and non-liner processes such as optical breakdown. The health hazards to the skin are both acute (thermal burns, sunburns, photo-sensitized reactions) and chronic (accelerated ageing and photo-carcinogenesis). The main health hazards to the eye are photo keratitis, cornel burns, photochemical and thermal cataract, ocular inflammation, and photochemical, thermal & thermo-acoustic retinal injury and optical breakdown within the eye. Secondary haemorrhage in the vitreous humor with complete loss of vision could be produced by severe damage to the retina.

HAZARD CLASSIFICATION OF LASERS

22. Lasers are classified into four classes, based on the light output and certain characteristics specified for each class and output's ability to injure personnel. The four classifications are as follows:

(a) Class I: Power output 0.4 milliwatt or less. No known biological hazard. The light is shielded from any possible viewing by a person and the laser system is interlocked to prevent the laser from being on when exposed. The laser systems in this category are not hazardous and are also called 'non-risk' lasers.

(b) Class II: Power 0.5 to 1 milliwatt. These lasers are not considered a optically dangerous device as the eye reflex will prevent any ocular damage. Eye damage if viewed directly for than 0.25 seconds intentionally, otherwise eye reflex will prevent any ocular damage. No known skin exposure hazard exist and no fire hazard exist. The laser systems in this class fall under the category of 'low risk' lasers.

(c) Class III a: Power output between 1 milliwatt to 5 milliwatt. These lasers can produce spot blindness under the right conditions and other possible injuries. No known skin or fire hazard exist. The laser systems in this class fall under the category of 'moderate risk' lasers.

(d) Class III b: Power output from 5 milliwatts to 500 milliwatts. These lasers are considered a definite eye hazard, particularly at higher power levels, which will cause eye damage. Skin may be burned at the higher levels of power output an some material with lower flash point may catch fire. These laser systems also fall under the category of 'moderate risk' lasers.

(e) Class IV: Power output >500 milliwatts. These lasers can and will cause eye damage. These lasers can cause materials to burn on contact as well as skin and clothing to burn. The reflected beam should be considered as dangerous as the primary beam. The high power lasers present the most serious of all laser hazards. The lasers in this category are called 'high risk' lasers.

EXPOSURE LIMITS FOR LASER RADIATION

23. Extensive studies on the biological effects of laser radiation were used to establish a rationale for exposure limits also called 'Maximum Permissible Exposure' (MPE). Levels at the MPE values given may be uncomfortable to view. Thus, it is good practice to maintain exposure levels as far below the MPE values as is practicable. The derivation of exposure limits required a careful analysis of the physical and biological variables that most affected reported biological data, including individual susceptibility, the increase in severity of injury for supra-threshold exposure dose, the possibility of unknown narrow-band absorption in biological molecules, the effect of eye movements, the actual mechanism of injury, and the reversibility of damage. Additional considerations were the accuracy of available radiometric instruments and desire for simplicity in expressing exposure limits. A safety factor is incorporated into exposure limits to preclude acute injury or minor effects that could give rise to delayed effects. The exposure limits are intended to provide an adequate margin of protection against significant or subjectively detectable acute injury. As per the principles of risk analysis, safety factors were generally largest where fewer experimental data were available.

Spectral considerations

24. The exposure limits for UV lasers are very similar to those for non-laser UV radiation. Because of the uncertainty regarding the actual action spectra for photo-keratitis and lenticular cataract genesis in the spectral region 300-315 nm, slightly more conservative exposure limits for UVB lasers than for non-laser sources were proposed.

25. Injury thresholds for both the cornea and the retina vary considerably with wavelength, and it seems acceptable to adjust the exposure limits for different wavelengths in a simple manner than that the biological data might indicate; which is accounted by making due allowance for spectral effectiveness by incorporating suitable correction factors.

26. At ocular exposure duration exceeding 10 s, short wavelength radiation causes photochemical retinal injury. The difference between the ocular exposures limits for short (less than 550 nm) and longer (550-700 nm) visible wavelengths therefore increases with greater exposure duration up to 10,000 s. It is taken into account by incorporating a wavelength correction factor, which adjust for this change in retinal sensitivity with wavelength.

Multiple wavelengths

27. For laser exposures with several different wavelengths, the exposures are considered to be additive where the same tissue (e.g. the cornea) is the site of absorption. The simultaneous exposure to pulses and CW radiation is not strictly additive but may be synergistic.

Point sources and extended sources

28. In the spectral region 400-1400 nm i.e. the 'retinal hazard region', the ocular exposure limit depends upon the viewing condition. In physiological optics it is customary to distinguish between a 'point source' and an 'extended source'; in the contest of laser safety, however exact geometrical definitions are not possible. Small sources often fall into the category of 'point source' because of retinal heat flow and eye movements which distribute the focal energy over larger retinal areas for increasing exposure duration. 'Extended source' conditions apply to sources that subtends a visual angle at the eye greater than 1 alpha-min' (α_{min}), which has a value of 1.5 mrad for pulsed lasers. Because of eye movements, α_{min} varies with exposure duration greater than 0.7 s. Exposure limits for large extended sources at angles greater than 0.1 rad can be described with different units like radiance (W m^{-2}) and integrated radiance (J m^{-2} sr^{-2}). The quantities of irradiance (W m^{-2}) and radiant exposure (J m^{-2}) are used for point-source exposure limits, and may also be used for smaller extended sources with angular subtended $\alpha < 0.1$ rad (i.e., $<5.7^0$).

EXPOSURE LIMITS FOR LASER RADIATION

29. The exposure limits should be used as guidelines for controlling human exposure to laser radiation. They should not be regarded as thresholds of injury or as sharp demarcations between 'safe' and 'dangerous' exposure levels. Exposure at levels below the Els should not result in adverse health effects. The International Commission on Non-ionizing Radiation Protection (ICNIRP) of The International Radiation Protection Association (IRPA) has given the guidelines on limits of exposure to laser radiation, which are summarized. Several other National bodies like American National Standards Institute (ANSI), Occupational Safety & Health Administration (OSHA), National Radiological Protection Board (NRPB) has given guidelines on exposure limits to laser radiation, which do not differ significantly from the one given by ICNIRP.

Exposure limits for some typical lasers

30. Table 6 gives the intra-beam exposure limits for eye and skin exposure to some common CW lasers.

31. These exposure limits are applicable to the general population; however, some rare photosensitive individual may react to UV laser exposures below these limits. Such individuals should take more rigorous precautions to avoid exposure to UV laser radiation. These exposure limits from 300 to 400 nm do not apply to infants or to aphakic individuals. Further, these limits are not applicable in case of medical treatment by lasers.

