METRIC

MIL-HDBK-828A
31 December 1996
SUPERSEDING
MIL-HDBK-828
15 April 1993

DEPARTMENT OF DEFENSE
HANDBOOK
LASER SAFETY ON RANGES AND IN OTHER OUTDOORS AREAS

This handbook is for guidance only.
Do not cite this document as a requirement.

AMSC N/A **FSC 4240**

Distribution Statement A. Approved for public release; distribution unlimited.

MIL-HDBK-828A

DEPARTMENT OF DEFENSE

LASER SAFETY ON RANGES AND IN OTHER OUTDOORS AREAS

1. The Department of Defense Laser Systems Safety Working Group (DoD LSSWG) developed this handbook. The working group, chartered by the Department of Defense, has representatives from the United States Army, United States Navy, United States Air Force, United States Marine Corps and the United States Coast Guard.

2. This document supplements departmental manuals, directives, military standards, and other related documents, to assist in standardization of basic information on laser range safety.

3. Beneficial comments (recommendations, additions, and deletions) and any pertinent data for improving this document should be addressed to Chief, Bureau of Medicine and Surgery, MED-212, 2300 E Street NW, Washington, DC 20372-5300.

FOREWORD

1. All Departments and Agencies of the Department of Defense approve the use of this handbook.

2. Obtain copies of this document through DoD publication channels.

Available from: Standardization Documents Order Desk
Bldg 4D
700 Robbins Avenue
Philadelphia, PA 19111-5094

3. To place an order by touch tone telephone, obtain a customer number (for urgent requests, a customer number may be obtained by calling (215) 697-2179 and access the telephone order entry system by dialing (215) 697-1187 (replace the letter “Q” with “7" and “Z” with “9").

TABLE OF CONTENTS

1. SCOPE 1
1.1 Scope 1
1.2 Application 1
1.2.1 Exclusions 2
1.2.2 High energy systems 2
1.2.3 Broad beam lasers 2
1.2.4 Force-on-force exercises 2
1.3 Content 2

2. APPLICABLE DOCUMENTS 3
2.1 General 3
2.2 Government documents 3
2.2.1 Standards 3
2.2.2 Other Government publications 3
2.3 Non-Government publications 5
2.4 Order of precedence 5

3. DEFINITIONS 6
3.1 Definitions 6
3.1.1 Aircraft exclusion zone 6
3.1.2 Aperture 6
3.1.3 Attenuation 6
3.1.4 Beam divergence 6
3.1.5 Buffer angle 6
3.1.6 Buffer zone 6
3.1.7 Laser footprint 6
3.1.8 Closed installation 6
3.1.9 Collateral radiation 6
3.1.10 Continuous wave (CW) 6
3.1.11 Controlled area 6
3.1.12 Diffuse reflection 7
3.1.13 Electromagnetic radiation 7
3.1.14 Exempted lasers 7
3.1.15 Field of detection 7
3.1.16 High energy laser 7
3.1.17 Infrared radiation (IR) 7
3.1.18 Irradiance (E) 7
3.1.19 Joule 7
3.1.20 Laser 7

3.1.21 Laser controlled area 7
3.1.22 Laser radiation 7
3.1.23 Laser safety officer (LSO)/laser system safety officer (LSSO) 8
3.1.24 Laser surface danger zone (LSDZ), nominal hazard zone (NHZ) 8
3.1.25 Maintenance 8
3.1.26 Maximum permissible exposure (MPE) 8
3.1.27 Milliradian (mrad) 8
3.1.28 Micrometer (µm) 8
3.1.29 Nanometer (nm) 9
3.1.30 Night vision goggles/devices 9
3.1.31 Nominal hazard zone (NHZ) 9
3.1.32 Nominal ocular hazard distance (NOHD) 9
3.1.33 Optical density (OD) 9
3.1.34 Optical radiation 9
3.1.35 Pulse duration. 9
3.1.36 Pulsed laser 9
3.1.37 Radian (rad) 9
3.1.38 Radiance (L) 9
3.1.39 Radiant energy (Q) 9
3.1.40 Radiant exposure (H) 9
3.1.41 Radiant flux or power ( ) 10
3.1.42 Reflectance or reflectivity (P) 10
3.1.43 Repetitively pulsed laser 10
3.1.44 Service 10
3.1.45 Solid angle ( ) 10
3.1.46 Specular reflector 10
3.1.47 Steradian (sr) 10
3.1.48 Support equipment 10
3.1.49 Transmittance or transmissivity (t) 10
3.1.50 Ultraviolet radiation 10
3.1.51 Visible radiation (light) 10
3.1.52 Watt (W) 10
3.1.53 Wavelength ( ) 10

4. GENERAL RANGE CONTROL PHILOSOPHY 11
4.1 General policy 11
4.2 Recommended targets 12
4.3 Beam control 13
4.4 Specular reflectors 13
4.5 Hazards 13
4.6 Unprotected personnel 14
4.7 Warning signs 14

4.8 Personnel protection 15
4.9 Magnifying optics 15
4.10 Night vision goggles/devices 15
4.11 Specific guidelines 16
4.12 Laser pre-firing and post firing restrictions 19
4.13 Stationary continuously operating lasers 19
4.14 Tactics 19
4.14.1 Ground laser designators 20
4.14.2 Airborne wingman laser designation 21

5. PLANNING REQUIREMENTS 26
5.1 Range evaluation planning 26
5.1.1 Background 26
5.1.2 Laser user 26
5.1.3 Range operator 26
5.1.4 Range evaluator 26

6. EVALUATION REQUIREMENTS 28
6.1 Range evaluation procedure 28
6.1.1 Evaluation sequence 28
6.1.2 Target and/or target area condition 33
6.1.3 System performance 33
6.1.4 Laser Surface Danger Zone (LSDZ) 33
6.1.4.1 LSDZ dimensions 34
6.1.5 Range facilities evaluation 37
6.1.6 Visual survey 40
6.1.7 Laser parameters 40
6.1.8 Laser footprint 41
6.1.9 Other considerations 43
6.1.10 Range control procedures and recommendations 43

7. REQUIREMENTS FOR USER LEVEL LASER INSTRUCTIONS 47
7.1 User-level laser instructions 47
7.1.1 Instruction 47
7.1.2 Directives 47
7.1.3 Standard Operating Procedures (SOP) 47
7.1.4 Safety briefing 47
7.1.5 Protective equipment 47
7.2 Systems briefings 48

8. NOTES 49
8.1 Intended use 49

8.2 Changes from previous issue 49
8.3 Subject term (keyword) listing 49
8.4 International standardization agreement 49

APPENDICES

APPENDIX A. SUMMARY OF LASER SAFETY INFORMATION FOR FIRE CONTROL LASER SYSTEMS A-1
A.1 SCOPE A-1
A.2 APPLICABLE DOCUMENTS A-1
A.3 FIRE CONTROL LASER SAFETY FEATURES A-1
A.3.1 Fire control laser systems. A-1
A.3.2 Current laser safety summary A-1
A.3.3 Ruby LRFs. A-1
A.3.4 Distance s A-1
A.3.5 Buffer zones. A-8
A.3.6 Eye protection. A-8
A.3.7 Description of fielded laser systems A-8
A.3.8 Description of inactive lasers and associated systems A-11

APPENDIX B. MILES OPTICAL SAFETY SUMMARY B-1
B.1 SCOPE B-1
B.2 APPLICABLE DOCUMENTS .....
B.3 OPTICAL SAFETY B-1
B.3.1 MILES B-1
B.3.2 Schwartz electro-optic controller gun B-1

APPENDIX C. AGES/AD, LATAGS, PGTS, AND AN/GVT-1 SAFETY SUMMARY C-1
C.1 SCOPE C-1
C.2 APPLICABLE DOCUMENTS C-1
C.3 SAFETY SUMMARY C-1

APPENDIX D. SAMPLE CONTENT FOR LASER SAFETY SOP FOR TRAINING WITH PORTABLE FIRE CONTROL LASERS D-1
D.1 SCOPE D-1
D.2 APPLICABLE DOCUMENTS D-1
D.3 WARNING D-1

APPENDIX E. EQUATIONS FOR LASER HAZARD EVALUATION E-1
E.1 SCOPE E-1
E.2 APPLICABLE DOCUMENTS E-1

E.3 APPLICATION OF EQUATIONS E-1
E.3.1 Introduction E-1
E.3.2 Hazard evaluation E-1
E.3.3 Footprint determinations E-4

APPENDIX F. DOD LASER RANGE SURVEY CHECKLISTS F-1
F.1 SCOPE F-1
F.2 APPLICABLE DOCUMENTS F-1
F.3 CHECKLISTS F-1
F.3.1 Laser range presurvey checklist F-2
F.3.2 Review of range SOP and/or laser safety instruction F-5
F.3.3 Range laser site survey F-7
F.3.4 Range survey report F-9

APPENDIX G. SPECULAR REFLECTION G-1
G.1 SCOPE G-1
G.2 APPLICABLE DOCUMENTS G-1
G.3 SPECULAR REFLECTION CHARACTERISTICS G-1
G.3.1 Introduction G-1
G.3.2 Flat reflectors G-1
G.3.3 Hazardous ranges of reflected laser beam G-2

APPENDIX H. SEPARATE TARGET (SEPTAR) AND SHIP'S TOWED TARGET OPERATIONS H-1
H.1 SCOPE H-1
H.2 APPLICABLE DOCUMENTS H-1
H.3 GUIDANCE H-1
H.3.1 SEPTAR operations H-1
H.3.2 Ship's towed target operations H-8

APPENDIX I. SATELLITE SAFETY PROCEDURES FOR SPACE DIRECTED LASERS I-1
I.1 SCOPE I-1
I.1.1 Scope I-1
I.2 REFERENCES I-1
I.3 DEFINITIONS I-1
I.4 APPLICABILITY I-1
I.5 CONCEPT OF OPERATIONS I-2
I.6 JCCDOA RESPONSIBILITIES I-2
I.7 LASER FACILITY RESPONSIBILITIES I-4

FIGURES

4-1. Direct intrabeam viewing 12
4-2. Reflected intrabeam viewing 13
4-3. Example: warning sign 14
4-4. Sample safety exclusion cone for ground laser designator 22
4-5. Sample side view of safety exclusion volumes for ground laser designator 23
4-6. Sample plan view of safety exclusion cones to prevent homing on laser designator aircraft during continuous laser designation 23
4-7. Sample vertical view of safety exclusion cones to prevent homing on continuous laser designator aircraft 24
4-8. Sample delayed laser designation safety exclusion cone, vertical view 24
4-9. Generalized concept of risk variables related to laser target designator and laser seeker field of view 25
6-1. Diffuse reflection and specular reflection 30
6-2. Laser Surface Danger Zone (LSDZ) 35
6-3. LSDZ without and with natural backstop 36
6-4. Example laser range danger fan/laser surface danger zone 38
6-5. Vertical buffer zone 39
6-6. Effects of backstops 40
6-7. Example of airborne beam reflection 42
6-8. Examples of the use of natural backstops, buffer zones, and restricted air space 46
6-9. Supervised laser demonstration for military training. (modified from FIGURE 2D, ANSI Z136.1) 47
E-1. Laser footprint with single target - side view E-5
E-2. Laser footprint with multiple targets - side view E-5
E-3. Laser footprint top view E-5
E-4. LSDZ - attack bearing 90 degrees E-6
E-5. LSDZ - attack bearing 70 degrees to 110 degrees E-6
E-6. LSDZ - attack from any direction E-6
E-7. LSDZ with rising terrain E-12
E-8. Use of natural backstops to control laser beam E-12
E-9. Insufficient backstop to control laser beam E-12
E-10. LSDZ with terrain sloping down. Range less than NOHD E-13
E-11. LSDZ with terrain sloping down. Range greater than NOHD E-13
E-12. Reflections from still water with LDZ E-13
E-13. Example of airborne laser beam reflection E-14
E-14. Potential exposure modes E-15
E-15. Reflections from flat specular surface - side view E-15
E-16. Reflections from flat specular surface - top view E-15

