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U. S. Army Artillery Board

U. S. ARMY TEST AND EVALUATION COMMAND
COMMODITY SERVICE TEST PROCEDURE

3471

LASER RANGEFINDERS

1. OBJECTIVE

The purpose of this ~~document~~ is to prescribe the general test procedures to be used to determine, under actual field operating conditions, the degree to which laser (Light Amplification ~~by Stimulated Emission~~ of ~~Radiation~~) rangefinders meet the military requirements stated in the qualitative materiel requirements (QMR) and the technical characteristics (TC).

2. BACKGROUND

The laser is a relatively recent development resulting from studies and research in changes in the energy state of atoms. It is an outgrowth of basic research which produced a very low noise radio amplifier called the maser (Microwave Amplification by Stimulated Emission of Radiation). Projections, in which the growth of the development of the laser were forecast, resulted in the finding that the laser had considerable potential for range measurement in connection with surveillance equipment, among numerous other potential applications.

Its ability to develop high peak power has made the laser attractive as a ranging device. Ground forces have always had a requirement for an accurate ground-to-ground rangefinder, however, no rangefinder has been entirely satisfactory. Optical rangefinders had been unsatisfactory because they depended mostly on a very small angle. Errors in this angle affect the range in proportion to the target distance. On the other hand, small radar rangefinders have relatively wide beams so that the range determination of targets is hindered by ground clutter. The laser incorporates the advantages of the radar pulse method of determining range combined with a very small beam which can be sighted optically to clear unwanted targets. Operation of a laser radar is illustrated in reference 4N.

There is a continuing need to improve the combat soldier's capability of rapidly and accurately determining the location of enemy targets of all descriptions.

In this connection, improved laser applications, as well as the continuing development of new hardware and techniques must be anticipated and evaluated.

3. REQUIRED EQUIPMENT

a. Field Ranges and Test Sites, with Surveyed Reference Points, as required for the field testing of the test item.

b. Vehicles for Transporting or Mounting of the Test Item, as required.

c. Secured Storage Facility for Classified Equipment

d. Maintenance Support Facilities, as required
e. Battery Recharging Facilities, as required
f. Special Manufacturer Test Equipment
g. Still and Motion Picture Cameras with Film, as required
h. Timing Devices, as required
i. Temperature Measuring Instruments, as required
j. Optical Instruments, for ground and aerial observations, as required
k. Electronic Surveillance Devices, for ground and aerial observations, as required
l. Radio and Wire Communication Facilities, as required
m. Acoustical Aids, as required
n. Targets, as specified by the accuracy and ranging tests
o. Equipment and Facilities, as specified by individual MTP's for individual tests

4. REFERENCES

A. D.A. Project Number 1-G-6-20801-D-453-06, Rangefinder, Lightweight, Laser (formerly 3D58-01-001-06)
B. D.A. Project Number 1-C-5-42709-D-360-30, Rangefinder, Lightweight, Laser XM23 (formerly 5W13-07-010-30)
C. Report R-1664, Human Factors Study of Design Configuration of the Laser Rangefinder, Frankford Arsenal, February 1963
D. USAMC Regulation 385-12, Verification of Safety of Materiel from Development through Testing and Supply to Disposition
E. USATECOM Regulation 385-6, Safety Release
F. USATECOM Regulation 385-7, Safety Confirmation
G. USATECOM Regulation 700-1, Value Engineering
H. USATECOM Regulation 750-15, Maintenance of Supplies and Equipment
I. AR 70-10, Research and Development, Army Materiel Testing
J. AR 325-63, Regulations for Firing Ammunition for Training Target Practice, and Combat
K. Applicable, Qualitative Materiel Requirements (QMR)
L. Applicable, Small Development Requirements (SDR)
M. Applicable, Technical Characteristics (TC)
N. Applicable, Military Characteristics (MC)
O. U. S. Army Signal Research and Development Laboratory, Laser Progress and Applications, H. J. Merrill, Fort Monmouth, N. J. 1962
P. U. S. AMC 385-224, AMC Safety Manual
Q. MTP 6-3-500, Physical Characteristics
R. MTP 6-3-501, Technical Inspection
S. MTP 6-3-502, Personnel Training Requirements
T. MTP 6-3-504, Ease of Installation and/Rigging and Operation
U. MTP 6-3-505, Emplacement, Action and March Order
V. MTP 6-3-506, Durability
W. MTP 6-3-509, Effects of Weather
X. MTP 6-3-510, Transportability of Communications Surveillance and Electronic Equipment
Y. MTP 6-3-512, Compatibility with Related Equipment

Z. MTP 6-3-517, Electrical Power Requirements
AA. MTP 6-3-523, Safety
AB. MTP 6-3-524, Maintenance
AC. MTP 6-3-525, Human Factors Evaluation
AD. MTP 7-3-512, Air Drop Capability (Suitability of Equipment For)

5. SCOPE

5.1 SUMMARY

This MTP describes the following tests to be conducted in the evaluation of laser rangefinders for service use:

a. Pre-Test Operations consisting of:

1) Technical Inspection - A check to verify that the test item is complete and in satisfactory condition prior to the start of testing.
2) Physical Characteristics - A verification of the physical characteristics of the test item
3) Electrical Characteristics - A study to ascertain the electrical characteristics of the test item and a determination of its' power requirements

b. Operational Characteristics consisting of:

1) Emplacement, Preparation for Action and March Order Suitability - A study to determine the ability of the service personnel to set-up the test item for operation and to restore it to its transport configuration
2) Accuracy and Ranging Capabilities - A study to determine the ability of the test item to locate a variety of stationary and moving targets under varying conditions of visibility and environment.
3) Vulnerability to Detection - A study to determine how secure the test item is from detection both visually and aurally, from ground and aerial observations and under a variety of conditions

c. Special Operations consisting of:

1) Transportability - A study to determine the suitability of the test item for surface and air transport
2) Air Drop Capability - A study to determine the suitability of the test item for air drop operations
3) Compatibility with Related Equipment - A study to determine the suitability of vehicle mounted test items for operation with the related vehicular equipment used for mounting, and supplying operational power

d. Full-test Evaluations consisting of:

1) Durability - An evaluation of the capability of the test item to withstand being transported over various types of terrain for a specified number of miles and to withstand the shock of repeated weapon firings nearby.
2) Maintainability and Reliability - An evaluation to determine the suitability of the test item to be maintained, the adequacy of its maintenance package and its overall ability to operate over long periods of time without adjustment or replacement of components.
3) Effects of Weather - An evaluation of the effects of various weather conditions on the operability of the test item.
4) Human Factors - An evaluation of the suitability of the test item for operation, servicing, transport and storage by service personnel without causing undue fatigue and mental errors.
5) Safety - An evaluation of the safeness of the test item in its various configurations, under a variety of conditions and the resultant safety hazards to service personnel.

e. Post-Test Inspection - A repetition of the technical inspection to determine any adverse effects of testing on the test item.

5.2 LIMITATIONS

This materiel test procedure shall be limited to those laser rangefinders which are vehicular mounted or portable and used in ground operations.

6. PROCEDURE

6.1.1 Scheduling

6.1.1.1 Personnel

a. Prior to the arrival of the test item, ensure that service personnel, with the appropriate backgrounds for the operation and maintenance of the test item and associated equipment, are adequately trained as prescribed by MTP 6-3-502.

b. Record the following for all service personnel:

1) Rank
2) MOS
3) Training time
4) Experience

NOTE: 1. Test personnel shall receive the minimum essential individual instruction in the operation and organizational, direct support and general support maintenance of the test item. The achievement of a skill level to operate the test item under simulated combat conditions shall be a requirement, assuming that the test can achieve results as set forth in the QMR. Training shall include all aspects essential to the test item including safety, multiple target situations and battery charging. Observation of operation and maintenance shall be made by technically qualified personnel.

c. Adequacy of training literature furnished with the test item shall be determined and recorded.

d. Ensure that experienced personnel are available for the duration of testing.