SAFE WORKING PRACTICES FOR LASER RADIATION

32. The most effective means of controlling laser hazard is total enclosure of the laser and all beam paths. For conditions where this is not possible, partial beam enclosure, laser eye protectors, restricted access to beam paths, and administrative controls may be necessary. Different eye protectors have to be used for different wavelength operation of the same system. In some laser operations, control measures are necessary for electrical and fire hazards, X-rays, noise and air-borne contaminants. Any laser hazard evaluation is based on information about parameters like output level, divergence of the beam, exposure duration, pulse repetition frequency, pulse duration, beam geometry, and characteristics of any reflecting surfaces.

33. Each laser system, regardless of its class, should be provided with a safety interlock for each portion of the protective housing which is designed to be removed or displaced during operation of maintenance, if the removal or displacement of that portion of the protective housing could permit access to laser radiation in excess of prescribed exposure limits.

34. Each laser system classified as a Class III or Class IV laser should incorporate a key actuated master control. The key should be removable and the laser should not be operable when the key is removed.

35. Each laser system classified as a Class II, III, or IV laser should be provided with a non-laser visible light or audio indicator to warn that the laser system is on and it is emitting laser radiation.

36. All Viewing optics, Viewports, and Display Screens incorporated into the laser product, regardless of the class, should attenuate at all times the accessible levels of transmitted laser. Radiation to less than the prescribed exposure limits.

37. Each Class II laser should have affixed a label bearing the word “CAUTION”, the laser outburst, and the following wording above the sunburst, the words “LASER RADIATION DO NOT STARE INTO BEAM”, under the sunburst the wavelength and the maximum output in mW. Laser hazard sign should be put both in the laboratory and on the door at all times the laser is in operation.

38. Each Class III laser should have a label affixed bearing the word “DANGER”, the laser sunburst, and above the tail of the sunburst, the words, “LASER RADIATION AVOID EXPOSURE TO BEAM”. The laboratory door should be pasted with a laser sign bearing the word “DANGER”, the laser sunburst, the words “DO NOT STARE INTO BEAM” and “DO NOT VIEW WITH OPTICAL INSTRUMENTS” and the type of laser. The following are several safety precautions for operating Class III lasers:

    (a) Never aim the beam at any person (especially at their eyes).
    (b) Enclose as much of the beam path as possible.
    (c) Avoid placing the unprotected eye along or near the beam.
    (d) Terminate the primary and secondary beams if possible at the end of their useful paths.
    (e) Use beam shutters and laser output filters to reduce the beam power to less hazardous levels when the full output power is not required.

(f) Attempt to keep laser beam path above or well below either sitting or standing person's eye level.
(g) Eye protection devices should be used when engineering and procedural controls are inadequate to eliminate potential exposure above the prescribed exposure limits.

39. Each Class IV Laser should have affixed a label bearing the danger symbol and laser sunburst. Above the tail of the sunburst the words "LASER RADIATION OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION" are used. The following are several safety precautions for operating Class IV lasers:

(a) The entire beam path including the target area 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 should be designed so as to prevent firing of the laser by dumping the stored energy into a dummy load.

(b) Eye Protection Devices which are designed for protection against radiation from the specific laser system, should be used when engineering the procedural controls are unable to eliminate potential exposure in excess to prescribed exposure limits.

(c) Whenever possible, the laser system should be fired and monitored from remote locations.

(d) An alarm system like an audible sound or non-laser warning light, visible through protective eyewear should be used prior to laser activation. The system should be provided with an operative keyed master interlock or switching device. The key should be removable and the device should not be operable when the key is removed.

40. The following general precautions may be observed to minimize the exposure to laser radiation:-

(a) Personnel should not look into the primary beam or at spectular reflections of the beam, unless necessary, even if the exposure limit is not exceeded.

(b) The laser operator should be familiar with the type of laser used and act responsively.

(c) Laser optical systems should be aligned in such a manner that the primary beam, or a spectular reflection of the primary beam, cannot result in an ocular exposure above the exposure limit.

(d) For non-visible laser beams, extra vigilance is necessary to ensure that the beam path is properly postulated and this may entail continuous environmental monitoring.

(e) All personnel working with high voltage and/or current should be trained in cardiopulmonary resuscitation (CPR) and a CPR instruction chart should be conspicuously posted.

PART – 4

GLOSSARY

Absorption. Transformation of radiant energy to a different form of energy by interaction with matter.

Accessible Emission Limit (AEL). The maximum accessible emission level permitted within a particular class.

Accessible Radiation. Radiation to which it is possible for the human eye or skin to be exposed in normal usage.

A thermal Effect. Any effect of electromagnetic radiation exclusive of the production of heat.

i.

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 or bright light. It can occur within 0.25 S, including the blink reflex time.

Coherent Beam. A light beam is said to coherent when the electric vector at any point in it is related to that at any other point by a definite, continuous function.

Conjunctivae discharge. Increased secretion of mucus from the conjunctivae surface of the eye.

Continuous wave (CW). The output of a laser which is operated in a continuous rather than a pulsed mode. In this standard, a laser operating with a continuous output for a period > 0.25 s is regarded as a CW laser. In microwave, a continuous wave is essentially a single frequency wave.

Cornea. The transparent anterior portion of the human eye which covers the iris, pupil and the crystalline lens. The cornea is the main refracting element of the eye.

Dose equivalent. The dose equivalent is numerically equal to the dose in rads weighted by the appropriate weighting factors like quality factor (which accounts for different types of radiation), dose distribution factors etc. The unit of dose equivalent is Sievert (Sv)

1 Sv = 1 J/kg = 100 rem

Effective field strength. It is obtained by adding the squares of the vertical and the horizontal components and taking the square root of this sum; with relation to time, the root mean square (RMS) of each component (electric and magnetic) is utilized. Units of E_{eff} and H_{eff} are V/m and A/m, respectively.

Electromagnetic radiation. The flow of energy consisting of orthogonally oscillating electric and magnetic fields lying perpendicular to the direction of propagation. X-rays, ultraviolet, visible, infrared, radio waves and microwaves occupy various portions of the electromagnetic spectrum and differ only in frequency and wavelength.

Energy density. Radiant energy in an element divided by volume of the element. Unit: joule/m^3.

Erythema. Redness of the skin due to congestion of the capillaries.

Fail-safe 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.

Hertz (Hz). The unit which expresses the frequency of a periodic oscillation in cycles per second.