E-17. Vertical buffer and LSDZ geometry E-17
E-18. Calculation of available buffer versus allowed buffer E-19
E-19. Airborne laser buffer geometry - level ground E-20
E-20. Example laser aircraft flight profile E-22
E-21. Laser target on sloping terrain E-23
G-1. LSDZ with specular reflections from standing still water G-3
G-2. LSDZ with specular reflective target - side view G-3
G-3. Specular reflectance from both surfaces of plate glass (index of refraction = 1.5) G-4
G-4. Specular reflectance from sea water (index of refraction = 1.378) G-5
G-5. Specular reflectance from fresh water (index of refraction =1.33) G-6
H-1. SEPTAR operations area and buffer zone H-2
H-2. Zones relative to towing ship's heading in which laser operations are permitted for A-6E TRAM, OV-10D NOS, F111-Pave Tack, and Pave Spike H-9

TABLES

6-I. Typical reflective surfaces 29
A-I. NOHD and range safety information for fielded military laser systems A-2
A-II. NOHD and range safety information for commercial off-the-shelf (COTS) military lasers A-7
A-III. Eye protection requirements for fielded lasers A-14
A-IV. Eye protection requirements for COTS military lasers A-16
B-I. NOHD for miles and other training lasers B-1
C-I. Cautionary distances for eye exposure to the AGES/AD, LATAGS, PGTS, TWGSS/PGS, JAVELIN, ISMT/IST, and AN/GVT-1 ..... C-2
E-I. Laser footprint table for: pave spike (using vacuum NOHD) E-7
E-II. Laser footprint table for: pave spike (including atmospheric attenuation for lasing from altitudes below 1 KM MSL only) E-8
E-III. Laser footprint table for: pave tack (using vacuum NOHD) E-9
E-IV. Laser footprint table for: pave tack (including atmospheric attenuation for lasing from altitudes below 1 KM MSL only) E-10
E-V. Laser footprint table for: any laser system with beam divergence < 0.5 MRAD E-11
G-I. Reflectivity of glass at various angles of incidence G-8
G-II. Reflectivity of fresh water at various angles of incidence G-9
G-III. Reflectivity of sea water at various angles of incidence G-10
G-IV. Reflectivity of shiny metal G-11
H-I. Flight profile against SEPTAR. One NMI buffer zone around one nautical mile operation area - 0 degree to 360 degrees H-3

H-II. Flight profile against SEPTAR. Two NMI buffer zone around one nautical mile operation area - 0 degree to 360 degrees H-4
H-III. Flight profile against SEPTAR. Three NMI buffer zone around one nautical mile operation area - 0 degree to 360 degrees H-5
H-IV. Flight profile against SEPTAR. Four NMI buffer zone around one nautical mile operation area - 0 degree to 360 degrees H-6
H-V. Flight profile against SEPTAR. Five NMI buffer zone around one nautical mile operation area - 0 degree to 360 degrees H-7

1. SCOPE

1.1 Scope. This handbook provides uniform evaluation guidance for the safe use of military lasers and laser systems on DoD military reservations or military controlled areas worldwide. Each military service establishes normal procedures for approving laser ranges. This guidance supplements those procedures. It does not replace those procedures or release individuals from compliance with the requirements of their particular service. The authority for guidance herein is the laser system safety-working group (LSSWG) established by DODI 5000.1. Guidance for lasers not addressed herein should be obtained from LSSWG through respective service health and safety organizations listed in 1.2.

1.2 Application. This handbook applies to:

a. All DoD ranges or operational test facilities where lasers are used and all DoD laser operations conducted on non-DoD controlled ranges or test facilities.

b. Laser systems that have been evaluated by the DoD Laser Safety Review Board health and safety specialists for your respective service are as designated below:

1. US Army Center for Health Promotion and Preventive Medicine
   ATTN: MCHB-DC-OLO
   Aberdeen Proving Ground, MD 21010-5422
   DSN 584-3932/2331, Commercial (301) 671-3932

2. Naval Surface Warfare Center (Code G-71)
   Dahlgren Division
   Dahlgren, VA 22448-5100
   DSN 249-1060/1149, Commercial (540) 653-1060/1149

3. Armstrong Laboratory
   Health Physics
   Optical Radiation Division
   Brooks AFB, TX 78235-5501
   DSN 240-4784, Commercial (210) 536-3625

c. Outdoor laser use.

d. Single-sided laser exercises.

e. Fixed and rotary wing airborne laser platforms, as well as ground- and ship-mounted laser systems.

1.2.1 Exclusions. This handbook does not apply to:

a. Indoor use; for example, laboratory laser repair depots or industrial laser facilities due to the unique control measures required.

b. Industrial and construction lasers such as those used for surveying.

c. New technology laser applications.

1.2.2 High energy systems. High energy laser systems (lasers capable of cutting material or burning standard target material) require unique control measures. Use of these lasers must be approved by the local Laser Safety Officer (LSO) in coordination with the specialists designated in 1.2b.

1.2.3 Broad beam lasers. Lasers with broad beam or autonomous scanning systems that are not directly under the operator's control may require additional evaluation assistance from the organizations listed in 1.2b.

1.2.4 Force-on-force exercises. Force-on-force exercises using lasers and laser devices (except training lasers such as the Multiple Integrated Laser Engagement System (MILES) which is addressed elsewhere in this Manual) are special cases requiring additional controls. These force-on-force lasers must be addressed on an individual basis by the local LSO with assistance from the Service component safety and health specialist designated in 1.2b.

1.3 Content. This handbook contains sections that give the general and detailed policies to be followed in evaluating and recommending laser range safety procedures. APPENDIX A provides safety hazard control data for specific laser systems evaluated by each of the service safety specialists. APPENDIX B provides safety information on lasers used for scoring tactical exercises. APPENDIX C summarizes safety data for gunnery training systems and simulators. APPENDIX D is a sample Laser Safety Standard Operating Procedure (SOP). APPENDIX E describes the equations utilized to determine Laser Surface Danger Zones (LSDZ)/Nominal Hazard Zones (NHZ). APPENDIX F contains checklists to be used for the laser safety pre-survey, the site survey, and the laser range safety evaluation reports. APPENDIX G discusses methods of evaluating hazards from specular reflections of the laser beam. APPENDIX H provides safety policy for at-sea operations against ship towed targets and separate targets (SEPTAR). APPENDIX I addresses procedures to obtain approval of Space Command Control Center for space directed emissions.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, and 5 of this standard. This section does not include documents cited in other sections of this handbook or recommended for additional information or as examples. Documents cited in sections 3, 4 and 5 of this handbook are requirements.

2.2 Government documents.

2.2.1 Standards.

MILITARY

MIL-STD-1425	Safety Design Requirements For Military Lasers And Associated Support Equipment

NATO STANDARDIZATION AGREEMENTS

STANAG 3606	Evaluation And Control Of Laser Hazards

(Copies of these standards are available from the Standardization Document Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.2.2 Other Government publications. The following other Government publications form a part of this handbook. This handbook supplements and does not supersede the regulations for each service. All offices responsible for laser safety will have a copy of the references applicable to their Service.

JOINT CHIEFS OF STAFF

JCS PUB 3-09.1 (JLASER)	Joint Laser Designation Procedures

DEPARTMENT OF DEFENSE

DoD Instruction 6055.11	Protection of DoD Personnel from Exposure to Radio frequency Radiation and Military Exempt Lasers, 21 Feb 1995
DoD Directive 3200.22	Operation on National Ranges and Test Facilities
DoD RCC Document 316-91	Laser Range Safety, Range Safety Group, DoD Range Commanders Council

US ARMY

TB MED 524	Control of Hazards to Health from Laser Radiation

US ARMY (continued)

DAPM 385-63/MCO P3570.1	Policies and Procedures for Firing Ammunition for Training, Target Practice and Combat
AR 40-46	Control of Health Hazards from Lasers and Other High Intensity Light Sources
AR 385-30	Safety Color Code Markings and Signs
AMCR 385-29	Safety-Laser Safety
AR 40-5	Preventive Medicine

US NAVY

SECNAV Instruction 5100.14B	Exemption of Military Laser Products
SPAWAR Instruction 5100.12B	Navy Laser Hazards Prevention Program
MCO 5104.1	Marine Corps Laser Hazards Control Program
NSWCDD/MP-94/289	Descriptions of Navy and Marine Corps Laser Systems, by Sheldon Zimmerman, September 1995
BUMED Instruction 6470.2A	Laser Radiation Health Hazards
EO410-BA-GYD-010	Technical Manual, Laser Safety
MCO P3570.1	Policies and Procedures for Firing Ammunition for Training, Target Practice and Combat

US AIR FORCE

AFOSH Standard 161-10	Health Hazards Control for Laser Radiation
USAFOEHL Report AL-TR-1991-0112	Base-Level Management of Laser Radiation Protection Program
USAFOEHL Report 87-091RC0111GLA	Laser Range Evaluation Guide For Bioenvironmental Engineers
AFI 13-212	Weapons Range Management

CODE OF FEDERAL REGULATIONS (CFR)

21 CFR Part 1040	Performance Standards for Light-Emitting Products

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

OSHA Publication 8-1.7	Guidelines for Laser Safety and Hazard Assessment

FEDERAL AVIATION ADMINISTRATION (FAA)

FAA 7930.2B	Notices To Airmen (NOTAM)

(Copies of specifications, standards, handbooks, drawings, publications, and other Government documents required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.3 Non-Government publications. The following document forms a part of this handbook to the extent specified herein.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI Z136.1 Safe Use of Lasers

(Obtain copies of this document through DoD publication channels for Government activities. For all others, application for copies should be addressed to American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036.)

2.4 Order of precedence. In the event of a conflict between the text of this handbook and other cited references, refer the conflict to the military service specialists in paragraph 1.2b who have jurisdiction of the laser range. Nothing in this handbook shall supersede applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Definitions. The following are definitions used in this handbook. More definitions associated with laser safety may be found in ANSI Z136.1.

3.1.1 Aircraft exclusion zone. A cone around the laser line-of-sight (LOS) that is 20 times the buffer angle. Laser operations must stop when another aircraft enters this zone.

3.1.2 Aperture. Any opening in the protective housing, shielding, or other enclosure of a laser product through which laser or collateral radiation is emitted, thereby allowing human exposure to such radiation.

3.1.3 Attenuation. The decrease in the energy of any optical radiation beam as it passes through an absorbing and/or scattering medium.

3.1.4 Beam divergence. The full angle width of the laser beam measured between the two points at which laser radiant exposure or irradiance in the laser beam is equal to 1/e (36.8 percent) of the maximum value.