6.1.1.2 Facilities and Equipment

a. Select and schedule the use of testing sites and facilities as required by the applicable test section and the corresponding MTP.

b. Upon notice of the arrival or estimated time of arrival of the test item, arrange for or secure the following:

1) Engineering safety release or a safety statement from the engineering agency as prescribed by references 4E and 4F.
2) Vehicles required for transporting or mounting the test item in its operating position, as applicable.
3) Maintenance support facilities, organization and personnel.
4) Assistance of the U. S. Army Electronic Proving Ground (USAEPG) as required during the conduct of this MTP.
5) Assistance of the U. S. Army Airborne, Electronics and Special Warfare Board (USAAESWBD) as required during the conduct of this MTP.
6) Establishment of a maintenance facility and storage area for classified material.

6.1.2 Safety

a. Verify that the test item safety statement is valid and up-to-date.

b. Verify that all service test personnel have been adequately trained in the safety requirements and the safety restrictions pertaining to the test item.

c. Conduct service testing of laser rangefinders under field conditions simulating tactical operations, but within the limitations imposed by the safety requirements.

d. Utilize Appendix A as a safety guide for personnel during service testing of laser rangefinders (See GLOSSARY for definitions of terms).

NOTE: At the present stage of development, lack of definition and reliable safety criteria for laser operations may impose limitations on service test phases which could cause their cancellation or postponement.

e. Observe safety precautions during firing tests as outlined in reference 40.

f. Provide for the same order of safety and security at the test sites as for weapon firings, to protect personnel from inadvertent exposure to laser radiation. Note the precautions discussed in Appendix A.

6.1.3 Pre-Test Operations

6.1.3.1 Technical Inspection

Perform a technical inspection on the test item as described by the applicable sections of MTP 6-3-501.

6.1.3.2 Physical Characteristics

Determine the physical characteristics of the test item as described by the applicable sections of MTP 6-3-500.

6.1.3.3 Electrical Characteristics

Determine the electrical characteristics and the power requirements of the test item as described by the applicable sections of MTP 6-3-517.

6.2 TEST CONDUCT

a. Subtests shall be conducted concurrently with, or in conjunction with, other subtests, whenever possible, so that the time taken to collect the required data can be minimized.

b. Subtests shall be conducted under all conditions of weather prevailing during the period of test.

6.2.1 Operational Characteristics

6.2.1.1 Optimum Environmental and Visibility Conditions

Perform paragraph 6.2.1.1.1 through 6.2.1.1.2 on a clear, light day having moderate ambient temperatures.

6.2.1.1.1 Emplacement, Preparation for Action and March Order Suitability -

Determine the ability of the service personnel to emplace, prepare for action and to march order the test item according to the criteria of MTP 6-3-505.

NOTE: Emplacement, preparation for action and march order shall be performed in conjunction with all subtests, as applicable.

6.2.1.1.2 Accuracy and Ranging Capabilities - Perform the following:

NOTE: 1. Moving targets shall be remotely controlled over predetermined courses.
2. Positioning of personnel during laser operation shall be in accordance with safety procedures established

in Appendix A to eliminate hazards to personnel. Mannequins may be substituted for those test target conditions requiring personnel and crew.

a. On a suitable test range, of varying elevation and background objects, introduce the following predetermined representative targets, randomly, at various ranges and azimuth intervals:

1) Moving targets when directed by the test plan such as:

a) Wheeled vehicles
b) Tracked vehicles

2) Stationary targets such as:

a) Permanent trig points
b) Block houses

3) Personnel targets such as:

a) Individuals
b) Small groups of men
c) Riflemen, in defensive positions

4) Infantry crew-served weapons such as:

a) Mortars
b) Recoilless rifles

5) Artillery crew-served weapons such as:

a) Howitzers
b) Guns
c) Missile systems

6) Terrain features such as:

a) Hills
b) Swamps
c) Ponds

NOTE: 1. Stationary target locations shall be predetermined and known to observer personnel while unknown to the test item operator(s).

2. Moving targets shall move in predetermined patterns between 70% and 95% of the maximum range of the test item. The patterns shall be known to observer personnel but unknown to the test item operator(s).

b. Determine and record the following for each target:

1) Range
2) Azimuth
3) Elevation
4) Type of target
5) Target identity

c. Introduce the following artillery projectile bursts as targets:

1) Air bursts
2) Impact bursts
3) White phosphorous impact bursts

d. Determine and record, within 5 rounds, the following for each type of burst:

1) Range
2) Azimuth
3) Elevation
4) Type of projectile burst

NOTE: Safety precautions for test, observer and downrange personnel shall be observed at all times.

e. At the completion of the accuracy and ranging tests, perform a technical inspection as described in the applicable sections of MTP 6-2-501.

6.2.1.1.3 Vulnerability to Detection - Perform the following:

a. From ground surveillance:

1) Determine and record the maximum distance that the test item can be detected by the following:

a) Naked eye
b) Optical instruments
c) Electronic surveillance devices

NOTE: The U. S. Army Electronic Proving Ground shall assist the test personnel in the use of electronic devices.

2) Determine and record the maximum distance that the test item can be detected aurally by the following:

a) Unaided ear
b) Acoustical aids

NOTE: At least three determinations shall be made for each detection observation.

3) Record the following for each visual and aural determination:

a) Type of observation
b) Equipment used for detection

b. From aerial surveillance:

1) Determine and record the maximum altitude at which the test item can be detected by the following:

a) Naked eye
b) Optical instruments
c) Electronic surveillance devices
d) Photography

NOTE: Aerial observations shall be the responsibility of the U. S. Army Airborne, Electronics and Special Warfare Board (USAAESWBD).

2) Record the type of equipment used for each observation.

6.2.1.2 Adverse Visibility Conditions

a. Repeat paragraphs 6.2.1.1.1 through 6.2.1.1.3, as applicable, under the following visibility conditions:

1) Smoke or fog between the test item and the target area
2) Twilight
3) Darkness (blackout)

6.2.1.3 Adverse Weather Conditions

Repeat paragraphs 6.2.1.1.1 through 6.2.1.1.3 under the various weather conditions of paragraph 6.2.3.3.

NOTE: Operation of the laser in rain, snow, fog or dust shall be avoided unless specifically authorized in the safety statement or safety release.

6.2.2 Special Operations

6.2.2.1 Transportability

a. Determine the surface and air transportability of the test item as described by the applicable sections of MTP 6-3-510.

NOTE: The conduct of airborne operations shall be the responsibility of the U. S. Army Airborne, Electronics, and Special Warfare Board (USAAESWBD).

b. At the completion of the test, the test item shall be subject to a technical inspection as described in the applicable sections of MTP 6-3-501.

6.2.2.2 Air Drop Capability

a. Determine the suitability of the test item for delivery by an individual parachutist, and for air drop as a door bundle from aircraft, as described by the applicable sections of MTP 7-3-512.

NOTE: The conduct of this procedure shall be the responsibility of the U. S. Army Airborne Electronics and Special Warfare Board (USAAESWBD).

b. At the completion of the test, the test item shall be subject to technical inspection as described in the applicable sections of MTP 6-3-501.

6.2.2.3 Compatibility with Related Equipment of Vehicular Mounted Test Item

Determine the compatibility of the test item with the related equipment as described by the applicable sections of MTP 6-3-512.

6.2.3 Full Test Evaluations

Evaluations are conducted during the entire period of testing under the various conditions specified in this MTP.

6.2.3.1 Durability

a. Determine the durability of the test item as described by the applicable sections of MTP 6-3-506.

NOTE: The test item shall be transported over paved roads, unpaved roads and cross-country terrain for a minimum of 600 miles in all transportable configurations.

b. Determine the ability of the test item, in its operating configuration, to withstand the shock of firing the following weapons within 100 yards of the test item:

1) Artillery - 155MM or 105MM howitzers
2) Tank weapons - 90MM or 105MM cannons
3) Infantry weapons - machine guns, mortars, rifles

c. Evaluate the ability of the transit case(s) to protect the test item from shock and vibration during transport.