Horn antenna. A wave guide that increases in cross sectional area towards the open end and transmits the radiation.

Infrared radiation. Electromagnetic radiation with wavelength in the range 0.7 μm to 1 mm.

Integrated radiance (L). The integral of the radiance over the exposure duration.Also known as pulsed radiance. Unit: joules per square centimeter per steradian (J. cm^{-2} .sr^{-1}).

Intrabeam viewing. The viewing condition whereby the eye is exposed to all or part of a laser beam.

Ionizing radiation. The electromagnetic or particular emanations produced by radiation sources capable of causing ionization or the ejection of electrons from the actions. Irradiance (E) Quotient of the radiant flux on an element of the surface containing the point at which irradiance is measured by the area of that element. Unit: watt per square centimeter (W. cm^{-2}).

Joule (J).A unit of energy.1 joule = 1 watt second.

Quality factor (QF). That factor which is multiplied by the absorbed dose to obtain the quantity which equates to a common scale the biological effectiveness of any type of ionizing radiation to which the individual is exposed. The dose equivalent for X-rays, gamma rays and β-rays is 1; for neutrons of unknown energy and α-rays is 10.

Lesion. An abnormal change in the structure of an organ or part due to injury or disease.

Limiting aperture. The maximum diameter of a circle over which irradiance and radiant exposure can be averaged.

Maximum permissible exposure (MPE). The level of laser radiation to which a person may be exposed without biological changes in the eye or skin.

Microwave radiation. The electromagnetic radiation in the frequency range 300 MHz to 300 GHz; highly directional when used for radiofrequency transmissions.

Minimum ignition energy. The minimum threshold energy required to ignite flammable vapour mixture by a spark discharge for a given mixture and electrode shape spacing.

Non-ionizing Electromagnetic Radiation. Electromagnetic waves of low frequency, long wavelength, and low photon energy unable to cause ionization (i.e. to remove an electron from an atom).

Poyting vector (S). A field vector quantity equal to the vector product of the electric and magnetic field strengths, and represents the magnitude and direction of the electromagnetic power density (energy flux density).

$$S = E^2/120\,\Pi = 120\,\Pi\ H^2 \text{ or } E^2/377\ H^2$$

When S is expressed in W/m^2, E in V/m and H in A/m.

Power (Φ). The rate at which energy is emitted, transferred or received. Unit: watts (joules per second). Also called radiant flux.

Power density. Power density is the radiant power incident on a small sphere, divided by the cross-sectional area of that sphere; derived limits of exposure to radio-frequency radiation in body absent situation are expressed in it. Unit: watt per square metre (W/m^2).

Protective housing. An enclosure that surrounds the laser or laser system that prevents access to laser radiation above the applicable MPE level. The aperture through which the useful is emitted is not a part of the protective housing.

Q-switched laser. A laser that emits short (≅ 30 ns), high power pulses by means of a Q-switch.

RAD. Red stands for Radiation Absorbed Dose and corresponds to energy absorption of 100 ergs per gram of the tissue. Its unit is Gray (Gy).

Radiance (L). Radiant flux or power per unit solid angle per unit area. Unit: joules per centimeter squared per Steradian ($W \cdot cm^{-2} \cdot sr^{-1}$).

Radiant energy (Q). Energy emitted, transferred, or received in the form of radiation. Unit: joule (J).

Radiant exposure (H). Surface density of the radiant energy received. Unit: joules per centimetre squared ($J \cdot cm^{-2}$).

Radiant intensity (I). Quotient of the radiant flux leaving the source and propagated in an element of solid angle containing the given direction, by the element of solid angle. Unit: watts per steradian ($W \cdot sr^{-1}$).

Radiation hazards (RADHAZ). Radio-frequency electromagnetic fields of sufficient intensity to produce harmful biological effects in human, casue ignition of volatile combustibles actuate explosive devices or inactivate electronic devices.

Radiofrequency Radiation (RF Radiation). Electromagnetic radiation in the portion of the spectrum from 100 kHz to 300 GHz.

Rem. An equilibrium of the dose of ionizing radiation to the body in terms of its estimated biological effects, relative to an absorbed dose of one roentgen of high voltage X-rays. The rem shall be the unit of dose record purposes. The SI unit of dose equivalent is Sievert (1 Sv = 100 rem).

Repetitively pulsed laser. A laser with multiple pulses of radiant energy occurring in sequence with a prf> 1Hz.

Retina. The sensory membrane which receives the incident image formed by the cornea and lens of the human eye. The retina lines the inside of the eye.

Roentgen. That amount of X-or gamma-radiation exposure which produce 2.083 x 10^9 ion pairs in 1 cc of air under standard conditions. The SI unit of exposure is C/kg (1 C/kg = 3876 R).

Secondary heat of radiation. Heat produced indirectly by the absorption of electromagnetic energy.

Sparks. An electric discharge occurring once or repetitively, of relatively short duration between initially separated electrodes.

Specific absorption rate (SAR). The specific absorption rate is the power absorbed per unit mass; the basic limits of exposure in the frequency region of 10 MHz and above are expressed in it. Unit: watt per kilogram (W/kg). For frequencies above 10 MHz, whole body average SAR (WBA-SAR) is taken as a quantity for establishing basic exposure limits and is the SAR value averaged over whole body. Local peak SAR may exceed WBA-SAR more than by a factor of 20 and its exposure limits are restricted accordingly.

Stormal haze (of the cornea). Cloudiness in the connective tissue or main body of the cornea.

Ultraviolet radiation. Electromagnetic radiation with wavelength smaller than those of visible radiation; 0.2-0.4 μm.

Visible radiation. Electromagnetic radiation which can be detected by the human eye, wavelength in the range 0.4 to 0.7 μm.

Watt (W). The unit of power or radiant flux.1 watt = 1 joule per second.

Whole body irradiation: A condition that exists when the entire body is exposed to incident electromagnetic energy.

Table 1.Frequency & Wavelength of Commonly Used Radiation

Type of Radiation	**Frequency Range**	**Wavelength**
Ultraviolet	3000—750 THz	100—400 nm
Visible	750—385 THz	400—780 nm
Infrared	385—0.3 THz	0.78—1000 μm
Radio frequency	300 GHz—0.1 MHz	1 mm —3000m
Microwave	300—0.3 GHz	1—1000 mm
Very low frequency	30—10 kHz	10—30 km
Low frequency	300—30 kHz	1—10 km
Medium frequency	3000—300 kHz	0.1—1 km
High frequency	30—3 MHz	10—100 m
Very high frequency	300—30 MHz	1—10 m
Ultra high frequency	3000—300 MHz	0.1—1 m
Super high frequency	30—3 GHz	1—10 cm
Extra high frequency	300—30 GHz	1—10 mm

Table 2.Occupational exposure limits to radiofrequency electromagnetic fields.