3.1.5 Buffer angle. The angle about the laser's LOS with apex at the laser aperture that is used to determine the buffer zone. As a minimum, it is typically set to five times the demonstrated pointing accuracy of the system plus the beam divergence. (Buffer angles for several lasers are assigned in TABLE A-I.)

3.1.6 Buffer zone. A conical volume centered on the laser's LOS with its apex at the aperture of the laser, within which the beam will be contained with a high degree of certainty. The buffer zone is determined by the buffer angle.

3.1.7 Closed installation. Any location where laser systems and products are used that will be closed or opaque to unprotected personnel during laser operations.

3.1.8 Collateral radiation. Extraneous radiation (such as secondary beams from optics, flash lamp light, radio frequency radiation, x-rays, and so forth) that is not the intended laser beam as a result of the operation of the product or any of its components. System indicator lights would not normally be considered sources of collateral radiation.

3.1.9 Continuous wave (CW). Output that provides a steady or continuous output power rather than a pulsed output is continuous wave. A laser that emits a continuous output in excess of or equal to 0.25 seconds is a CW laser.

3.1.10 Controlled area. An area where the occupancy and activity of personnel within is subject to control and supervision of protection from radiation hazards.

3.1.11 Diffuse reflection. Reflection from a surface in which the beam is scattered in all directions (for example, a reflection from a rough surface). An ideal diffuse surface in which reflected brightness is independent of the viewing angle is called a Lambertian surface.

3.1.12 Electromagnetic radiation. The propagation of energy consisting of alternating electric and magnetic fields that travels through space at the velocity of light and includes light, radio frequency radiation, and microwaves.

3.1.13 Exempted lasers. Military lasers exempted from 21 CFR 1040 when compliance would hinder mission fulfillment during actual combat or combat training operations or when the exemption is necessary in the interest of national security. These lasers shall comply with MIL-STD-1425. See DODI 6050.11.

3.1.14 Field of detection. A volume of space within which a laser detecting system (for example, laser guided munitions, laser spot tracker, NVG) may acquire a laser designated target.

3.1.15 High energy laser. All Class 4 lasers with power of at least 20 kilowatts for more than l.5 seconds or energy of at least 30 kilojoules for less than l.5 seconds.

3.1.16 Infrared radiation (IR). Electromagnetic radiation with wavelengths within the range of 700 nanometers (nm) to 1000 micrometers (µm). This region is often divided into three spectral bands by wavelength: IR-A (700 nm to 1400 nm), IR-B (1400 nm to 3000 nm), and IR-C (3 nm to 1000 µm). IR-A is sometimes called near-infrared.

3.1.17 Irradiance (E). Measure of radiant power in watts per square centimeter.

3.1.18 Joule. A unit of energy, used principally for pulsed lasers, equal to l watt-second or 0.239 calories (cal).

3.1.19 Laser. Any device that can produce or amplify optical radiation primarily by the process of controlled stimulated emission. A laser may emit electromagnetic radiation from the ultraviolet portion of the spectrum through the infrared portion. An acronym for Light Amplification by Stimulated Emission of Radiation.

3.1.20 Laser controlled area. Any area that contains one or more lasers where the activity of personnel is subject to control and supervision for the protection from radiation hazards associated with laser operation.

3.1.21 Laser footprint. The projection of the laser beam and buffer zone onto the ground or target area. The laser footprint may be part of the laser surface danger zone if the laser footprint lies within the nominal ocular hazard distance (NOHD) of the laser.

3.1.22 Laser radiation. Coherent electromagnetic radiation produced by controlled stimulated emission within the spectral range of 200 nm to 1000 µm.

3.1.23 Laser safety officer (LSO)/laser system safety officer (LSSO). An individual trained in laser safety and appointed by the commander to be responsible for control of laser hazards at a particular installation. The term Laser System Safety Officer in the Navy differentiates the LSSO from the Landing Signal Officer (LSO). Each Service's regulations stipulates training requirements for LSOs/LSSOs and may differentiate among:

a. Laser Safety Consultants. Service Experts who evaluate and advise on laser safety.

b. Base Laser Safety Officer (for example, Air Force Bio-Environmental Engineer (BEE), Army Radiation Protection Officer, Navy Base Safety Office) who is responsible for paperwork, administration, safety training and compliance inspections at the installation.

c. Unit Laser Safety Officer is the individual in the laser user's chain of command who is responsible for all laser issues at the operational level, including but not limited to: establishing unit specific laser regulations and procedures and ensuring compliance to the appropriate laser regulations and restrictions of the host facility, that the appropriate operational and safety training for the laser weapon shall be used, maintaining unit laser accountability, and ensuring that all other unit related laser safety issues are addressed.

d. Installation Range Laser Safety Officer has the physical control of the Laser Range and is responsible for its use; including but not limited to: establishing range specific Laser Safety Regulations and procedures and ensuring that all users comply with all appropriate laser safety regulations in place at the range. The Range Laser Safety Officer may be from the range installation or a visiting Unit Laser Safety Officer.

3.1.24 Laser surface danger zone (LSDZ), nominal hazard zone (NHZ). Designated region where laser radiation levels may exceed the maximum permissible exposure level.

3.1.25 Maintenance. Performance of adjustments or procedures to be performed by the user for ensuring the intended performance of the product. Maintenance does not include operation or servicing. This definition is equivalent to the DoD concepts of operator- performed maintenance and/or organizational maintenance. This organizational maintenance could include firing the laser.

3.1.26 Maximum permissible exposure (MPE). Laser radiation exposure levels published in ANSI Z136.1 and established for the protection of personnel. These are levels of laser radiation to which a person may be exposed without known hazardous effects or adverse biological changes of the eye or skin. The MPEs contained in ANSI Z136.1 are used in this handbook and are in concurrence with STANAG 3606.

3.1.27 Milliradian (mrad). Unit of angular measure. One mrad equals one thousandth of a radian. One degree equals 17.5 milliradians.

3.1.28 Micrometer (µm). A measure of length equal to 0.000001 meter (10^{-6} meter). Formerly termed micron.

3.1.29 Nanometer (nm). A measure of length equal to .000000001 meter (10^{-9} meter). Sometimes termed millimicron.

3.1.30 Night vision goggles/devices. Any individual or crew served viewer which employs a non-thermal image intensification device (that is, ANVIS, Cat's Eyes or AN/PVS-7).

3.1.31 Nominal hazard zone (NHZ). See Laser Surface Danger Zone.

3.1.32 Nominal ocular hazard distance (NOHD). The distance along the axis of the laser beam beyond which the irradiance (W/cm^2) or radiant exposure (J/cm^2) is not expected to exceed the appropriate MPE; that is, the safe distance from the laser. The NOHD-O is the NOHD when viewing with optical aids.

3.1.33 Optical density (OD). The following logarithmic expression for the attenuation produced by a filter such as an eye protection filter:

$$OD = \log_{10} (I_o/I_t)$$

Where I_o is the power incident upon the filter and I_t is the power transmitted through the filter at a specific wavelength.

3.1.34 Optical radiation. Electromagnetic radiation with wavelengths that lie within the range of 180 nm to 1 millimeter (mm). This radiation is often divided into three spectral regions by wavelength: ultraviolet radiation (180 nm to 400 nm), visible radiation (400 nm to 700 nm), and infrared radiation (700 nm to 1 mm).

3.1.35 Pulse duration. The time increment measured between the half-peak-power points on the leading and the trailing edges of a pulse.

3.1.36 Pulsed laser. A laser that delivers its energy in discontinuous bursts; that is, there are time gaps during which no energy is emitted. For the purpose of this handbook, a laser that emits a pulse for less than 0.25 second.

3.1.37 Radian (rad). A unit of angular measure equal to 57.3 degrees.

3.1.38 Radiance (L). The radiant energy per unit solid angle emitted by a source.

3.1.39 Radiant energy (Q). Energy in the form of electromagnetic waves, usually expressed in units of joules. Commonly used to describe the output of pulsed lasers.

3.1.40 Radiant exposure (H). The radiant energy per unit area incident upon a given surface. It expresses exposure dose to pulsed laser radiation and is commonly expressed in joules per square centimeter or joules per square centimeter per pulse.

3.1.41 Radiant flux or power ( ) . The time rate of flow of radiant energy given in units of watts. Used to describe the output power of CW lasers or the average output power of repetitively pulsed lasers.

3.1.42 Reflectance or reflectivity (P). The ratio of total reflected energy to total incident energy.

3.1.43 Repetitively pulsed laser. A pulsed laser with a sequentially recurring pulsed output.

3.1.44 Service. The performance of those procedures or adjustments described in the manufacturer's service instructions that may affect any aspect of the product's performance for which this handbook has applicable requirements. Service does not include maintenance or operation as defined in this herein. This definition is equivalent to DoD concepts of maintenance above the organizational level.

3.1.45 Solid angle ( ) . The ratio of the area on the surface of a sphere to the square of the radius of that sphere. Solid angle is expressed in steradians.

3.1.46 Specular reflector. A mirror-like reflector at the wavelength of the incident radiation.

3.1.47 Steradian (sr). The unit of measure for a solid angle. There are 4 pi steradians in a sphere.

3.1.48 Support equipment. Devices or enclosures procured specifically for, or modified for, laser test, calibration, maintenance, or other support not part of the primary laser mission.

3.1.49 Transmittance or transmissivity (t). The ratio of total transmitted radiant power to total incident radiant power.

3.1.50 Ultraviolet radiation. Electromagnetic radiation with wavelengths between soft X-rays and visible radiation. This region is often divided into three spectral bands by wavelength: UV-A (315 nm to 400 nm), UV-B (280 nm to 315 nm), and UV-C (200 nm to 280 nm).

3.1.51 Visible radiation (light). Electromagnetic radiation detectable by the human eye. Visible radiation describes wavelengths that lie in the range between 400 nm and 700 nm.

3.1.52 Watt (W). The unit of power or radiant flux equal to one joule per second. Used principally with CW lasers.

3.1.53 Wavelength ( ) . The distance between two points in a periodic wave that have the same phase is termed one wavelength. The velocity of light in centimeters per second divided by frequency (given in Hz) equals the wavelength (given in cm).