6.2.3.2 Maintainability and Reliability

a. Evaluate the maintainability and reliability of the test item according to criteria established by reference 4H.

b. Complete the authorized maintenance tasks in accordance with the test item maintenance allocation chart, and technical literature.

c. Determine the maintainability of the test item as described by the applicable sections of MTP 6-3-524.

d. Record the following:

1) Time and number of personnel required to perform scheduled and non-scheduled maintenance tasks on the test item
2) Frequency of repairs
3) Test item down-time (cumulative)
4) Nomenclature of repair parts used

e. Evaluate the adequacy and accuracy of the test item maintenance package.

f. Determine and record the number of ranging operations which the test item can accomplish without recharge or replacement of batteries under the various test conditions.

6.2.3.3 Effects of Weather

a. Determine the effect of weather on the test item operability as described by the applicable sections of MTP 6-3-509.

b. Evaluate the ability of the transit case(s) to protect the test item from moisture, dust and other debris.

6.2.3.4 Human Factors

a. Determine the suitability of the test item design with respect to the man-equipment relationship as described by the applicable sections of MTP 6-3-525.

b. Determine and record the suitability and the compatibility of the test item with the service personnel who will operate and service it, as regarding their skills, aptitudes and physical limitations.

NOTE: Each test item detail requiring human attention and/or manipulation shall be observed and evaluated.

6.2.3.5 Safety

Determine the test item safety hazards resulting from storage, transport, operation and maintenance as described by the applicable sections of MTP 6-3-523.

NOTE: 1. The safety confirmation shall be prepared in accordance with USATECOM Regulation 385-7.
2. Hazards to test personnel due to laser operation shall be eliminated as far as possible in accordance with procedures described in Appendix A. This point cannot be overemphasized.

6.2.4 Post-Test Inspection

Upon completion of testing, the test item shall be subjected to the technical inspection as described by the applicable sections of MTP 6-3-501 and any deletrious effects on the test item due to the testing program shall be recorded.

6.3 TEST DATA

6.3.1 Preparation for Test

6.3.1.1 Personnel

Record the following for all service personnel:

a. Rank
b. MOS
c. Training time in months
d. Experience in years

6.3.1.2 Pre-Test Operations

6.3.1.2.1 Technical Inspection -

Record data as collected under the applicable sections of MTP 6-3-501.

6.3.1.2.2 Physical Characteristics -

Record data as collected under the applicable sections of MTP 6-3-500.

6.3.1.2.3 Electrical Characteristics -

Record data as collected under the applicable sections of MTP 6-3-517.

6.3.2 Test Conduct

6.3.2.1 Operational Characteristics -

Record the following for each test conducted:

a. Visibility condition (daylight, twilight, smoke or fog, darkness, etc.)
b. Ambient temperature in degrees F.
c. Weather condition (clear, rain, snow, sleet, etc.)
d. Test item identity (vehicle mounted laser rangefinder, portable)

6.3.2.1.1 Emplacement, Preparation for Action and March Order Suitability -

Record data as collected under the applicable sections of MTP 6-3-505.

6.3.2.1.2 Accuracy and Ranging Capabilities -

a. Record the following for each target observation:

   1) Range in meters
   2) Azimuth in degrees or mils
   3) Elevation in degrees or mils

4) Type of target (stationary, moving, etc.)
5) Target identity (wheeled vehicle, mortar, etc.)
6) Time required for each target location in seconds

b. Record the following for each artillery burst:

1) Range in meters
2) Azimuth in degrees or mils
3) Elevation in degrees or mils
4) Type of projectile burst (air burst, impact burst, etc.)

c. Record the number of rounds required to locate each type of burst.

d. Record any difficulties encountered in operating the test item during the ranging tests.

e. Record technical inspection data collected as described in the applicable sections of MTP 6-3-501.

6.3.2.1.3 Vulnerability to Detection -

a. From ground surveillance:

1) Record the following for each visual observation:

a) Maximum distance at which the test item can be detected in meters
b) Type of observation (visual)
c) Type of detection device used (naked eye, optical instrument, etc.)
d) Detection device nomenclature, as applicable

2) Record the following for each aural observation:

a) Maximum distance at which the test item can be detected in meters
b) Type of observation (aural)
c) Type of detection device used (unaided ear, acoustical aids)
d) Detection device nomenclature, as applicable

6.3.2.2 Special Operations

6.3.2.2.1 Transportation -

a. Record the following:

1) Transportability data collected as described in the applicable sections of MTP 6-3-510
2) Technical inspection data collected as described in the applicable sections of MTP 6-3-501

6.3.2.2.2 Air Drop Capability -

Record the following:

a. Air Drop data collected as described in the applicable sections of MTP 7-3-512.

b. Technical inspection data collected as described in the applicable sections of MTP 6-3-501.

6.3.2.2.3 Compatibility with Related Equipment -

Record data as collected under the applicable sections of MTP 6-3-512.

6.3.2.3 Full-Test Evaluations

6.3.2.3.1 Durability -

a. Record data as collected under the applicable sections of MTP 6-3-506.

b. Record the following for each test item transportable configuration:

1) Mileage over paved roads
2) Mileage over unpaved roads
3) Mileage over cross-country terrain

c. Record the following for each shock of firing test with the test item in its operational configuration:

1) Nomenclature of fired weapon
2) Number of rounds fired
3) Amount of test item adjustment required after firing shock
4) Time taken to adjust the test item in seconds

d. Record comments on the suitability of the transport case(s) to protect the test item from shock and vibration during transport.

6.3.2.3.2 Maintainability and Reliability -

a. Record data as collected under the applicable sections of MTP 6-3-524.

b. Record the following for scheduled and non-scheduled maintenance tasks performed on the test item:

1) Time taken to perform the maintenance task in hours
2) Number of men required to perform the maintenance task

c. Record the following for the test item:

1) Number of repairs required
2) Test item down-time
3) Nomenclature of repair

d. Record comments on the adequacy and accuracy of the test item maintenance package.

e. Record the number of range measurements that the test item can accomplish without:

1) Battery recharge
2) Battery replacement

6.3.2.3.3 Effects of Weather -

a. Record data as collected under the applicable sections of MTP 6-3-509.

b. Record comments on the suitability of the transport case(s) to protect the test item from the following:

1) Moisture
2) Dust
3) Other debris

6.3.2.3.4 Human Factors -

a. Record data as collected under the applicable sections of MTP 6-3-525.

b. Record comments on the suitability and compatibility of the test item with service personnel who operate and service it with regard to:

1) Personnel skills
2) Personnel aptitudes
3) Personnel physical limitations

6.3.2.3.5 Safety -

a. Record data as collected under the applicable sections of MTP 6-3-523.

6.3.2.4 Post-Test Inspection

a. Record data as collected under the applicable sections of MTP 6-3-501.

b. Record any deleterious effects of the test program on the test item.

6.4 DATA REDUCTION AND PRESENTATION

Data obtained from all test sections shall be summarized, compared and evaluated according to procedures described in the applicable individual MTP's. Appropriate charts, graphs and tabulated summaries shall be used to present the data in a clear manner. Special consideration shall be given to any condition or circumstance contributing to any test result.

Calculations shall be performed as specified by the individual MTP's, wherever applicable, and all photographs, motion pictures and illustrative material shall be suitably identified.

Comparisons concerning the accuracy and ranging capabilities of the test item shall be made as follows:

a. Knowing the coordinate location and elevation of the test item, compute the coordinate location and elevation of each of the stationary targets sighted.

b. Compare the computed locations with the known target locations.

c. Tabulate the test results according to environmental and visibility conditions and make further comparison.

d. Compute the coordinate locations and elevations of the moving targets observed, at given times.

e. Compare the computed locations with the known moving target tracks traced on a coordinate map or grid system.

f. Compare the times taken for each type of target ranging under the various conditions.

g. Compute the locations and elevations for the various bursting targets.

h. Co bursting target locations, as well as possible, with approximate known locations of the bursts for the various conditions.

i. Compare the time taken and the numbers of rounds required to collect the data for the various bursts under the various conditions.

The evaluation of the test item accuracy and ranging capability shall be based on the summarized data, and, like all qualitative and quantitative data collected, shall be measured by the QMR and TC to determine the degree of fulfillment of the performance specifications of the test item.

For the evaluation of the vulnerability of the test item to detection average distances and altitudes shall be computed, tabulated and compared for the various observation methods under the various conditions.

A safety confirmation, based on the data of paragraph 6.3.2.3.5, shall be presented in accordance with USATECOM Regulation 385-7.