Frequency f(MHz)	**Unperturbed RMS Field Strength**		**Equivalent plane wave power density**	
	Electric (V/m)	**Magnetic H(A/m)**	**$P_{eq}(W/m^2)$**	**$P_{eq}(mW/cm^2)$**
0.1-1	614	1.6/f	---	---
>1-10	614/f	1.6/f	---	---
>10-400	61	0.16	10	1
>400-2000	$3f^{1/2}$	$0.008f^{1/2}$	f/40	F/400
>2000-300000	137	0.36	50	5

Table 3.General public exposure limits to radiofrequency electromagnetic fields.

Frequency f(MHz)	**Unperturbed RMS Field Strength**		**Equivalent plane wave power density**	
	Electric E(V/m)	**Magnetic H(A/m)**	**P_{eq}(W/m²)**	**P_{eq}(mW/cm²)**
0.1-1	87	$0.23/f^{1/2}$	---	---
>1-10	$87/f^{1/2}$	$0.23/f^{1/2}$	---	---
>10-400	27.5	0.073	2	0.2
>400-2000	$1.375f^{1/2}$	$0.0037f^{1/2}$	f/200	f/2000
>2000-300000	61	0.16	10	1

Table 4.Induced and contact radiofrequency currents

Frequency Range	**Maximum Current (mA)**		**Contact**
	Through both feet	**Through one feet**	
Occupational workers			
0.003-0.1 MHz	2000f	1000f	1000f
0.1-100 MHz	200	100	100
General Public			
0.003-0.1 MHz	900f	450f	450f
0.1-100 MHz	90	45	45

f = frequency in MHz

Table 5.Regions of the optical radiation spectrum

Region	**Wavelength range**
Ultraviolet	100 to 400 nm
UV-C	100 to 280 nm
UV-B	280 to 315 nm
UV-A	315 to 400 nm
Light (visible)	400 to 760 nm
Infrared	760 nm to 1 mm
IR-A	760 nm to 1.4 mm
IR-B	1.4 µm to 3.0 µm
IR-C	3.0 µm to 2 mm

Table 6.Intrabeam exposure limits which are applicable to many common CW lasers for eye and skin exposure to laser radiation

Laser type	Primary wavelength (nm)	Exposure limit for eye	Exposure limit for skin
Helium-Cadmium	441.6	a) 2.5 mW/cm^2 for 0.25 s	0.2 W/cm^2
Argon	488/514.5	b) 10mJ/cm^2 for 10 to 10^4 s c) 1 μ W/cm^2 for t > 10^4 s	for t > 10 s
Helium-Neon	632.8	a) 2.5 mW/cm^2 for 0.25 s b) 10 mJ/cm^2 for 10 s c) 70 mJ/cm^2 for t > 453 s d) 17 μW/cm^2 for t > 10^4 s	0.2 W/cm^2 for t > 10 s
Krypton	647	a) 2.5 mW/cm^2 for 0.25 s b) 10 mJ/cm^2 for 10 s c) 280 mJ/cm^2 for t > 871 s d) 28 μW/cm^2 for t > 10^4 s	0.5 W/cm^2 for t > 10 s
Neodymium: YAG Gallium-Arsenide at room temperature	1064 905	1.6 mW/cm^2 for t > 1000 s 0.8 mW/cm^2 for t > 1000 s	1.0 W/cm^2 0.5 W/cm^2 for t > 10 s
Helium-Cadmium Nitrogen	325 337.1	a) 1 J/cm^2 for 10 to 1000 s b) 1 mW/cm^2 for t > 1000 s	a) 1 J/cm^2 for 10 to 1000 s b) 1 mW/cm^2 for t > 1000 s
Carbon-dioxide (and other lasers 1.4 μm to 1000 μm	10600	0.1 W/cm^2 for t > 10 s	0.1 W/cm^2 for t > 10 s