4. GENERAL RANGE CONTROL PHILOSOPHY

4.1 General policy. Laser range safety prevents injury to personnel from laser radiation and misdirection of laser guided weapons. The laser safety evaluations of DoD laser ranges provides guidance to protect personnel and property from misguided laser directed weapons and ensures exposures of unprotected personnel to laser radiation below the protection standards specified in ANSI Z136.1, without placing unnecessary restrictions on laser system use. Provided below and on FIGURES 4-1 and 4-2 are procedures for safety evaluations:

a. Locate target areas where no line-of-sight (LOS) exists between lasers and uncontrolled, potentially occupied areas within the NOHD for aided and unaided viewing.

b. Remove specular surfaces from targets and target areas. Do not use a laser to designate or range still water, flat glass, mirrors, glazed ice, Plexiglas, or other specular reflectors.

c. Laser beams and the associated buffer zone must be terminated or the radiation level attenuated below the MPE limit within the controlled range or test facility or in controlled airspace. If energy below the MPE is allowed to leave the range, the possibility of optically aided viewing by unprotected individuals must be considered in the safety evaluation.

d. Lasers should be of the lowest emission level consistent with mission requirements.

e. All areas requiring personnel or moving targets need a determination and evaluation of the relative laser hazard area. The type of laser protective devices required, if any, must then be determined for each occupied location.

f. Safety evaluations and degree of restrictions shall consider:

1. Extent of range boundaries.

2. Required warning signs.

3. Number and location of specular reflectors.

4. Ease of public access to the range.

5. Airspace restrictions.

6. Local operating procedures.

7. Environmental conditions.

g. In joint laser exercises, all parties shall be informed of the intended laser operations prior to scheduling, including the:

1. Range Control Office.

2. Range Safety Office.

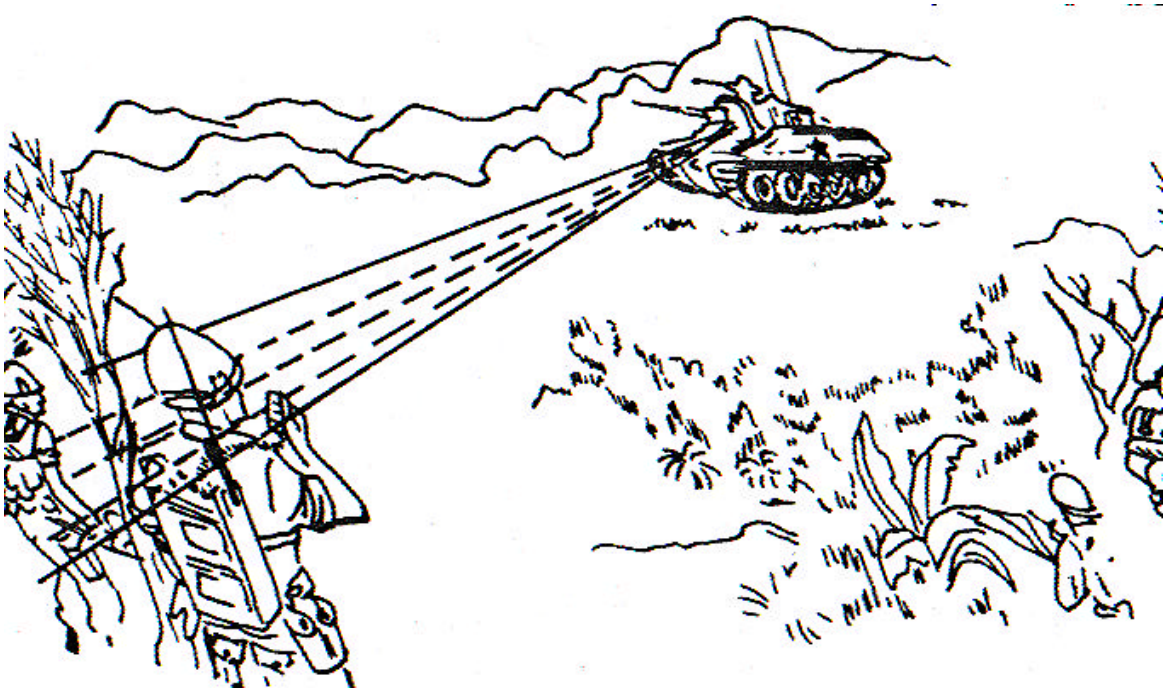
3. LSO/LSSO/Radiation Protection Office (RPO).

4. Liaison Office for the Services involved.

When coordinating with these offices, ensure preparation and issuance of Notice to Airmen (NOTAM) and Notice to Mariners (NOTMAR), in accordance with FAA, USCG, and DMA regulations as required. Ensure that use of Class 3 or Class 4 lasers above the horizon is approved by US Space Command (Laser Clearing Housing) DSN 268-4496, (719) 474-4496.

4.2 Recommended targets. Recommended target areas are areas without specular (mirror-like) surfaces. Glossy foliage, raindrops, fog, snow and most other natural objects are not considered hazardous specular surfaces. Remove all reflectors posing a specular reflectance hazard from the Laser Surface Danger Zone (LSDZ). Calm, smooth water and clean ice can reflect laser beams, especially at low angles of incidence. Consider these potential reflections when establishing target areas. The range safety or laser range safety officer shall close ranges when water ponds on the ground if these potential reflections have not been considered for the approved target area.

FIGURE 4-1. Direct intrabeam viewing.



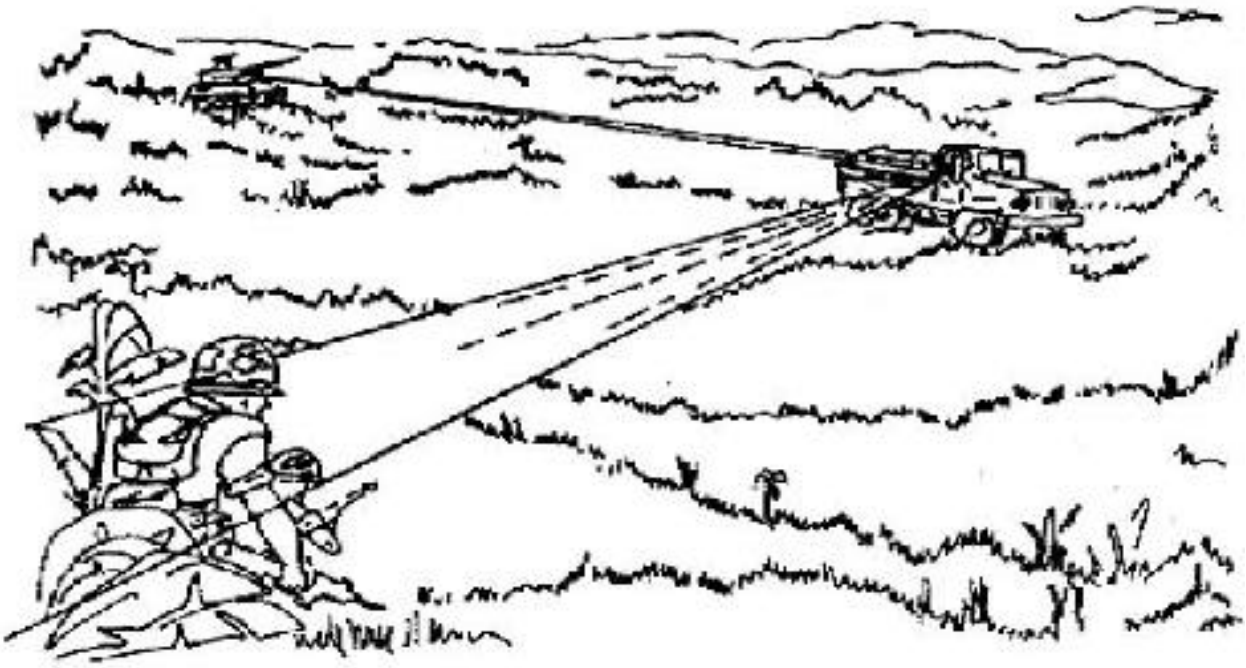


FIGURE 4-2. Reflected intrabeam viewing.

4.3 Beam control. When target areas have no flat specular surfaces, range control measures can be limited to the control of the beam path between laser and backstop.

4.4 Specular reflectors. Specular surfaces within distances (see APPENDIX A, TABLE A-I, TABLE A-II, and APPENDIX B) of the laser target, visible to unprotected personnel through binoculars or magnifying optics, will be removed, covered, painted, or destroyed. For lasers used from fixed wing aircraft, clear the entire buffered laser footprint area of specular reflectors (See APPENDIX E).

4.5 Hazards.

a. Laser devices, such as those listed in APPENDIX A, TABLE A-I and TABLE A-II, can seriously injure the unprotected eyes of individuals within the hazard zone of the laser beam. Intrabeam viewing of either the direct beam or a beam reflected from a flat mirror-like surface might expose unprotected eyes to a potential injury, therefore warranting avoidance.

b. Every diffuse reflecting object that the laser beam strikes reflects back some energy in all directions and toward the laser. To avoid hazardous specular reflections, clear the area around the target of specular (mirror-like) reflectors. Some Class 3b and Class 4 lasers may also pose a burn hazard to the skin. The hazard of exposure to the skin is small when compared to the eye; however, personnel should avoid direct laser beam exposure to high power lasers.

c. A less severe hazard exists for the devices listed in the Tables of APPENDICES C and D, but for safety avoid intrabeam viewing of the laser beam at distances less than that specified with the unprotected eye.

d. Dazzle and momentary flash blindness can occur from visible laser exposures below MPE limits. Laser eye protection may not attenuate the radiation sufficiently to eliminate these effects. Take appropriate precautions if expecting exposure to laser radiation levels that may cause dazzle or momentary flash blindness, especially for personnel performing critical tasks, such as flying aircraft.

4.6 Unprotected personnel. Prohibit exposure of unprotected personnel to laser radiation in excess of the MPE from either the direct or reflected beam.

4.7 Warning signs. Evaluation of each anticipated operating condition must include development of procedures for ensuring proper placement of warning signs. Local SOPs should provide for the placement of temporary signs during operation. Signs should be in accordance with AR 385-30, SPAWARINST 5100.12B or AFOSH Std 161-10, see FIGURE 4-3.

Form # NAVSEA 1995/17 Stock No. 0118-LF-020-1100
Available from:

Naval Publications and Forms Center
Code 1062
5801 Tabor Avenue
Philadelphia, PA 19120-5099

Order on DD FORM 1348. Provide cost accounting data. Cost $118/package of 5.
Customer service phone DSN 442-2626.

4.8 Personnel protection. Individuals within the horizontal or vertical LSDZ, such as moving target operators, support personnel, and aircrew members, should wear laser protective eyewear with curved protective lenses during laser firing. The curved lenses are necessary if there is a probability laser eye protection specularly reflecting the beam into an uncontrolled area. Require eye protection with side shields if the laser beam can reasonably get behind the lens. Eyewear approval is mandatory for the wavelength of the laser device being fired. A laser filter designed to protect against one wavelength of laser may not protect against harm from another. APPENDIX A, TABLE A-III provides the wavelength and optical density required for the current fielded devices. If using more than one type of device, protective measures must cover all devices. For devices of the same wavelength, use the highest required optical density.