GLOSSARY

1. Angstrom (A°): Unit of measure of wavelengths equal to 10^{-10} meter or 0.1 nanometer (millimicrons).

2. Beam Divergence: Angle of beam spread in milliradians (1 milliradian = 3.4 minutes of arc).

3. Closed Installation: Any location where lasers are used which will be closed to personnel during laser operation such as remote firing and TV monitored operations.

4. C. W. Laser: Continuous wave laser as distinguished from a pulsed laser.

5. Decibel (db): The unit used to express a beam intensity ratio. The decibel is equal to 10 times the logarithm of the beam intensity ratio as expressed by the following equation:

$$n(db) = 10 \log_{10} \frac{(P_1)}{(P_2)}$$

Where P_1 and P_2 designate two amounts of power or energy density and n the number of decibels corresponding to their ratio.

6. Electromagnetic Radiation: The propagation of varying electric and magnetic fields through space at the speed of light.

7. Emergent Beam Diameter: Diameter of the laser beam at the exit aperture of the system.

8. Energy Density: The intensity of electromagnetic radiation per unit area per pulse expressed as joules per square centimeter.

9. Gas Laser: A class of laser in which the laser action takes place in a gas medium usually a C. W. Laser.

10. Hazard Evaluation Survey: Evaluation of the hazards to personnel working or remaining in the vicinity of laser equipment.

11. Joule (j): A unit of energy. Used in describing a single pulsed output of a laser. It is equal to one watt-second or 0.239 gram-calories.

12. Joule/cm^2 (j/cm^2): Unit of energy density used in measuring the amount of energy per area of absorbing surface or per area of a laser beam. It is a unit for predicting damage potential of a laser beam.

13. Laser: Light amplification by stimulated emission of radiation.

14. Laser Light Region: A portion of the electromagnetic spectrum which includes ultraviolet, visible, and infrared light.

15. Maser: Microwave amplification by stimulated emission of radiation. When used in the term optical maser, it is often interpreted as molecular amplification by stimulated emission of radiation.

16. Maximum Permissible Power or Energy Density: The intensity of laser radiation that, in light of present medical knowledge, is not expected to cause detectable bodily injury to a person at any time during his lifetime.

17. Open Installation: Any location where lasers are used which will be open during laser operation to operating personnel and may or may not specifically restrict entry to casuals.

18. Optical Density (OD): A logarithmic expression of the attenuation afforded by a filter. Alternatively, OD may be expressed as one-tenth the attenuation in db.

19. Optically Pumped Laser: A class of laser which derives its energy from a noncoherent light source such as a xenon flash lamp. This laser is usually pulsed.

20. Output Power and Output Energy: Power is used primarily to rate C. W. lasers since the energy delivered per unit time remains relatively constant (output measured in watts). However, pulsed lasers which have a peak power significantly greater than their average power produce effects which may best be categorized by energy output per pulse. The output power of C. W. lasers is usually expressed in milliwatts (mw = 1/1000 watts), pulsed lasers in kilowatts (1000 watts), and q-switched pulsed lasers in megawatts (MW = million watts) or gigawatts (GW = billion watts). Pulsed energy output is usually expressed in joules.

21. Power Density: The intensity of electromagnetic radiation present at a given point. Power density is the average power per unit area usually expressed as milliwatts per square centimeter.

22. Pulsed Laser: A class of laser characterized by operation in a pulsed mode, i.e., emission occurs in one or more flashes of short duration (pulse length).

23. Pulse Length: Duration of laser flash. May be measured in milliseconds (msec = 10^{-3} sec), microseconds (μ sec = 10^{-6} sec), or nanoseconds (nsec = 10^{-9} sec).

24. Q-Switched Laser: (also known as Q-spoiled) A pulsed laser, capable of extremely high peak powers, for very short durations (pulse length of several nanoseconds).

25. Semiconductor or Junction Laser: A class of laser which normally produces relatively low power outputs. This class of laser may be "tuned" in wavelength and has the greatest efficiency.

26. Solid-State Laser: A class of laser which utilizes a solid crystal such as ruby or glass. This class most commonly is used as an optically pumped, pulsed laser.

27. Metric and Exponential Systems: The following explanation of the metric system and the exponential method of expressing numbers is presented as a source of reference:

(1) Metric System Abbreviations:

meter - m
centimeter - cm
millimeter - mm
micron - μ
nanometer - nm
angstrom - Å

Equivalent Units

1 m = 100 cm = 1,000 cm = 39.37 inches
1 cm = 0.3937 inches; 1 inch = 2.54 cm
1 μ = 10^{-6} meters = 10^{-4} cm
1 msec = 1/1,000 seconds = 1 x 10^{-3} seconds
1 μsec = 1/1,000,000 seconds = 1 x 10^{-6} seconds
1 nsec = 1 x 10^{-9} seconds
1 milliradian = 10^{-3} radians = .057 degrees = 3.4 arc-minutes

(2) Exponential System: For convenience in writing and manipulation, unwieldy numbers are written as factors of appropriate powers of 10. The following examples will illustrate:

2,380,000,000 = 2.38×10^{9}
238 = 2.38×10^{2}
0.238 = 2.38×10^{-1}
0.000000238 = 2.38×10^{-7}

APPENDIX A

CONTROL OF HAZARDS TO HEALTH FROM LASER RADIATION

1. INTRODUCTION

Recent developments in laser technology have resulted in an increase in the utilization of these devices for military applications, both for research and field use. Moreover, the widespread use of these systems greatly increases the probability of personnel exposure to injurious intensities of laser radiation. Therefore, it is highly important that adequate protective measures be employed to prevent accidental injury. This publication has been prepared in the interest of expediting implementation of such measures.

2. CHARACTERISTICS OF LASER RADIATION

Existing laser systems utilize portions of the electromagnetic spectrum including ultraviolet, visible and infrared light. This wavelength increment is commonly designated as the "light" region of the electromagnetic spectrum. The following characteristics of this type of radiation become apparent when it is inserted into its proper position in the electromagnetic spectrum, and its location noted in relation to the circumscribing wavelengths:

a. It is bounded on the short wavelength end of the electromagnetic spectrum by far ultraviolet. It should not be confused with ionizing radiation (x and gamma rays) although very high power or energy densities have been known to produce ionization in air and other material.

b. It is bounded on the long wavelength end of the electromagnetic spectrum by far infrared.

c. The effects of laser radiation are essentially the same as light generated by more conventional ultraviolet (u.v.), infrared (i.r.) and visible light sources. The unique properties attributed to laser radiation are generally those resulting from the very high intensities and high monochromaticity of laser light. Laser light sources differ from conventional light emitters primarily in their ability to attain highly coherent light (in phase). The increased directionality and intensity of the light generated by a laser enables it to deliver concentrated light intensities at considerable distances (miles). Although these effects can be used to good advantage, they are potentially dangerous and must be given careful consideration.

3. BIOLOGICAL EFFECTS OF LASER RADIATION

a. The biological effects of the laser beam are essentially those of visible, ultraviolet or infrared energy upon tissues. However, the intensity of the light is of magnitudes that could previously be approached only by the sun, nuclear weapons, magnesium burning or arc lights. This is one of the important properties that make lasers exceedingly hazardous.

b. A laser beam striking tissue will be reflected, transmitted, and/or absorbed. The degree to which these occur depends upon various properties of the tissue involved. Absorption is selective, as in the case of visible light, darker material such as melanin or other pigmented tissue absorbing the energy.

c. Skin effects may vary from mild reddening or erythema, to blisters and charring, depending upon the amount of energy transferred. Dark skin is more sensitive than light skin.

d. The effect upon the retina may be physiological, i.e. a temporary spot without pathologic changes, or it may be more severe with pathologic changes that heal by fibrosis. The least reaction may be simple reddening; as the energy increases, the lesions progress in severity from blistering to edema, ulceration, and charring, with tissue reaction around the lesion. Very high energies will disrupt the retina and the eye. Portions of the eye, superficial to the retina, may also be injured, depending upon the region where the greatest absorption occurs and the relative sensitivity of tissue affected. (See Figures A-1 and A-2 for Eye Radiation Absorption Properties and Wavelength Effect on the Ocular Media)

e. Infrared light produces heat with its characteristic effect on tissue and the lens of the eye. Ultraviolet light produces "flash burn", an acute inflammation of the conjunctiva, common in arc welders. Light in the far infrared such as the 10 micron wavelength from the carbon dioxide lasers may be absorbed only in the cornea.

f. The following table indicates the minimum retinal exposure level that will produce retinal damage which can be observed ophthalmoscopically for three types of lasers.