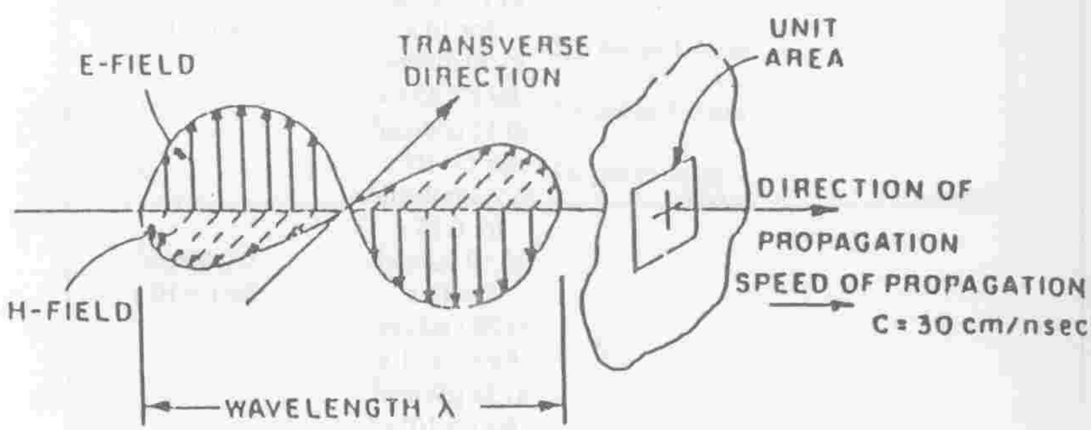

Fig.1. E- and H- Fields Relationships of an Electromagnetic Wave in Free Space

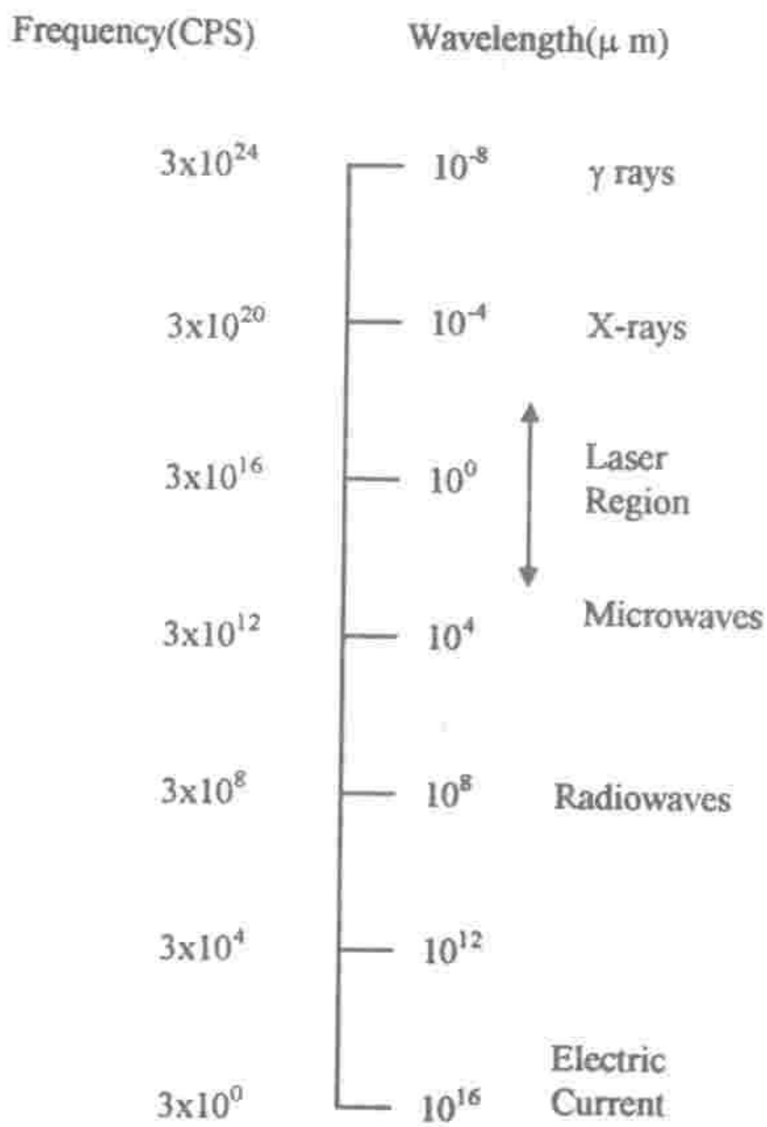

Fig.2. Electromagnetic Radiation Spectrum

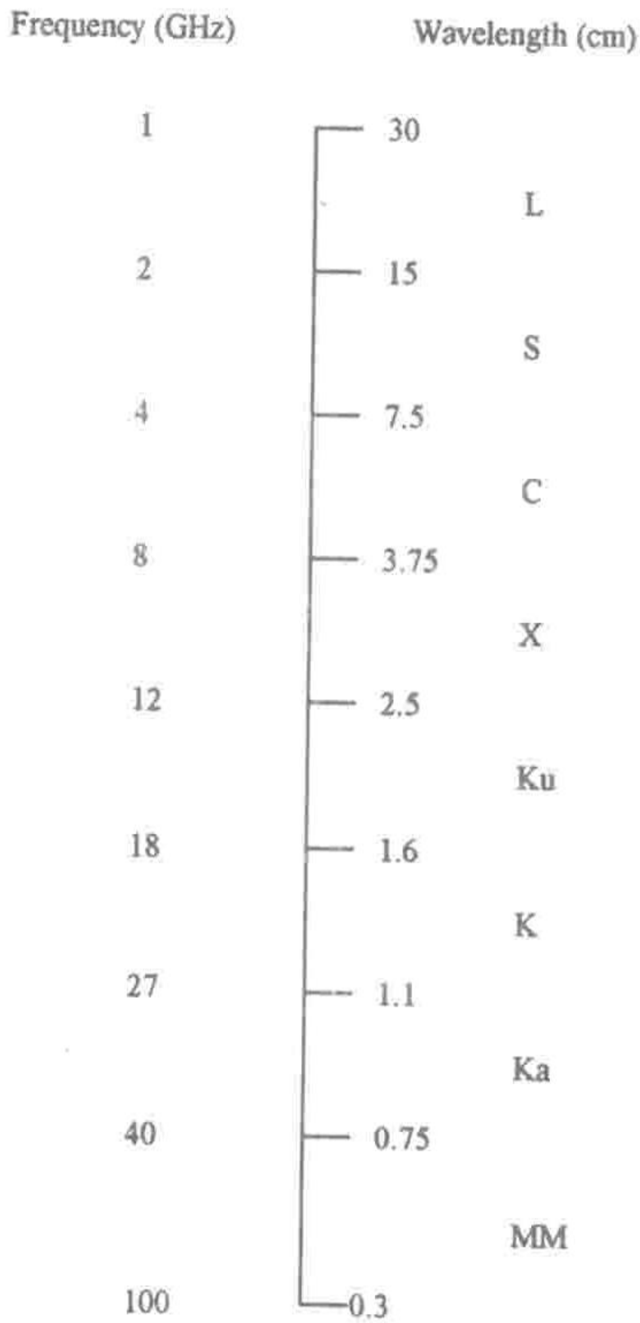

Fig. 3 Standard Radar Band

Appendix-1

DETAILED EXPOSURE LIMITS FOR LASER RADIATION

Injury thresholds for both the cornea and the retina vary considerably with wavelength, and it seems acceptable to adjust the exposure limits for different wavelengths in a simple manner than that the biological data might indicate. Exposure limits in the spectral region 700-1500 nm increase with wavelength by a factor C_A, C_A increases from 1 to 5 as the wavelength increases from 700 to 1050 nm as shown in Fig. I. Between 1050 and 1400 nm, exposure limits for both eye and skin include a constant spectral correction factor C_A of 5 and for ocular exposure to ultra-short pulses, an additional factor of 2. The reciprocal of the retinal absorption relative to corneal irradiances, shown in Fig. II, is an indication of the relative effectiveness of different wavelengths in causing retinal injury. For IR exposure limits, a correction factor C_C is applied with values in the range. 1 to 8. This factor accounts for the greatly decreased retinal hazard at wavelengths greater than 1100 nm, C_C results from increased absorption of energy in the ocular media.

At ocular exposure durations exceeding 10 s, short wavelength radiation causes photochemical retinal injury. The difference between the ocular exposure limits for short (less than 550 nm) and longer (550-700 nm) visible wavelengths therefore increases with greater exposure durations up to 10,000 s. Another wavelength connection factor C_B, is used to adjust for this change in retinal sensitivity with wavelength. Applying C_B at wavelengths between 550 and 700 nm leads to greater exposure limit values at these longer visible wavelengths for exposure durations exceeding 10 s. Values of C_B are given in Fig. II.