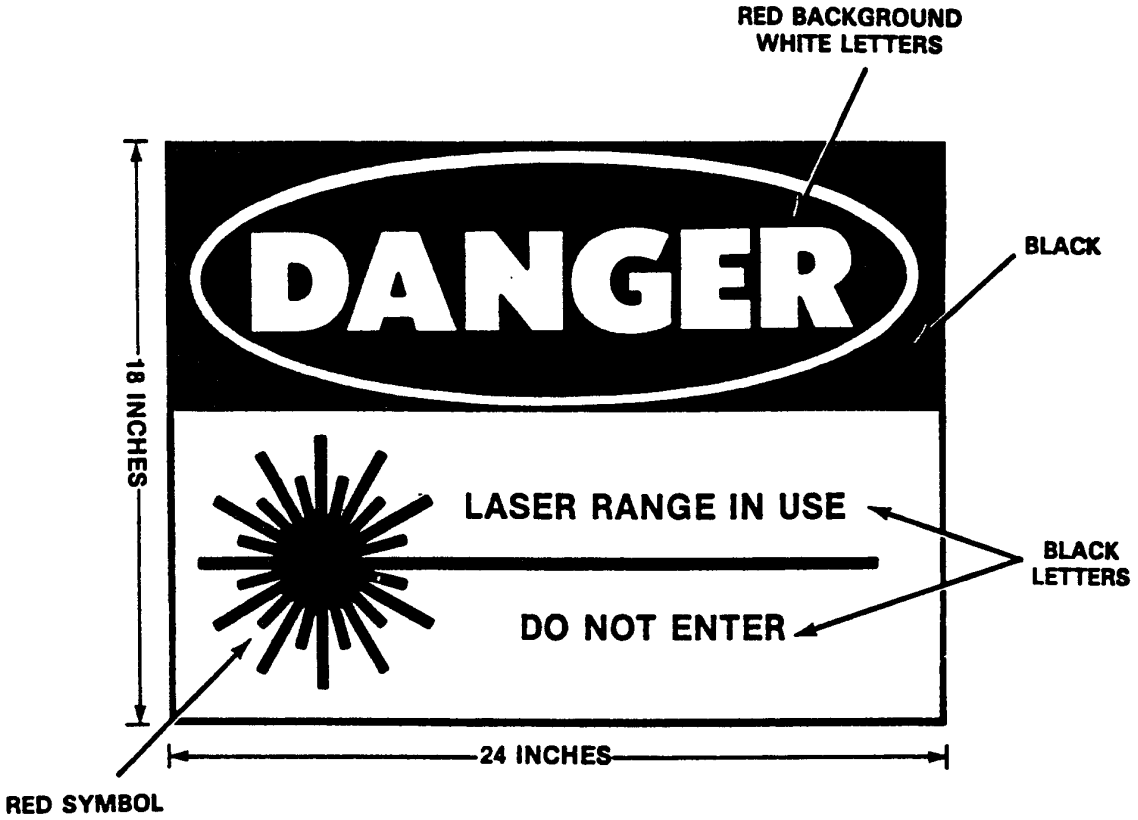


FIGURE 4-3. Example: warning sign

4.9 Magnifying optics. The use of magnifying daylight optical devices to observe the target during laser operation is allowable if removing flat mirror-like surfaces from the target area. Observe mirror-like targets only when placing appropriate laser safety filters in the optical train of the magnifying optics. Appropriately mark all protected optics such as sights.

4.10 Night vision goggles/devices. Because night vision goggles (NVGs) provide a substitute for the human eye during nighttime operations, NVGs are mission critical items. Devices such as ANVIS or CATS EYE, MXU-810/U, designed for aviators are as important as the aviators' eyes during night time operations. Although some NVGs protect the eye from laser damage (NOTE: CATS EYE NVG provide no protection for the eye), the damage threshold for NVGs may be as low or lower than the damage threshold for the eye. The impact of damaging the aviators NVGs during flight could be fatal. Therefore physically (optical, electrical, and so forth) or procedurally protected these devices from laser damage. Resources listed below determine the safe operating ranges for NVGs, with several service specific points of contact:

Naval Research Laboratory
Code 6656
4555 Overlook Avenue
Washington, DC 20375-5345
(202) 767-6978

USA CECOM NVESD, AMSEL-RD-NV-LPD
10221 Burbeck Road, Suite 430
Fort Belvoir, VA 22060-5806
(703) 704-2031

WL/MLPJ BLDG 651
3005 P Street, Suite 1
Wright Patterson AFB, OH 45433-7702
(513) 255-3808, ext-3169

4.11 Specific guidelines. The following specific guidelines provide minimum control procedures from hazardous laser energy:

a. Publish and enforce safety regulations for laser usage in specific areas. Provide detailed written procedures to minimize laser radiation hazards and other laser related range hazards such as erroneously homing on the laser target designator, wrong targets, and so forth.

b. Assign a laser safety officer (LSO) at the base, range and user levels as defined in chapter 3 to be responsible for ensuring appropriate safety control measures are followed.

c. Require users to prepare a safety standard operating procedure (SOP) for each different laser system and different type of laser operation. At any enclosed area such as a preliminary laser testing facility, post a generic safety SOP.

d. Keep records of the date, start and stop time for lasing periods and type of laser or other appropriate information for each laser operation.

e. Post the range boundaries to advise the public of the presence of laser operations where deemed appropriate by the local laser safety officer. These signs shall be in accordance with MIL-STD-1425, see FIGURE 4-3.

f. Fire lasers only at authorized targets.

g. Where possible, use eyesafe-attenuating filters over the laser output.

h. Do not fire the laser at still water, flat glass, mirrors, glazed ice, Plexiglas, or any other specular reflectors, unless specifically authorized by the Laser Safety Officer.

i. Do not fire the laser at aircraft, unless specifically authorized by the Laser Safety Officer.

j. Before operating fire control lasers or rangefinders, positively identify the target under the crosshairs of the scope or on the operator's monitor or in accordance with specific safety procedures approved by the Laser Safety Officer.

k. Cease laser operations if the operator or range control notes poor target tracking.

l. Cease laser operations if unprotected and/or unauthorized personnel enter the laser hazard area.

m. Clear the range using range personnel or by a flyover of the range to ensure that no unprotected and/or unauthorized personnel are in the laser hazard area. This includes all boats where operating on island or shoreline ranges.

n. For air operations, cease laser firing if unprotected and/or unauthorized aircraft enter the operations area or a restricted zone between the aircraft carrying the laser and the target. The restricted zone for most fire control lasers is twenty times the assigned buffer zone. For example, when using a laser with a buffer zone of five milliradians, the restricted zone around the laser beam out to the NOHD for other aircraft with unprotected personnel would be a one hundred milliradians or five degree (half angle) cone surrounding the laser LOS to the target with the aircraft carrying the laser at the apex.

o. Maintain two-way communication between the laser system operators and all affected range personnel.

p. Establish a laser operator-training program.

q. Provide a Pre-mission Brief to all laser operators and affected personnel prior to laser operations. The Brief shall include all potential hazards (radiation, weapons misguidance, and so forth) and control measures specific to the lasers employed and the range upon which they are used. The brief shall include as a minimum:

1. Maps depicting the targets and/or target areas and their laser hazard area.

2. Drawings or photographs of the target/targets proposed.

3. Run-in headings and flight profiles proposed for airborne laser operations and permissible firing fans for ground-based laser operations.

4. Review of mission profiles to prevent misguidance of Laser Guided Weapons by ensuring that the LGW or laser spot tracker field of view (FOV) always encompasses the target and not the space near the laser designator.

r. Do not direct Class 3 and 4 lasers above the horizon unless coordinated with US Space Command (Laser Clearing House) and with the regional FAA office for laser radiation above the MPE for outside restricted airspace. (See APPENDIX I)

s. Ensure ground-based lasers are at the approved operating position or firing points and always pointed down range toward the target.

t. For ground based lasers, ensure all unprotected personnel in the immediate area of the laser firing position are outside the laser surface danger zone or behind the laser operator while the laser is in use. Laser operators or observation personnel require no laser eye protection when viewing a target area with no specular reflectors, even when using binoculars. However, personnel must never enter the LSDZ without appropriate eye protection.

u. Consult the individual service's medical regulations for medical surveillance requirements for down range target area personnel. Immediately report any suspected injury or defective equipment (for example, misalignment of the laser beam with the pointing optics) so the cognizant supervisor can take appropriate action to remove the product from service until it cleared for further operation by competent authority. Include laser injuries in the local medical emergency plans. Timeliness in examination and treatment of suspected laser injuries by specialists to prevent further internal damage is of the utmost importance. The following Commands retain ophthalmologists trained in treating laser injuries:

USAMRD-BAFB
7914 A Drive
Brooks AFB, TX 78235-5138
Commercial: 210-536-4622
DSN: 240-4622
Fax: 210-536-3450

AL/OEO
8111 18th Street
Brooks AFB, TX 78238-5215
DSN: 240-4816
Fax: 210-536-3903

AL/AOCO
2507 Kennedy Circle
Brooks AFB, TX 78235-5117
Commercial: 210-536-3241
DSN: 240-3241
Fax: 210-536-5165
Brooks AFB Command Post that is manned at all times: DSN 240-3278.

v. Do not operate the laser or use it experimentally outside the range area without the operation being specifically authorized by the local Laser Safety Officer. Follow the safety procedures of ANSI Z136.1 for laser operations within any indoor firing pretest or laser testing facility. For example, use electrical door interlocks to prevent laser firing if opening entry door.

4.12 Laser pre-firing and post firing restrictions. When not using lasers, prevent hazardous laser output by use of such devices as output covers, or rotating the laser into the stow position, unless otherwise specifically authorized by the local Laser Safety Officer.

a. The local Laser Safety Officer must in accordance with operating procedures approve any maintenance performed in a range environment.

b. Make prefire checks that require operation of the laser in a controlled area with the laser beam terminated by an opaque backstop. Prefire checks that do not require operation of the laser, but require use of the optics may be safely made in a controlled area. To operate the optics without firing the laser, institute operating procedures to ensure turning off power to the laser, in accordance with local lock-out/tag-out procedures.

c. Cover the laser exit port or laser otherwise stow and turn off, when:

1. Crossing the range

2. Travelling on public highways or in uncontrolled air space or shipping lanes.

d. Non-laser operations (such as viewing through common optics) can be conducted in a non-laser controlled area with the laser exit port cover removed if instituting procedures that ensure turning off the power to the laser.

4.13 Stationary continuously operating lasers. Uses of Lasers such as LIDARS or space probes operating continuously into airspace may require additional controls. Besides coordinating these emissions with the FAA and Space Command, automatic shut down features may be necessary to prevent illumination of aircraft above MPE or to prevent danger of glare. These shut down features could be a radar beam which senses incoming craft or an aircraft transponder which signals to the laser to shut down (see APPENDIX I).

4.14 Tactics. Laser guided munitions and other laser detectors have unintentionally acquired radiation sources within the field of detection other than the target resulting in fratricide. Fields of detection vary and are specific to individual weapons. All tactics must be planned to ensure that the angle between the laser designator LOS and laser detectors (for example, laser guided munitions, laser spot tracker, NVG) will not mistakenly aim the munitions at the laser source or scattered radiation from the laser platform, see Joint Chiefs of Staff Joint PUB 3-09.1.

4.14.1 Ground laser designators. When employing laser spot trackers with ground laser target designators use following procedures:

a. Terminal Controllers will provide aircrews with an attack heading or laser-to-target line. The attack heading must allow aircrews to acquire the laser energy reflected from the target. Ensure designators for other targets on the range are not using the same laser codes.

b. Due to the possibility of false target indications from atmospheric scatter of the laser beam close to the laser exit port, attack headings should avoid target-to-laser designator safety cones unless the tactical situation safely dictates otherwise. The safety cone is usually a 20-degree cone whose apex is at the target and extends 10 degrees either side of the target-to-laser designator line. Both Rayleigh scattering and Mie scattering may cause scattered radiation that the seeker can detect. Rayleigh scattering of radiation from atmospheric molecules is what makes the sky blue, it is strongest for shorter wavelengths (varies inversely by the fourth power of the wavelength), it is about twice as strong at 0 degrees and 180 degrees than at 90 degrees from the laser LOS. However, at 90 degrees it shows the greatest polarization. Mie scattering from aerosols is very strong in the forward direction of the beam even in the cleanest of atmospheres, it is not as dependent on wavelength as Rayleigh scattering and has no strong polarizing effect.

c. The optimal attack zone is a 50 degree zone from 10 degrees to 60 degrees either side of the target-to-laser designator line at an elevation that will assure adequate target acquisition. The risk of acquiring the laser designator vice the target in this zone varies from moderate to low as the angle increases.

d. WARNING the degree of hazard to ground personnel operating the laser target designator varies with the attack angle of Laser Spot Tracker from the laser LOS. See FIGURE 4-4. In some situations, Laser Spot Trackers shift from the designated target to the Laser Target Designator while operating in the 50-degree attack zone. For this reason, Laser Spot Trackers should not be the sole source for target verification. Aircrews should always verify the target through additional means. As a minimum, compare and evaluate the laser spot cue provided on HUD with the expected target location. For close air support missions the target location given in line 6 of the 9-line brief should help to confirm the laser spot. For aircraft equipped with an INS and/or GPS, steering cues provided by these aids should always act as back up for the laser mark. Other verification means include, visual target description and laser pointers or non-laser target marks provided by direct or indirect fire from conventional weapons. If the laser spot tracker cue is not coincident with the expected target location aircrew should not deliver ordnance on the laser spot.

e. To reduce the potential for seeker lock-on to the designator position, the designator should mask themselves from the seeker field of view. Terrain, vegetation or other obstruction can sometimes mask the designator.