TABLE A-1

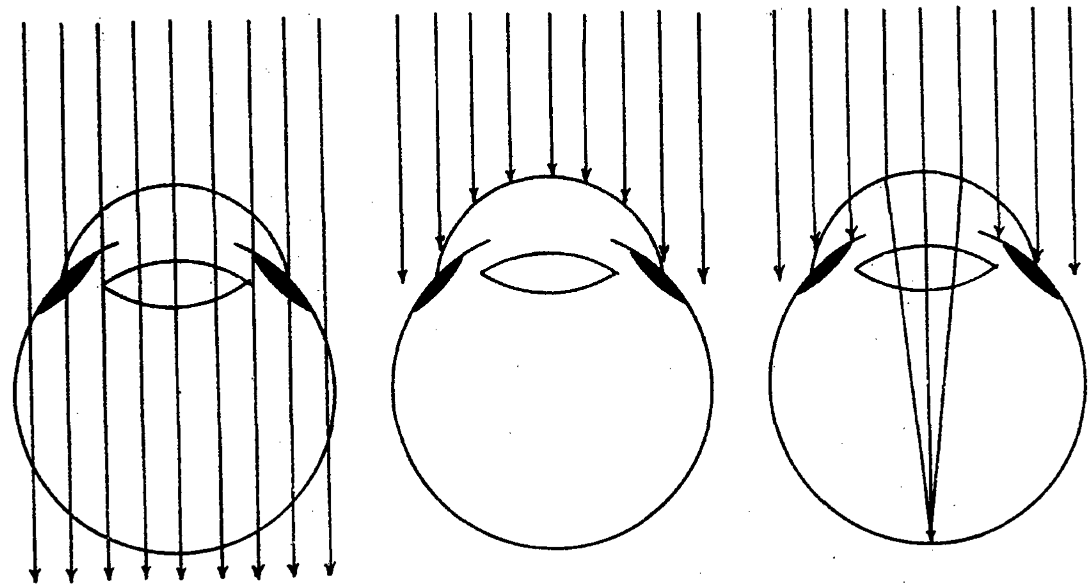
TYPE	WAVELENGTH	PULSE DURATION	LEVEL
Non-q-switched	6943Å	200 microsec.	0.85 joules/cm^2
Q-switched	6943Å	30 nanosec.	0.07 joules/cm^2
Continuous Wave	White Light	-------------	6.0 watts/cm^2

It is reasonable to assume that the threshold levels for other wavelengths absorbed at the retina (specifically the pigment epithelium) are approximately the same. It is emphasized that, due to the focusing effect of the eye, the energy density at the retina will be several orders of magnitude greater than the level before entering the eye. There is evidence that unobservable retinal changes are produced by energy densities approximately fifty percent below those shown in the table (i.e. q-switched-0.035 j/cm^2, and non-q-switched at 0.42 j/cm^2).

4. MEDICAL SURVEILLANCE

An individual whose occupation or assignment may result in overexposure to laser radiation should have a preplacement medical examination and a periodic eye examination, preferably, at six month intervals, or at such other times as there may be reason to believe that eye damage from laser may have occurred. A general eye examination, near and distance visual acuity and a detailed ophthalmoscopic evaluation of the retina should be made. A retinal fundus photograph of the foveal area at the time of preplacement examination is advisable. It is advisable to repeat this at anytime retinal damage is suspected. For individuals exposed to lasers emitting radiation

ABSORPTION PROPERTIES OF THE EYE FOR ELECTROMAGNETIC RADIATION



GAMMA AND X RADIATION

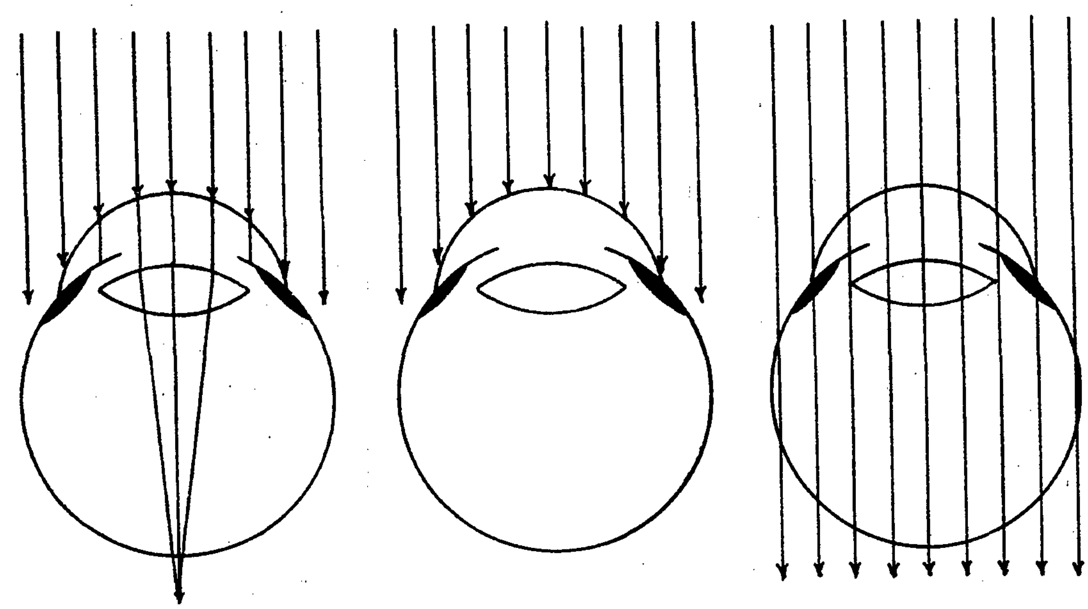
a) Most higher energy x-rays and gamma rays pass completely through the eye.

SHORT ULTRAVIOLET

b) Absorption occurs principally at the cornea.

LONG ULTRAVIOLET AND VISIBLE

c) Light is refracted at the cornea and lens and absorbed at the retina.



NEAR INFRARED

d) Energy is absorbed in the ocular media and at the retina; near infrared rays are refracted.

FAR INFRARED

e) Absorption is locallized at the cornea.

MICROWAVES

f) Microwave radiation is transmitted through the eye although a large percentage may be absorbed.

FIGURE A-1

TRANSMISSION IN OCULAR MEDIA TIMES ABSORPTION IN PIGMET EPITHELIUM

VS.