EXPOSURE LIMITS FOR LASER RADIATION

The exposure limits for eye and skin are given in Table I, II and III; the values listed are to be used for the indicated wavelength ranges for single exposures. The exposure limits for the eye are always specified at a plane tangential to the cornea at the point of the optical axis of the eye, for skin, exposure limits are specified at the skin surface.

To assess potential laser hazards to the eye, the intra-beam exposure limits as given in Table I are normally considered. Table II gives the exposure limits for extended source situations. The extended source correction factor C_E increases the exposure limits in Table I – applicable to the point source-to indicate more accurately the real risk of injury to the retina.

Limiting apertures

Radiant exposures or irradiances as given in these guidelines may be averaged over one of the three principal circular apertures with a receptor having a cosine response within the specified field-of-view. At wavelengths outside the retinal hazard spectral region (400-1400 nm), these are as follows: a 1-mm diameter aperture for pulsed exposure of the eye, a 3.5-mm diameter aperture for all continuous exposures of the eye, and a 3.5-mm aperture for pulsed and continuous wave exposures (> 10s) of the skin. For exposure duration between 0.3 s and 10 s and comparison with the ocular exposure limits for infrared wavelengths between 1.4 and 10^2μm, there is a variable aperture function given in Table IV. For comparison with the ocular exposure limits in the retinal hazard spectral range between 400 and 1400 nm, the measurements should be made using a detector with a 7-mm limiting aperture (pupil) with a receptor field-of-view of at least α_{min} for point sources and α or α_{max} or extended sources.

Table I.Intra-beam laser ocular exposure limits.

Wavelength λ. (nm) Ultraviolet	Exposure duration, t	Exposure limit	Restrictions
180-302	1 ns to 30 ks	3.0 X 10^{1} Jm^{-2}	
303	1 ns to 30 ks	4.0 X 10^{1} Jm^{-2}	
304	1 ns to 30 ks	6.0 X 10^{1} Jm^{-2}	
305	1 ns to 30 ks	1.0 X 10^{2} Jm^{-2}	
306	1 ns to 30 ks	1.6 X 10^{2} Jm^{-2}	
307	1 ns to 30 ks	2.5 X 10^{2} Jm^{-2}	All exposures limits
308	1 ns to 30 ks	4.0 X 10^{2} Jm^{-2}	for $\lambda < 315$ nm
309	1 ns to 30 ks	6.3 X 10^{2} Jm^{-2}	must be ≤
310	1 ns to 30 ks	1.0 X 10^{3} Jm^{-2}	5.6X 10^{3} $t^{1/4}$ Jm^{-2}
311	1 ns to 30 ks	1.6 X 10^{3} Jm^{-2}	for t < 10 s
312	1 ns to 30 ks	2.5 X 10^{3} Jm^{-2}	
313	1 ns to 30 ks	4.0 X 10^{3} Jm^{-2}	
314	1 ns to 30 ks	6.3 X 10^{3} Jm^{-2}	
315-400	1 ns to 10 s	5.6 X $10^{3}t^{1/4}$ Jm^{-2}	
315-400	10 s to 30 ks	1.0 X 10^{4} Jm^{-2}	
Visible and IRA			
400-700	1 ns to 18 µs	0.005 Jm^{-2}	
400-700	18 µs to 10 s	18 $t^{3/4}$ Jm^{-2}	
400-550	10 s to 10 ks	100 Jm^{-2}	
550-700	10 s to T_1	18 $t^{3/4}$ Jm^{-2}	
550-700	T_1 to 10 ks	100C_B Jm^{-2}	
400-700	10 ks to 30 ks	0.01 C_B Wm^{-2}	
700-1050	1 ns to 18 µs	0.005 C_A Jm^{-2}	
700-1050	18 µs to 1 ks	18 C_A $t^{3/4}$ Jm^{-2}	
1051-1400	1 ns to 50 s	0.05 C_C Jm^{-2}	
1051-1400	50 µs to 1 ks	90 C_C $t^{3/4}$ Jm^{-2}	
701-1400	1 ks to 30 ks	3.2 C_A C_C W m^{-2}	
IRB and IRC			
1401-1500	1 ns to 1.0 ms	1000 Jm^{-2}	
1401-1500	1.0 ms to 10 s	5600 $t^{1/4}$ Jm^{-2}	
1501-1800	1 ns to 10 s	10^{4} Jm^{-2}	
1801-2600	1 ns to 1.0 ms	1000 Jm^{-2}	
1801-2600	1.0 ms to 10 s	5600 $t^{1/4}$ Jm^{-2}	
2601-10^{6}	1 ns to 100 ns	100Jm^{-2}	
2601-10^{6}	100 ns to 10 s	5600 $t^{1/4}$ Jm^{-2}	
1401-10^{6}	10 s to 30 ks	1000 Wm^{-2}	

$C_A = 1$ if λ = 400-700 nm; $C_A = 10^{[0.002(\lambda-700)]}$ if λ = 700-1050 nm;
$C_A = 5$ if λ = 1051-1400 nm;
$C_B = 1$ if $\lambda < 550$ nm; $C_B = 10^{[0.015(\lambda-550)]}$ if λ = 550-700 nm;
$T_1 = 10 \text{ X } 10^{[0.02(\lambda-550)]}$ s if λ = 550-700nm; and $C_C = 1$ if $\lambda < 1150$; $C_C = 10^{0.0181(\lambda-1150)}$ if $1150 < \lambda < 1200$; $C_C = 8$ if $1200 < \lambda < 1400$.

Table II. Extended-source laser ocular exposure limits for λ = 400-1400 nm

Small extended sources with angular substance less than 0.1 radian

The exposure limits for extended sources with subtended angel greater than α_{min} and less than α_{max} are determined by multiplying the appropriate intra-beam exposure limits in Table 1 by an extended-source correction factor C_E, where

C_E = 1.0 for $\alpha \leq \alpha_{min}$,
$C_E = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \leq \alpha_{max}$,

And the angular subs tense, α, of the source, where

α_{min} = 1.5 mrad for t < 0.7 s;

$\alpha_{min} = 2\ t^{3/4}$mrad for 0.7 s ≤ t < 10 s;

α_{min} = 11 mrad for t ≥ 10 s;

α_{max} = 100 mrad for all values of t.

Therefore, expressed specifically,

$C_E = (\alpha/1.5$ mrad) for all exposure duration of t < 0.7 s;

$C_E = [\alpha/(2t^{3/4})$ mrad] for exposure duration of 0.7 s ≤ t < 10s; and

$C_E = (\alpha/11$mard) for exposure durations of t ≥ 10 s.