WARNING: THIS DOES NOT GUARANTEE THAT THE LASER SEEKER WILL NOT LOCK ONTO THE LASER DESIGNATOR.

It may be possible to detect an improper lock-on in time to prevent a mishap by aborting the bombing run, if the seeker's acquisition can monitor the aircraft with the laser spot tracker or seeing a laser guided bomb (LGB). See FIGURES 4-4 and 4-5 for an example of a plan for ground laser designator tactics. Refer to individual Laser Spot Tracker/Laser Guided Weapons technical orders and procedures for additional safety information.

4.14.2 Airborne wingman laser designation. Laser guided weapons (LGW) or laser spot trackers (LST) can erroneously lock onto the scattered radiation from buddy lasing or wingman aircraft laser designators. In addition, if the airborne laser designator points toward the LGW or LST the designator itself may become tracked. In lock-on-before-launch (LOBL) mode, the LGW seeker LOS displays in most launch aircraft. If the LOS cue is well above the horizon, then the missile probably locked onto an erroneous spot such as the designator aircraft or atmospheric scatter vice the desired target spot and the mission should abort. If the LGW is in the lock-on-after-launch (LOAL) mode, no LGW LOS cue is available to the launch aircrew. Wingman designators must be wary that even if planning a LOBL, launch aircrews train to employ the missile in a LOAL mode if no laser spot once cleared to launch.

a. If the missile properly locked onto the target in LOBL mode, the only risk to the designator, would be midair potential if the designator aircraft operates below the missile trajectory apex. In LOBL mode, the wingman aircraft altitude should remain substantially above the nominal LGW apex altitude keeping in mind that missiles can climb to altitudes well in excess of their nominal apex values especially if they track a laser designator.

b. When employed in a LOAL mode, the laser guided missile will execute a climbing profile, searching for a laser coded energy prior to tipping over and scanning its field of view (FOV) downward. The risk to the wingman designator is highest during the initial staring phase of the LGW profile. If it locks onto the designating aircraft there is a probability that it will track and kill the laser designator. The dimensions of the instantaneous FOVs of the LGWs are not absolute and some are capable of detecting forward or back scattered radiation at many degrees off boresight.

c. The geometry and timing for buddy/wingman laser tactics must be precise to preclude the weapon from targeting the designating platform. Designator positions behind the launch platform are inherently the safest. If that is not possible, select a designator spot that will keep the aircraft out of the LGW FOV. FIGURES 4-6, 4-7, 4-8, and 4-9 show example Laser Designator NO FLY CONE profiles. Refer to individual LST/LSW technical orders and procedures for additional safety information. Ensure other designators on the range are not using the same laser code.

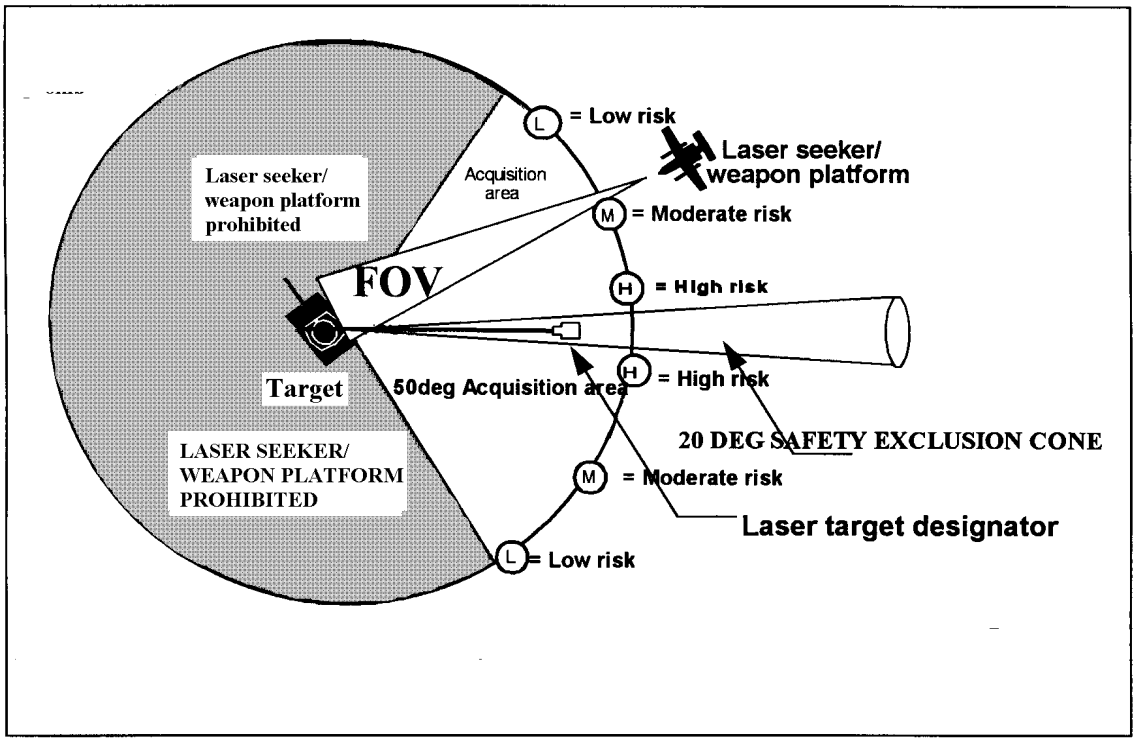


FIGURE 4-4. Sample safety exclusion cone for ground laser designator.

NOTE 1: Situational check must ensure seeker field of view covers the target and not the area of the laser target designator out to a distance in front of the designator where seeker cannot detect scatter.

NOTE 2: This is an example. Obtain details from system specific documents and publications such as JCS PUB 3-09.1.

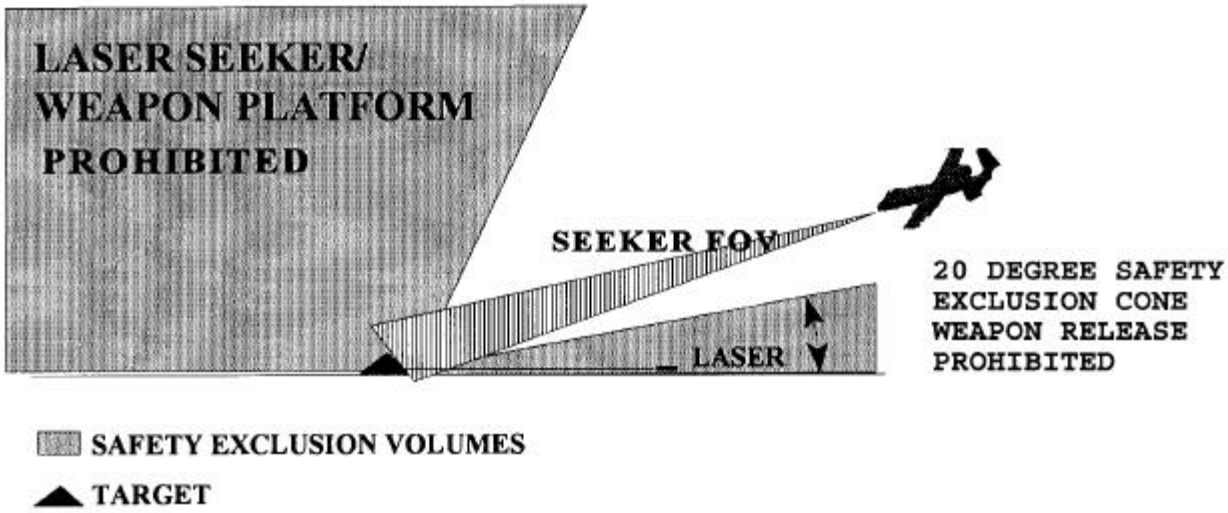


FIGURE 4-5. Sample side view of safety exclusion volumes for ground laser designator.

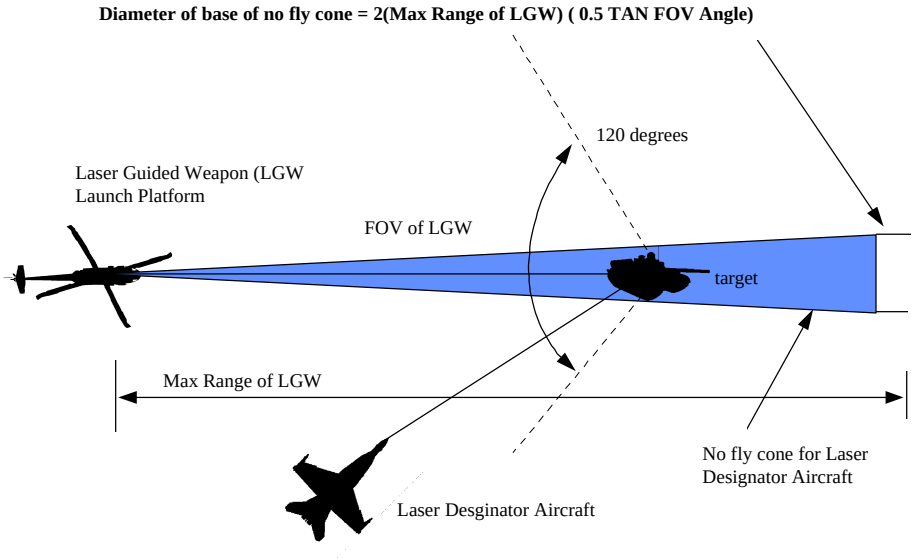
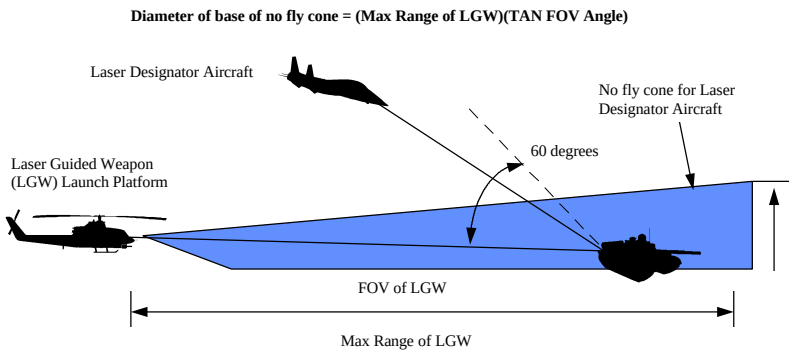


FIGURE 4-6. Sample plan view of safety exclusion cones to prevent homing on laser designator aircraft during continuous laser designation



.