WAVELENGTH

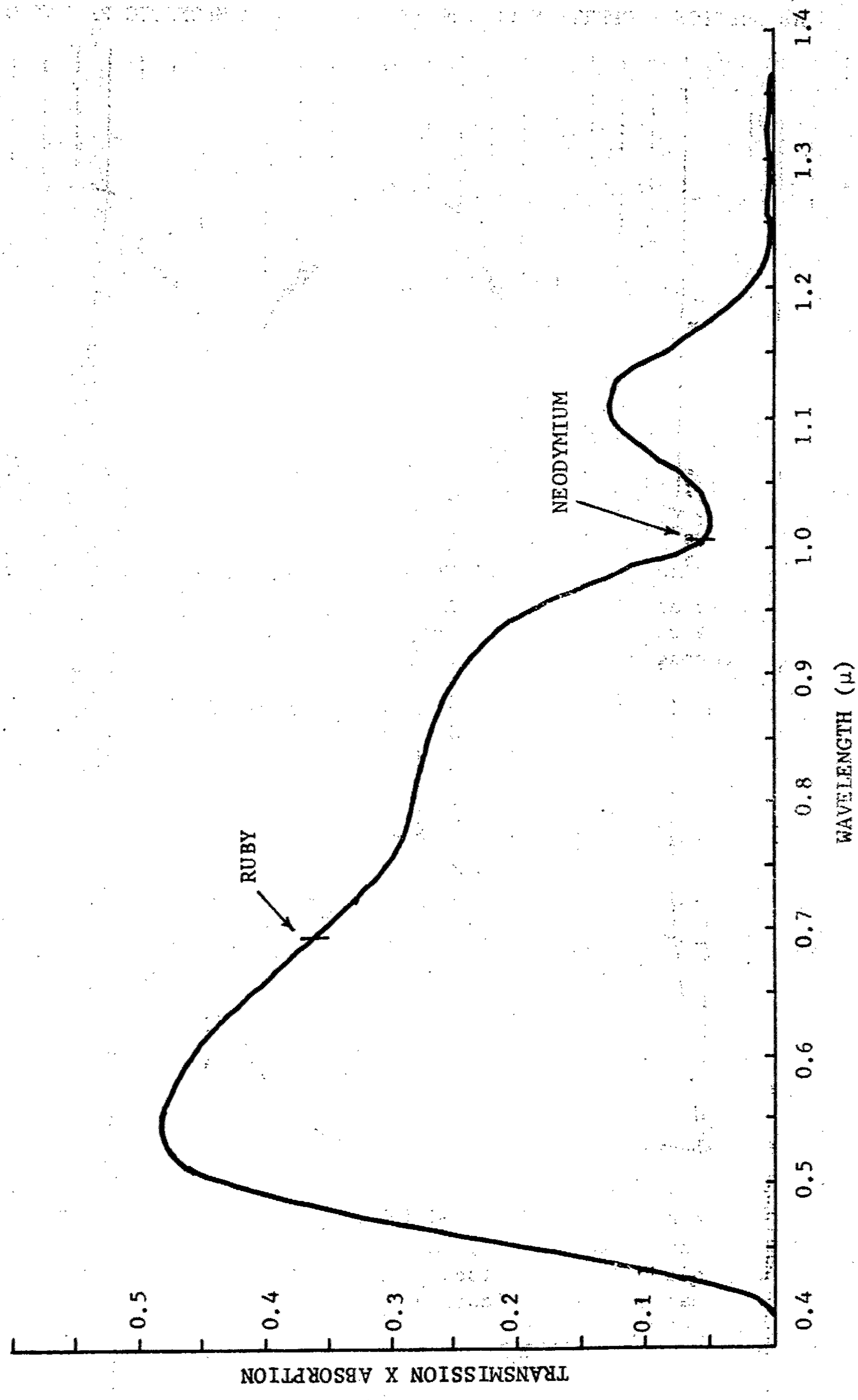


FIGURE A-2

in the ultraviolet and infrared regions, it is advisable to make a slit lamp examination periodically.

5. EXPOSURE OF PERSONNEL

a. Eye Exposure

(1) Design Criteria. An energy density of 1×10^{-7} joules per square centimeter at the cornea is considered to be a practical criterion for design purposes in the development of q-switched laser devices. Since this energy level is believed to be close to "the damage threshold" it should not be used for purposes of hazards evaluation of devices in use.

(2) Occupational Exposure Levels. Maximum permissible exposure levels at the cornea depend on several factors including the wavelength of the radiation, duration of exposure and pupil size (dependent upon ambient light levels). Exposure of the eyes to direct illumination or specular (mirror-like) reflections should not exceed the levels in the following table:

TABLE A-II

Maximum Permissible Occupational Exposure Levels for Laser Radiation at the Cornea for Direct Illumination or Specular Reflection at $\lambda = 6943\text{Å}$

	Daylight 3mm pupil	Laboratory 5mm pupil	Night 7.5mm pupil
Q-switched pulse Joules/cm^2	5×10^{-8}	2×10^{-8}	1×10^{-8}
Non-q-switched pulse Joules/cm^2	5×10^{-7}	2×10^{-7}	1×10^{-7}
Continuous Wave Laser Watts/cm^2	5×10^{-6}	2×10^{-6}	1×10^{-6}

These levels could be adjusted for other wavelengths by using the graph of energy transmitted to, and absorbed at, the retina (Figure A-2), and normalizing the curve at $\lambda = 6943\text{Å}$. However, under no circumstances should these adjusted levels exceed the corresponding levels in Table A-II by a factor greater than ten.

b. Skin Exposure

Maximum permissible exposure levels for the skin should not exceed the nighttime levels for the eye (Table A-II) by a factor or more than 10^5 (u.v. not applicable).

6. HAZARD EVALUATION

As the eye is the structure most sensitive to damage from a laser beam, hazard evaluation based on safe levels for this structure can safely be applied to the entire body.

a. Hazard Evaluation of the Primary Beam (direct viewing)

The worst possible situation would exist if the eye were focused at infinity and the beam concentrated at the retina in a diffraction spot. Under these conditions the levels in Table A-II, would be applicable. The beam intensity at the point of interest may be calculated by equation (2) of paragraph 10.

b. Viewing the Reflected Beam

(1) Specular Reflection. Specular reflection requires a mirror-like surface. If the reflecting surface is flat, the characteristics of the reflected beam may be considered identical to those of the direct beam except that the range is the sum of the distances from the laser source to reflector and from reflector to the eye. If the surface is not flat, the reflected light intensity arriving at the retina is less and may be readily calculated for a uniformly curved surface, if the curvature is known.

(2) Diffuse Reflection. The reflection from a flat diffuse surface obeys Lambert's Law (see equation (4) of paragraph 10) which relates the energy or power per solid angle to the surface brightness (i.e. essentially the "inverse square law"). A maximum brightness for the illumination of a diffuse material may be calculated from Table A-III. Such a maximum brightness would be the same regardless of the distance of the viewer or apparent size of the image, since the energy or power density at the retina remains the same. If the size of the reflection subtends an angle less than θ_{min} (equation (5), paragraph 10), the maximum allowable brightness may be greater. In this case, the level of reflected light arriving at the eye may again be calculated by Lambert's Law. The level reaching the retina may then be calculated in the same manner as for direct viewing.

TABLE A-III

Maximum Illuminance from a Diffuse Surface Reflection as Measured at the Reflecting Surface

Nature of Exposure	Environment: Daylight 3mm pupil	Laboratory 5mm pupil	Night 7.5mm pupil
Q-switched Pulse Joules/cm^2	.45	.15	.07
Non-q-switched Pulse Joules/cm^2	5.5	2.0	.9
Continuous Wave Laser Watts/cm^2	13.5	6.0	2.5

NOTE: The actual illuminance from a diffuse surface may be calculated by multiplying the energy or power density of the beam impinging upon the surface by the reflectance (a property of the material).

c. Other Factors

(1) Atmospheric Effects. The effect of atmospheric attenuation may become a major factor in evaluating the energy or power density at distances greater than a few kilometers. This attenuation is the sum of three effects: first, Mie (or large particle) scattering, where the particle size is greater than λ (wavelength of the light), and is normally the greatest contributor; second, Rayleigh (or molecular) scattering (where particle size is much less than the wavelength) is reasonably constant for a given wavelength; and, third, absorption by gas molecules which is relatively insignificant in comparison to scattering and may, therefore, be disregarded. Attenuation due to scattering is much more pronounced at shorter wavelengths, thus red light from a ruby laser is scattered far less than wavelengths in the blue end of the visible spectrum. A clean atmosphere may therefore be expected to be quite transparent to the ruby wavelength. The atmospheric attenuation effect upon a non-diverging beam is expressed by equation (1) of paragraph 10. The scattering effect may attenuate a ruby laser beam by as little as 10% at 10 kilometers and 60% at 100 kilometers. Atmospheric turbulence results in increased attenuation, but assuming a very stable atmosphere (the worst possible case), this effect can be disregarded. The meteorological visibility, based upon the entire visible spectrum, may not be readily utilized in arriving at the attenuation coefficient at a given wavelength.

(2) Effect of Optical Viewing Instrument

(a) Viewing Diffuse Reflection. The effect on the retinal energy density, by viewing a diffuse reflection of an extended object through a telescope, is often to lower it slightly. This is due to the fact that, although the total light energy entering the eye is greater, it is distributed over a greater area on the retina. The maximum increase in light energy entering the eye is the ratio of the area of objective aperture to the area of the exit pupil aperture. The true value will be slightly less due to the absorption of some light in the optical system. The size of the image is increased by the magnification (or power) of the optical system which results in an increase of image area of the power squared. The energy or power density of a retinal image does not vary for subject-to-reflection distance as long as the image is not diffraction-limited.