Large extended sources with angular substance greater than 0.1 radian

If the visual angle α subtending the source is greater than 0.1 rad (i.e. $\alpha > \alpha max$ = 100 mrad), the integrated radiance or radiance L_{EL} shall not exceed

$L_{EL} = (8.5 \text{ X } 10^3) \text{ X } (El_{pt\ source})\ Jm^{-2}\ sr^{-1}$ for t < 0.7 s;

$L_{EL} = (6.4 \text{ X } 10^3\ t^{4/3}) \text{ X } (El_{pt\ source})\ Jm^{-2}\ sr^{-1}$ for 0.7 s ≤ t < 10 s; and

$L_{EL} = (1.16\text{X}10^3) \text{ X } (El_{pt\ source})\ Jm^{-2}\ sr^{-1}$ (or $Wm^{-2}\ sr^{-1}$ as applicable for t ≥ 10 s.

Alternatively, the value of C_E for α> 0.1 rad could be calculated with
$C_E = \alpha^2/(\alpha_{min}\alpha_{max})$ for the exposure limit expressed in Jm^{-2}.

Table III. **Laser radiation exposure limits for the skin**

Wavelength, λ (nm)	Exposure duration, t	Exposure limit	Restrictions
Ultraviolet			
180-400	1 ns to 30 ks	As for eye	
Visible and IRA			
400-1400	1 ns to 100 ns	0.2 C_A kJm^{-2}	See Table 8 for
400-1400	100 ns to 10 s	11 C_A $t^{1/4}$ kJm^{-2}	limiting apertures
400-1400	10 s to 30 ks	2.0 C_A kWm^{-2}	
Far infrared			
$1401\text{-}10^6$	1 ns to 30 ks	As for eye[a]	

[a]For exposed skin areas greater than 0.1 m^2, the exposure limit is reduced to 100 W m^{-2}. For exposed areas between 0.01 and 0.1 m^{-2}, the exposure limit is inversely proportional to the exposed area.

C_A = 1 if λ = 400-700 nm; $C_A = 10^{[0.002(\lambda-700)]}$ if λ = 700-1050 nm; C_A = 5 if λ = 1051-1400 nm.

Table IV. Limiting apertures for applying the exposure limits

Spectral region	Exposure duration,t	Eye exposure (mm)	Skin exposure (mm)
180-400 nm	< 10 s	1.0	3.5
	$\geq$10 s	3.5	3.5
400-1400nm	1 ns to 30 ks	7.0	3.5
1400 – 10^5nm	1 ns to 0.3 s	1.0	3.5
	0.3 s to 10 s	1.5 $t^{3/8}$	3.5
	10 s to 30 ks	3.5	3.5
10^5-10^6 nm	1 ns to 30 ks	11.0	11.0

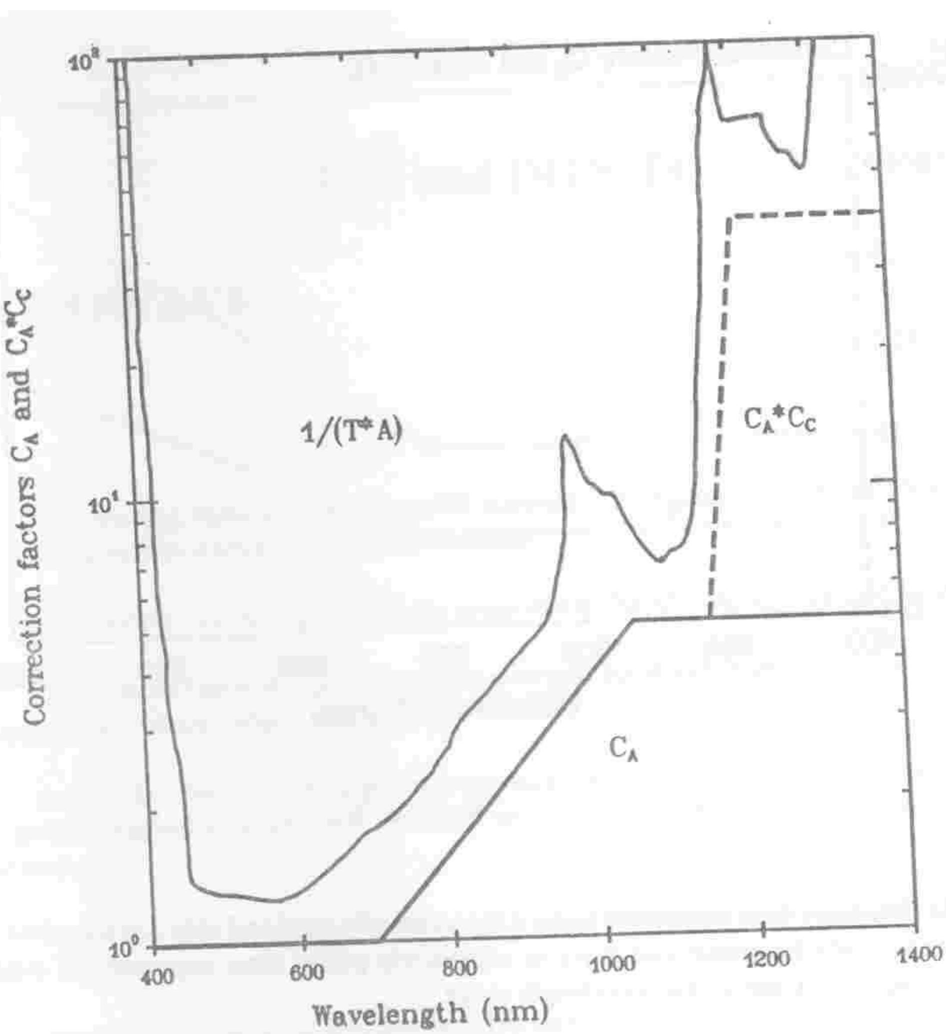

Fig. I. Retinal absorption and the spectral weighting factors C_A and C_C . The upper curve is the reciprocal of the retinal absorption A and transmittance T of the ocular media It may also be thought of as the reciprocal of the action spectrum for the retinal thermal injury as measured at the cornea. A more useful spectral weighting factor, C_A, is the lower function composed of straight-line segments to approximate (1/TA) between 400 and 1,150 nm and C_AC_C which approximated (1/TA) for longer wavelengths.