FIGURE 4-7. Sample vertical view of safety exclusion cones to prevent homing on continuous laser designator aircraft.

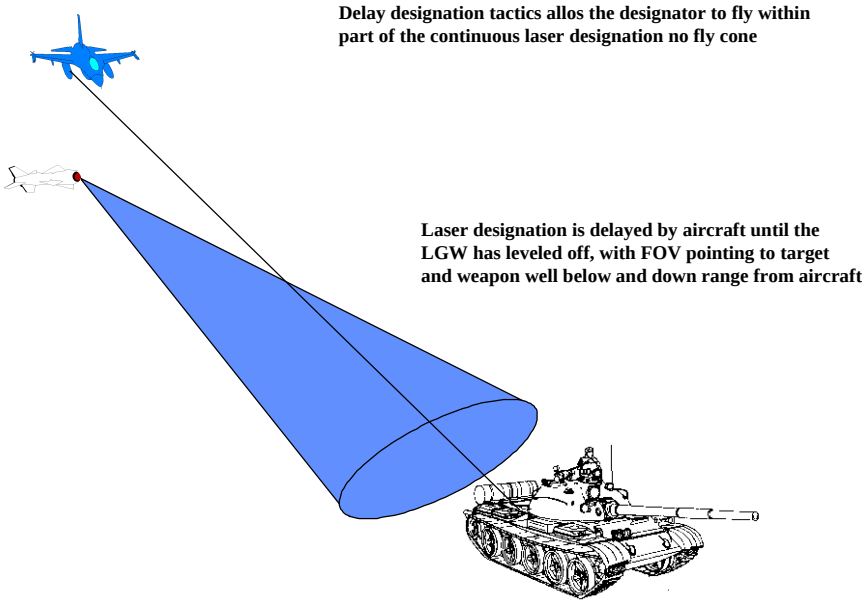
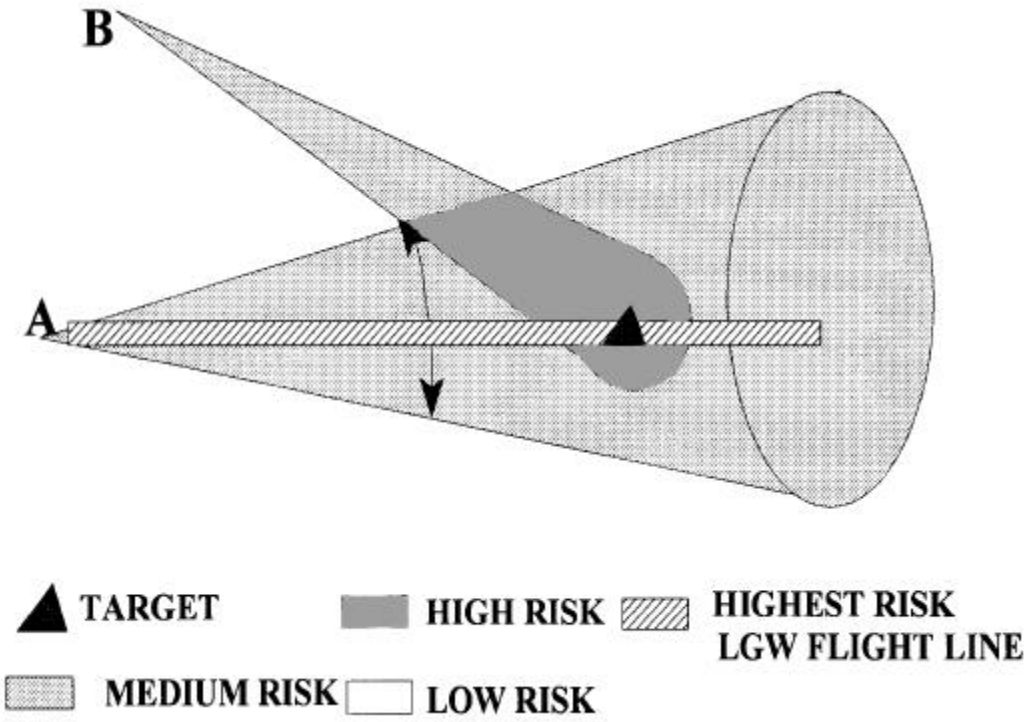


FIGURE 4-8. Sample delayed laser designation safety exclusion cone, vertical view.

CONE A (SEEKER)	CONE A (RISK VARIABLES)
·Scan (FOV)	·Last pulse logic
·Stability	·Range control
·Tracker	·Distance
·Platform	·Atmosphere(laser beam scatter, visibility, refraction, night, day, and so forth)
·Munitions Flight	·Pilot indicators (Flight plan, HUD, LST, GPS, INS, target markers, laser position markers, use of NVG, and so forth)
CONE B (Laser Designator)	CONE B (RISK VARIABLES)
·Stability	·Distance
·NOHD	·PPE (Goggles, and so forth)
	·Shielding
	·Tactics



NOTE: To minimize risk of fratricide, ensure the target is always in the seeker FOV when the laser designator is on and minimize intersection of the laser seeker FOV with the laser beam especially close to the laser.

FIGURE 4-9. Generalized concept of risk variables related to laser target designator and laser seeker field of view (FOV) for laser guided weapons (LGW).

5. PLANNING REQUIREMENTS

5.1 Range evaluation planning.

5.1.1 Background. Before any laser range operations, fully evaluate the hazards of using the system on the range. Both the laser user and the range control personnel must mutually agree on the conditions for laser operations. APPENDIX F provides a sample checklist for this data collection.

5.1.2 Laser user. The laser user shall provide:

a. Technical orders, Technical Manuals, and/or reports on the laser system and associated hazards as requested by the range evaluator.

b. NOHDs and sources of evaluations or the parameters required to perform the safety evaluations.

c. Standard operating procedures on the laser.

d. Intended operational environment for laser use to include types of targets and position, laser firing locations, run-in headings, maximum and minimum firing altitudes and ranges, direction of laser operations, and any other special considerations.

e. Laser systems parameters.

f. Hazardous failure modes (that is, those that affect laser parameters or beam steering, secondary beams, inadvertent firing, and other potential system problems).

5.1.3 Range operator. The range operator shall provide:

a. Local instructions that outline general range operating and safety requirements.

b. Detailed range maps showing laser location, target location, restricted airspace or artificial backstops, flight path, and range boundaries, populated areas, public roads, no lase areas.

5.1.4 Range evaluator. The range evaluator reviews laser system data, maps, targets, instructions, SOPs, and other information provided by the laser user and range operator to determine which existing requirements impact the safety of laser operations on the range such as:

a. Limitations on allowable laser locations and run-in headings for aircraft.

b. Minimum and maximum flight altitudes (airborne platforms only).

c. Airspace surveillance.

d. Flyover requirements to ensure range security.

e. Locations of control towers and other manned areas.

f. Locations of non-controlled personnel access to the areas surrounding the target area.

g. Specific information on maintenance, boresighting, or other activities on the range.

6. EVALUATION REQUIREMENTS

6.1 Range evaluation procedure.

6.1.1 Evaluation sequence. Perform a laser range evaluation for a specific laser system or for a group of similar lasers. An evaluation of a group of similar lasers is preferable if available land permits and there is no severe mission impact. To perform this general evaluation, use the worst case conditions of all possible systems and missions. If these conditions are too restrictive, perform separate evaluations for each system. Conduct the evaluation on-site at the laser range, including flyover, drive-through and walk-through inspections. To simplify the range evaluation procedure, divide it into five steps: laser; range; target; mission; and laser surface danger zone.

a. The laser. To evaluate a laser for use on a range, one must determine the hazard potential of the system by determining the following:

1. Maximum Permissible Exposure (MPE) Limits. Determine the applicable MPE for the evaluated laser. ANSI Z136.1 provides appropriate MPEs.

2. Laser Classification. Classify the laser using procedures in MIL-STD-1425 to determine laser control procedure requirements (interlocks, warning labels, and so forth).

3. Nominal Ocular Hazard Distance (NOHD). Determine the distance from an operating laser to the point where the laser is no longer an eye hazard using procedures designated by the specialists of 1.2b, or, use the values given in Appendices A and C.

4. Reflections. Determine if the laser is capable of producing hazardous reflections under established conditions using procedures designated by specialists in 1.2b or APPENDICES A and C.

A. Specular Reflections. Determine what kinds of surfaces will act as specular reflectors at the laser wavelength. See FIGURE 6-1, TABLE 6-I, and APPENDIX G.

B. Diffuse Reflections. Determine if the laser is capable of producing hazardous diffuse reflections. Lasers that can produce hazardous diffuse reflections are Class 4 and have an associated diffuse reflection hazard distance (t). It is unusual for field type lasers to produce diffuse hazards (presently, only the M60 Tank, the M551A1 Sheridan Vehicle, and the OV-10D Night Observation System produce hazardous diffuse reflections). Normally for a diffuse hazard, the beam path out to the distance t as provided in TABLE A-I, is a denied occupancy area and no objects are permitted in the beam path out to this distance.

TABLE 6-I. Typical Reflective Surfaces
(See FIGURE 6-10 for illustration)

Diffuse Reflectors	Flat Specular Reflectors	Curved Specular[1] Reflectors
dry foliage	flat glass[2]	wet foliage
rocks	vision viewblocks	beer bottle
camouflage	still water[3]	turbulent water
soil	vehicle rear view mirror	glossy paint
matte paint	instrument gauges	optical sights
aluminum cans	flat windows[2]	curved windows
old ordnance	detector windows	automobile bumpers

[1] Generally not a hazard beyond a few meters.
[2] See TABLE G-I for reflectivity at various angles of incidence.
[3] Unrippled surface such as puddles, ponding on any surface, and so forth.

5. Optical Density (OD). The degree of protection required to reduce the incident laser energy to safe eye and skin levels must be determined. These are available in APPENDICES A and B and from the designated specialists of 1.2b.

6. Optical Viewing. Consider the possibility of personnel directly viewing the beam (intrabeam viewing), or reflections of the beam, through optical instruments such as binoculars. The light-gathering ability of the optics can significantly increase the degree of hazard for the eyes (increase OD and NOHD). Procedures to evaluate this are in AFOSH Standard 161-10, ANSI Z136.1, and TB MED 524. Some evaluation results are included in APPENDICES A and B.

7. Atmospheric Attenuation. Atmospheric attenuation can be quite high for infrared lasers operating over distances of 10 kilometers or greater. It can reduce the NOHD considerably and therefore requires inclusion in the laser evaluation.

8. Laser Platform Stability. The stability of the laser platform is needed to determine pointing accuracy of the laser system. The pointing accuracy determines the size of the buffer angle. The typical buffer angle for airborne (aircraft), ground based, or shipboard stable platforms (tripods) is 5 milliradians, while hand-held lasers normally require 10 milliradians. Paragraphs later in this chapter further discuss the buffer angle.

b. The Range. Laser range evaluations require a range map, a topographic map and an air space map of the area.