(b) Viewing Specular Reflection. If, however, the laser beam is viewed directly, or by specular reflection, the laser spot size is, essentially, a point source and is still diffraction-limited upon "magnification" by the optical system. The power, then, does not affect the energy density since the image size is still a retinal diffraction pattern, thus allowing the optical device to increase the retinal energy density considerably. The situation may be further complicated by an image not quite being diffraction-limited. For the purpose of simplification it may be assumed that the level on the retina will increase as the square of the magnification of the optical instrument.

7. EXPOSURE CONTROL

Control of occupational hazards, incidental to the use of lasers, must be aimed at maintaining exposures not greater than the maximum permissible level. Potential occupational hazards include: damage to the eyes, skin and other human organs; "burns" from contact with liquid nitrogen or other substances used as coolants; electrical shock; exposure to gases such as ozone; and explosions at capacitor banks, optical pump systems and target areas. A complete safety program must be maintained for the protection of operating personnel and other persons who may be required to be present at laser installations. Suitable control should be provided as indicated by the nature of the operation. Provision for a closed installation is desirable. The equivalent of a closed installation can be achieved by installing a laser in a light-proof enclosure. Where neither of these alternatives are followed an open installation results and the following safeguards should apply:

a. General Precautions Applicable to All Laser Installations

(1) Looking into the primary beam and at specular reflections of the beam must be avoided when power or energy densities exceed the maximum permissible exposure levels.

(2) Aiming the laser with the eye should be avoided to prevent looking along the axis of the beam, which increases the hazard from reflections.

(3) Work with lasers should be done in areas of high general illumination to keep pupils constricted and thus limit the energy which might inadvertently enter the eyes.

(4) Safety eyewear designed to filter out the specific frequencies, characteristic of the system, affords partial protection. Safety glasses should be evaluated periodically to insure maintenance of adequate optical density at the desired laser wavelength. There should be assurance that laser goggles, designed for protection from specific lasers, are not mistakenly used with different wavelength lasers. Laser safety glasses exposed to very intense energy or power density levels may lose effectiveness and should be discarded.

(5) The laser beam should be terminated by a material that is nonreflective and fire resistant, and an area should be cleared of personnel for a reasonable distance on all sides of the anticipated path of the laser beam.

(6) Suitable precautions to avoid electrical shock should be followed in connection with the potentially dangerous electrical circuits (both high and low voltage).

b. Special Precautions for High-Powered Pulsed Lasers

(1) Safety interlocks at the entrance to the laser facility should be constructed so that unauthorized or transient personnel are denied access to the facility while the laser power supply is charged and capable of firing.

(2) Laser electronic firing systems should be designed so that accidental pulsing of a stored charge is avoided. The design should incorporate a "fail-safe" system.

(3) An alarm system including a muted sound, flashing lights (visible thru laser safety eyewear) and a countdown is advisable once the capacitor banks begin to charge.

(4) Installations using liquid nitrogen coolant should be adequately ventilated.

(5) Walls and ceiling should be painted with diffuse non-gloss paint, preferably black, near the target area, and a light color elsewhere, to increase ambient light level.

(6) Where feasible, solid-state lasers such as ruby pulsed devices, because of their higher power output (in the megawatt and gigawatt range), should be operated by remote control firing with television monitoring to eliminate the requirement for personnel to be in the same room with the laser. An alternative is to enclose the laser and beam within a light-tight box.

c. Special Precautions for Low Powered Gas C.W. and Semi-Conductor Lasers*

It is especially important to avoid the hazard from specular reflection, during the alignment of the beam by eye.

(1) The use of a diffuse matte to position the beam is advisable, but the matte should be of such a color, or reflectivity, as to minimize reflection while still making the beam visible.

(2) Elimination of all reflective material from the area of the beam (good housekeeping) is essential.

(3) Higher power (watt range) infrared lasers such as the CO_2 laser (10 microns) must be used with the utmost precaution, due to its invisible beam and the associated fire hazard.

d. Carbon Dioxide - Nitrogen (CO_2-N_2) Gas Lasers

(1) The principal hazard associated with the CO_2-N_2 lasers is the fire hazard. A sufficient thickness of firebrick or asbestos should be provided as a backstop for the beam.

(2) The laser assembly should be constructed of a material opaque to ultraviolet light generated by the gas discharge. Quartz tubing transmits ultraviolet light, whereas certain heat-resistant glass tubing is reasonably opaque at this part of the spectrum.

(3) Reflections of the infrared laser beam should be attenuated by enclosure of the beam and target area, or by eyewear constructed of a material opaque to the CO_2 wavelength, such as plexiglass.

*High Powered Gas and Semi-Conductor Lasers are to be treated as Pulsed Lasers.

e. Additional Precautions for Lasers in an Outdoor Environment

(1) Personnel should be excluded from the beam path to a distance where power or energy density is within permissible levels. This may be accomplished by: The use of physical barriers; administrative control; interlocks; and limiting beam traverse.

(2) The inadvertent or intentional tracking of non-target vehicular traffic or aircraft should be prohibited if it is within the calculated hazardous distance.

(3) Operation of the laser in rain, snow, fog or dust should be avoided.

(4) The beam path should be cleared of all objects capable of producing potentially hazardous reflections.

f. Warning Signs

Evaluation of each anticipated operating condition should include the consideration and development of procedures for ensuring the proper placement of warning signs for that operation. Local standard operating procedures should prescribe the placement of temporary or permanent signs during periods of operation. A sign such as that shown below should be used.

FIGURE A-3

8. PERSONNEL PROTECTIVE EQUIPMENT

a. Personnel exposed to laser beams must be furnished suitable laser safety goggles of optical density (O.D.) adequate for the energy involved. The following table lists the maximum power, or energy density, for which adequate protection is afforded by glasses of optical densities (O.D.) from 1 thru 8. This table is based on the maximum permissible exposure levels for a darkness adapted eye.

TABLE A-IV

Attenuation of Laser Safety Glass

O.D.	db Attenuation	Attenuation Factor	Q-switch Max. Energy Density (j/cm^2)	Non-q-switch Max. Energy Density (j/cm^2)	C.W. Max. Power Density(watts/cm^2)
0	0	0	10^{-8}	10^{-7}	10^{-6}
1	10	10	10^{-7}	10^{-6}	10^{-5}
2	20	10^{+2}	10^{-6}	10^{-5}	10^{-4}
3	30	10^{+3}	10^{-5}	10^{-4}	10^{-3}
4	40	10^{+4}	10^{-4}	10^{-3}	10^{-2}
5	50	10^{+5}	10^{-3}	10^{-2}	10^{-1}
6	60	10^{+6}	10^{-2}	10^{-1}	1.0
7	70	10^{+7}	10^{-1}	1.0	10
8	80	10^{+8}	1.0	10	100

b. Exposure of the skin of personnel should be prevented by the use of protective gloves where only the hands are to be involved. Where other than the hands are to be exposed, protective coverings, or shields, should be used. The face should be turned away from the target area. Laser welding facilities should have sufficient shielding surrounding the article being welded.

c. Impervious, quick-removal type, gloves, face shields, and safety glasses should be provided as minimum protection for personnel who handle the extremely low temperature liquid coolants used in higher powered lasers.

9. REQUESTS FOR TECHNICAL ASSISTANCE

Assistance in evaluating potential health hazards to Army personnel from the operation or testing of laser equipment is available from the U. S. Army Environmental Hygiene Agency, Edgewood Arsenal, Maryland 21010. This Agency maintains a capability for investigating and evaluating health hazards associated with the use of this equipment. The services of the Agency are available upon request to: The Surgeon General, ATTN: MEDPS-P, Department of the Army, Washington, D. C. 20315.