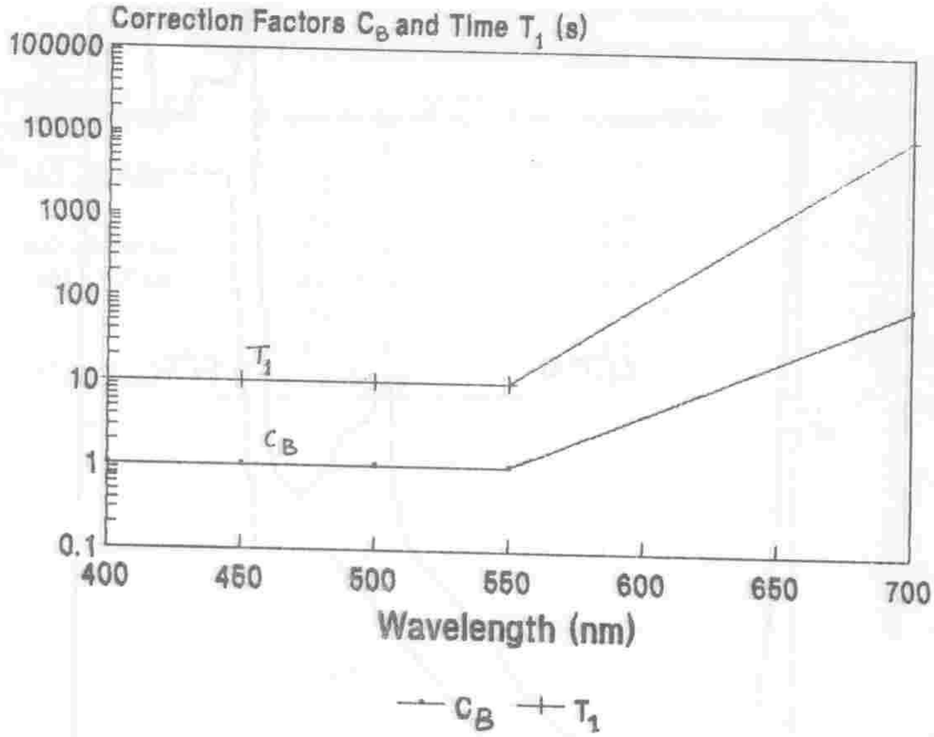

Fig. II. Exposure limit correction factor C_B and time T_1 **used in Table** 1 are applied when calculating limits for continuous wave or repetitively **pulsed laser** exposures of durations greater than 10 s in the visible wavelength range.

Appendix-2

DOs and DON'Ts

MICROWAVE

DOs

1. Post warning signs in areas where RF intensity is in excess of $1mW/cm^2$ Period of stay in these areas should be kept to an absolute minimum.

1. (a) Use barriers to restrict access to the areas where the RF field may exceed $1mW/cm^2$.

2. Use dummy loads or other absorptive materials to absorb high power RF radiation when the equipment is being tested.

3. Adjust the elevation of radar antennas to be above working zone. Make provision of appropriate interlocks on antennas elevation and azimuth so as to prevent pointing antenna at populated areas.

4. Fence the area around antenna in such a way that radiation levels are safe outside fenced areas.

5. Familiarise all radiation workers with the safety procedure or codes of safe practice.

6. Ensure that operational procedures are such that the use of personnel protective devices (special eye, head protectors, clothing etc.) is a last resort.

7. Ground all shielding materials used for controlling RF radiation.

8. Avoid direct as well as indirect coupling effects of RF radiation. The large metallic objects, which act as reflectors, should not be placed near the RF emitting devices.

9. Carry out microwave radiation survey of all installations of devices likely to emit RF radiation above accepted levels. In cases where explosive limits are exceeded, take necessary steps to reduce the microwave radiation level to acceptable limit. Special attention should be paid to the coupling joints.

DON'Ts

1. Do not direct the energy beam towards inhibited areas or other personnel groups.

2. Do not inspect visually the open ends of the wave guides, feed horns and other opening emitting RF electromagnetic energy devices.

3. Do not discharge, under test, the RF output of high power generators emitting average power levels of mW/cm^2 or more into surroundings.

4. Do not orient the beam from high power radar of air craft towards populate area.

5. Do not allow persons with pace makers or other metallic implants to enter RF field.

6. Do not locate RF facilities near work area, tactical sites and troop quarters, power lines and other EMF sources.

7. Don't allow personnel to work to antenna, wave guide or feed horn structures when the system is energized. In case work is to be done on the antenna of the search radar, the radiation from the Height Finder must be de-energized; but if work is to be done on the Height Finder Antenna, then the search radar should be de-energized if the distance between the two is less than 100 m.

LASER

DOs

1. Put an appropriate logo indicating the type of laser in the hazard area.

2. Put a warning like "BEWARE: Danger ahead" before the hazard area.

3. Put a signal (audible or light) to indicate that the laser is on.

4. Permit only authorized personnel to enter the hazard area.

5. Only trained and experienced personnel should be allowed to operate laser system.

6. Use eye protection device specific to the laser system during its operation.

7. All laser eyewear should be clearly labeled with optical density values and wavelengths for which protection is afforded.

8. With infrared laser, protective dress for the skin should be worn by the personnel.
9. Periodic medical examination of the personnel should be carried out.

10. Enclose as much of the beam path as possible.

11. Use beam shutters and laser output filters to reduce the beam power to less hazardous level.

12. Use dark, absorbing, diffuse, fire resistant targets and back stops where feasible.

13. All laser system should be labeled with their danger statements.
14. In each laser laboratory, first aid facilities should be available.
15. Each laser product should have a protective housing, regardless of its class.
16. Class III and IV laser should be operated by remote control.
17. Maintenance of laser system should be done after specific time intervals.
18. The exposure limits should be used as guidelines for controlling human exposure to laser radiation.

DON'Ts

1. Do not stare at the laser beam.
2. Do not view the laser beam directly.
3. Do not permit any unauthorized person to enter the hazardous area.
4. Do not traverse the laser path.
5. Do not point the laser at a person's eye unless some useful purpose exists.
6. Do not operate class IV laser in the atmosphere contaminated with smoke or dust as this material may give rise to hazardous diffuse reflection.
7. Do not wear bright reflecting objects.
8. Do not put any inflammable material in the infrared laser path.
9. Do not view the laser beam directly even through optical like binoculars.
10. Do not work with laser when fatigued/hungry/under medication which may affect the performance of the individual.
11. Do not view laser beam without proper safety eye wear or eye protective devices.
12. Do not allow a person with aphakic eye to operate laser devices.

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