10. CALCULATIONS

a. The following symbols are used in laser computations:

E = level of radiation leaving the laser (output measured in milliwatts or watts; pulsed output measured in joules)

r = range from the laser to the point of concern (cm)

r_1 = range from the laser target to the point of concern (cm)

I = intensity at range, r, measured in joules/cm^2 for pulsed, and watts/cm^2 for C.W. lasers

I_o = emergent Beam intensity at zero range

a = diameter of emergent laser beam (cm)

ϕ = emergent beam divergence measured in radians

e = base of natural logarithms

μ = atmospheric attenuation coefficient (cm^{-1}) at a particular wavelength

f = effective focal length of eye in air (1.7 cm)

θ_{min} = minimum angle subtended by the minimal retinal spot size (radians)

d_e = diameter of the pupil of the eye (varies from approximately 0.2 to 0.8 cm)

D_e = diameter of the exit pupil of an optical system (cm)

D_L = diameter of laser beam at range r (cm)

D_o = diameter of objective of an optical system (cm)

d_{min} = diameter of minimal spot on retina (cm)

R = spectral reflectance of a diffuse object

P = magnification or power of an optical system

L = ratio of retinal energy or power density for an optically aided eye to retinal energy or power density for an unaided eye

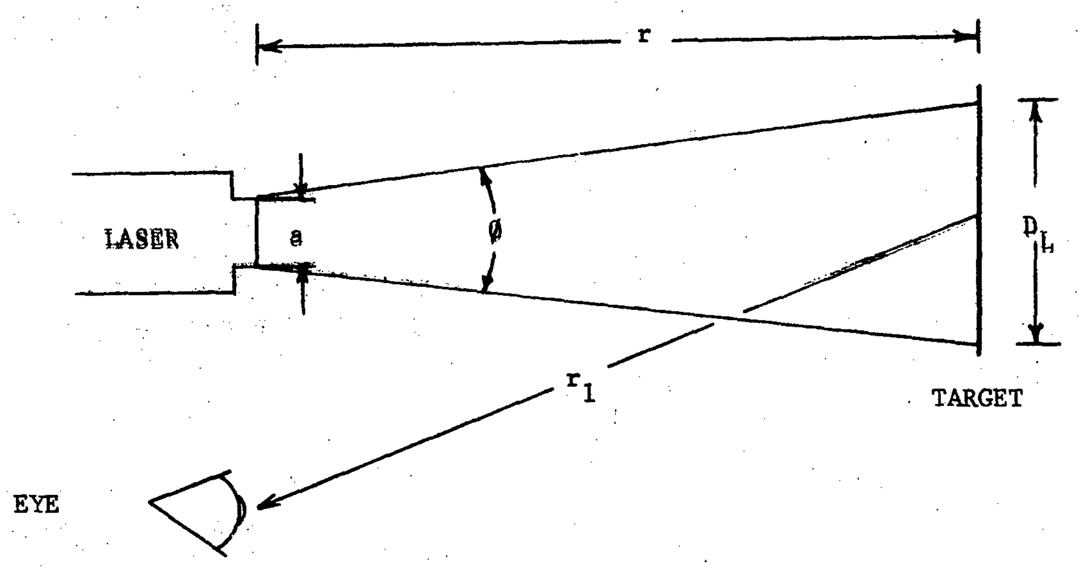


FIGURE A-4. Graphical Representation of the Symbols Used

b. The following formulas are used:

(1) Beam intensity for <u>non-diverging beam</u> at range, r, which is attenuated by the atmosphere is:

$$I = I_o e^{-\mu r} \qquad \text{(Eqn 1)}$$

Note: The attenuation coefficient, μ, varies from 10^{-4} per cm in thick fog to 10^{-7} in air of very good visibility. The Rayleigh scattering coefficient at 6943Å is 4.8×10^{-8} cm^{-1}, and 1.8×10^{-8} cm^{-1} at 5000Å. The effect of aerosols in even the cleanest atmospheres usually raises μ at 6943Å to at least 10^{-7} cm^{-1}.

(2) Beam intensity at range, r, (direct circular beam) is the total energy in the beam at that range divided by the area of the beam at that range:

$$I = \frac{E\, e^{-\mu r}}{\pi \left(\frac{a + r\phi}{2}\right)^2} \qquad \text{(Eqn 2)}$$

Note: Accurate only for small ϕ; i.e., accuracy of ϕ better than 1 percent for angles below .17 radian (10°) and better than 5 percent for angles less that .37 radian (21°).

Example 1: To find the energy density at 1 Km (10^5cm) of a 0.1 joule ruby laser which has a beam divergence of 1 milliradian (10^{-3} radians) and an emergent beam diameter of 0.7 cm:

$$I = \frac{(0.1\ j)\quad e^{-(.01)}}{3.14 \left[\frac{0.7 + (10^5)(10^{-3})}{2}\right]^2} = \frac{(0.1)\ (.99)}{3.14 \left(\frac{0.7 + 100}{2}\right)^2}$$

$$= 1.25 \times 10^{-5}\ j/cm^2.$$

(3) Minimum beam diameter at range r:

$$D_L = a + \phi r, \text{ for small } \phi \qquad \text{(Eqn 3)}$$

Example 2: To find the diameter of a laser beam at 1 kilometer where the emergent beam diameter is 10 cm and the beam divergence is 0.1 milliradian:

$$D_L = 10^5 \text{cm} + (10 \text{ cm})(10^{-4} \text{milliradians}) = 10 + 10$$

$$= 20 \text{ cm}$$

(4) Reflected energy density from diffuse reflector:

$$I = \frac{ER}{\pi r_1^2} \quad (\text{for } r_1 \gg D_L) \qquad \text{(Eqn 4)}$$

Example 3: To find the maximum reflected energy density from a diffuse matte of reflectance 0.6 which would return a distance of 10 meters to the operator of a 0.1 joule laser:

$$I = \frac{(0.1j)(0.6)}{(3.14)(10^3 \text{cm})^2} = 1.91 \times 10^{-8} \text{ j/cm}$$

(5) Limiting angle for extended object:

$$\theta \text{ min} = d_{min} f \qquad \text{(Eqn 5)}$$

$$= 0.5 \text{ milliradians for } d_{min} = 10 \text{ microns}$$

(6) Ratio L of energy or power density at the retina when viewing is aided by an optical system, as opposed to viewing by the naked eye:

(a) Direct viewing and specular reflection (or diffuse spot unresolved by eye and optical system):

$$L = \frac{D_o^2}{d_e^2} \quad \text{for } d_e \geqq D_e \qquad \text{(Eqn 6)}$$

and

$$L = \frac{D_o^2}{D_e^2} = P^2 \quad \text{for } d_e \leqq D_e \qquad \text{(Eqn 7)}$$

(b) Indirect viewing of a diffuse reflection; extended objects only (i.e., object subtends angle greater than .5 milliradians when magnified):

$$L = \frac{D_o^2}{P^2 d_e^2} \quad \text{for } d_e \geqq D_e \qquad \text{(Eqn 8)}$$

and

$$L = \frac{D_o^2}{p^2 D_e^2} = 1 \quad \text{for } d_e \leq D_e \qquad \text{(Eqn 9)}$$

Example 4: The laser operator of Example 3 desires to view the laser flash thru a pair of 10x50 binoculars (i.e. P = 10 and D_o = 50 mm). For bright daylight find the relative hazard to this man's eyes. Since the exit pupil is not given, Eqn 8 will give a conservative, if not exact answer:

$$L = \frac{(5\text{cm})^2}{(10)^2(0.3\ \text{cm})^2} = \frac{25}{(100)(.09)} = 2.78$$

The hazard is equivalent to a corneal irradiance on the naked eye of: $(2.78)(1.91\text{x}10^{-8}\text{j/cm}^2) = 5.3\text{x}10^{-8}\ \text{j/cm}^2$.

Example 5: A laser operator views a specularly reflected beam at a point where the beam energy density measures 2×10^{-9} j/cm^2. If he were to view the beam through a pair of 7 X 50 binoculars, what would be the relative hazard compared with unaided viewing? The magnification, P, of the binoculars is 7 and, if inserted in equation 7 will provide the simplest solution:

$$L = P^2 = 7^2 = 49$$

Thus the operator would be viewing a level 49 times greater than by the naked eye, or a corneal irradiance of nearly 10^{-7} j/cm^2.