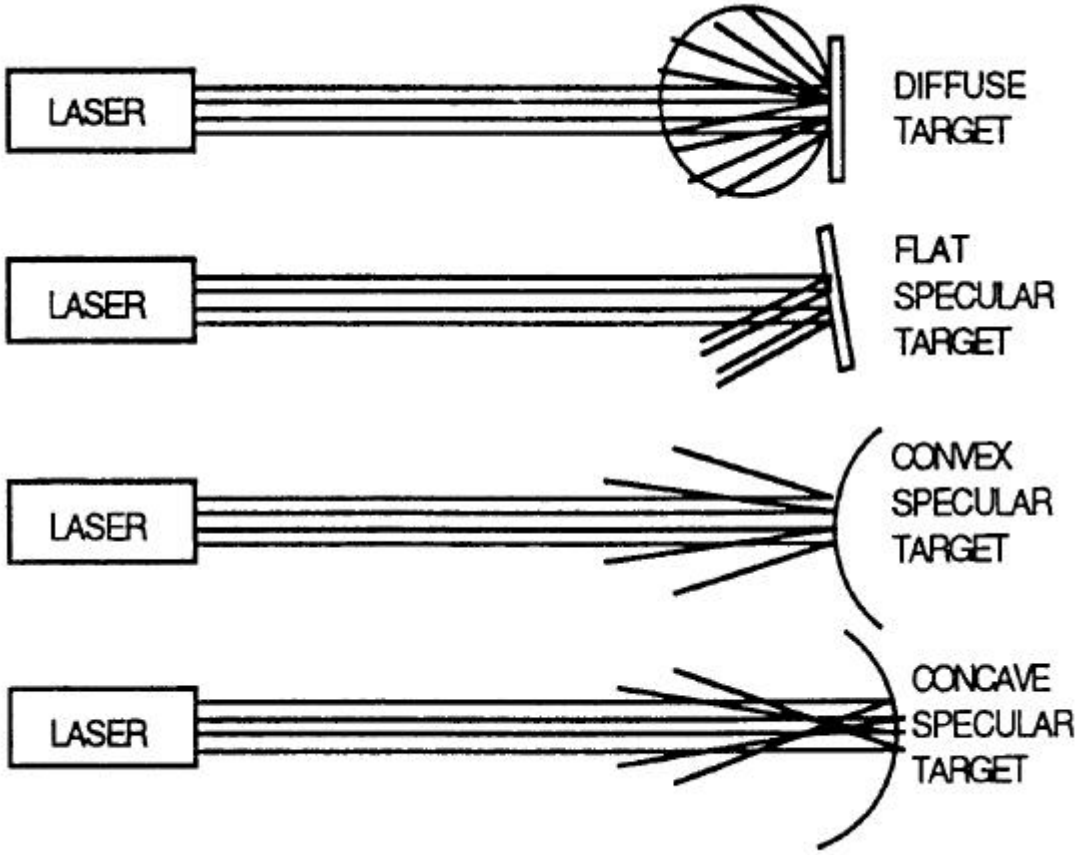


FIGURE 6-1. Diffuse reflection and specular reflection

1. Range Map. The range map is essential to establish accurate distances from target area to range boundaries. The range map should have the boundaries and include geographic items such as towers, buildings, and so forth, which should be on the map. Boundaries of special purpose areas such as an airstrip and the location of the targets are required.

2. Topographic Map. The topographic map is important because it enables the evaluator to determine the elevation of the target area relative to the surrounding terrain. It is important that no portion of the beam that exceeds the MPE limits extend beyond the controlled area. Using natural geographic backstops such as hills can control the beam. A topographic map is very helpful in identifying these backstops and in repositioning targets if necessary.

3. Airspace Map. Controlled airspace is that airspace associated with the range having specific, possibly non-coincident lateral boundaries and a specific minimum and maximum altitude. It is important that this controlled airspace and any other special conditions are made

known. Laser operations are not normally authorized outside the controlled airspace or when other aircraft are between the laser and the target. Also, if the beam is directed up, or if hazardous reflections could exceed the height of the controlled airspace, additional controls may be necessary.

c. The Target and Target Area. The size, location, and type of targets to be fired at on a range are of primary importance in determining the hazard zone.

1. Optimum Target. The optimum target from a safety point of view is a nonreflective surface. Flat specular surfaces must be removed or covered because reflections from these surfaces can retain high collimation. A flat specular surface is one in which you can see a relatively undistorted image. Examples of specular surfaces are windows, Army tank vision blocks, search light cover glass, plastic sheets, glossy painted surfaces, still water, clean ice, flat chrome, and mirrors. Snow is not a specular surface, but if thawed and refrozen, hazardous reflections can be found, especially at low angles of incidence. Glossy foliage, raindrops, and other natural objects are not hazardous targets since their curved reflective surfaces as well as other curved reflective surfaces cause the beam to spread and the reflected irradiance (energy per unit area) decreases quickly with distance. The only exception to this is concave reflective surfaces, which can focus the reflected beam and cause the reflection to be more hazardous than the incident beam. Practically, these reflections are of little concern since it is improbable that the surface is perfectly concave (focuses the beam to a single point) or perfectly reflective. Additionally, the focal point(s) of concave reflectors would probably be very close to the object (small radius of curvature) and be of little concern since people don't normally put their head close to objects and if they did, they would probably block the incident beam. Concave surfaces with a large radius of curvature which could focus at longer distances would appear nearly flat and must be removed or covered. Although curved surface reflection may not be hazardous at typical laser to target engagement ranges, large shiny curved surfaces should be removed. An example of such a surface is a curved automobile bumper. Lastly, a diffuse surface is one that totally distorts (or diffuses) the beam shape, normally resulting in a safe to view reflection from outside the target area. TABLE 6-I lists some common items found in a typical range area and their type classification for reflection. APPENDIX G provides additional information.

2. Size and Location. The number and location of targets (distribution) will affect the size of the hazard zone. On ranges with limited space, it is important that all targets be as close together as tactically feasible.

3. See APPENDIX H for Navy separate target (SEPTAR) operations.

d. The Mission. An evaluation must be accomplished for each type of laser used on the range. The laser operating mode; that is, air-to-ground, ground-to-ground, ship-to-target, and so forth, must be determined. At the present time, air-to-ground, ground-to- ground, and ship-to-target are the normal modes used by tactical forces. In the near future, training exercises and tests will include the ground-to-air mode as more state-of-the-art airfield and ground force air defense systems are developed. The air-to-air mode is used for R and D projects and then only with special permission. Required information is listed below for each case:

1. Air-to-Ground. Determine desired flight profiles. Flight information necessary to perform an evaluation are: altitudes, ranges, and directions of the aircraft relative to the target during laser operations. Various terms are used to describe the aircraft direction during ordnance delivery; they include: approach track, attack heading, and run-in heading. These headings can be on a single bearing, a range of bearings, and unrestricted approach (360 degrees).

Typical mission profiles are:

A. Toss Delivery, General Profile:
Slant Range: 1,800 feet-70,000 feet
Altitude: 200 feet-2,600 feet

B. Toss Delivery, Mode A:
Slant range: 20,000 feet-70,000 feet
Altitude: 200 feet-320 feet

C. Toss Delivery, Mode B:
Slant range: 10,000 feet-25,000 feet
Altitude: 1,000 feet-3,400 feet

D. Straight and Level Delivery:
Slant range: l,800 feet-30,000 feet
Altitude: 1,500 feet-3,300 feet

E. Dive Delivery
Slant range: 8,500 feet-14,000 feet
Altitude: 4,000 feet-7,600 feet

2. Ground-to-Ground. Determine possible laser locations and direction of laser operations.

3. Ship-to-Target. Determine the possible laser locations, direction of laser operations, and ship headings.

e. LSDZ. LSDZ (also called buffered laser footprint for airborne/elevated lasers) must be determined using the procedures provided in 6.1.3, 6.1.5, 6.1.7, 6.1.8, and 6.1.9.

6.1.2 Target and/or target area condition. Careful attention must be paid to the condition of the target and surrounding laser hazard area. Any specular reflectors on or around the laser targets must be either removed or rendered diffuse. Painting with a flat (non-specularly reflecting) paint may render specular reflectors diffuse. Merely covering a specular reflector is not adequate, since the covering material is usually susceptible to damage by ordnance. The position and orientation of any specular reflectors that cannot be removed or rendered diffuse must be noted so that they can be considered during the laser safety evaluation. Generally, specular reflectors larger than one half

inch in diameter must be removed from the LSDZ. If this is too restrictive, individual LSOs may refer to the specialists in 1.2b. Target area conditions should be reviewed periodically as determined necessary by local safety authority.

6.1.3 System performance. To meet mission requirements, the stability, pointing accuracy, and boresight retention capabilities of a laser rangefinder and/or designator system must exceed those required for range safety.

a. Buffer Zones. In establishing the laser safety buffer zone for a particular system, a factor of at least five times the demonstrated accuracy of the system is used. This factor has been used to compensate for such factors as untrained operators, adverse environmental factors, and use of the system at the limits of its capability. These buffer zones for specific systems are addressed in APPENDIX A, TABLE A-I.

b. Variety of Lasers. If a variety of laser systems with similar capabilities is to be used on the same range, only the worst-case parameters are used in the laser safety evaluation of the range. As an example, the A-6E Target Recognition Attack Multisensor (TRAM), the OV-10D Night Observation System (NOS), and the F-111 Pave Tack systems have similar performance capabilities and may be considered for use on the same range facility. The NOHD's of the systems, as measured in the far field, are 8.1 nautical miles (NMI), 6.1 NMI, and 8.6 NMI, respectively. All three systems have been assigned a safety buffer zone of 5 mrad. A range safety evaluation based on an NOHD of 8.6 nmi and a 5-mrad buffer zone would, therefore, allow safe use of any one of the three systems on the range without the confusion of three different sets of restrictions. The system parameters are also adequately similar so that the least hazardous systems are not unduly restricted.

6.1.4 LSDZ. The LSDZ consists of the target area plus the horizontal and vertical buffer zones (see FIGURE 6-2). The LSDZ considers both direct hazards (main beam) and indirect hazards (reflections). The boundaries of the LSDZ depend on which of the two overlapping zones, direct hazard zone or the indirect hazard zone, are larger. If there are no specular reflectors on the range and the laser is not a diffuse reflection hazard, there will not be an indirect hazard zone. The direct hazard zone will always exist if laser to target distance is less than the NOHD. The LSDZ includes the laser beam plus a buffer zone around the beam to account for laser platform instability. The three types of LSDZs are as follows:

a. The total hazard zone is LSDZ area Z or simply the LSDZ. It extends out to the NOHD/NOHD-O or beam backstop and the edges of the laser beam buffer zone.

b. The area that must be cleared of specular surfaces is LSDZ area S. For ground based lasers that do not project a well-defined footprint on the ground around the target (beam and buffer footprint are contained on target), LSDZ area S is usually defined by a circle of radius s (as specified in APPENDIX A, TABLE A-I) around the target. For airborne laser operations, area S is the same as LSDZ area Z. For ground based laser operations from elevated platforms where the

laser projects a well defined buffer footprint, area S should equal LSDZ area Z. Backstop areas where the energy of the incident beam is capable of producing a specular reflection hazard are considered LSDZ area S.

c. The diffuse reflection hazard zone is LSDZ area T. It extends to distance t, the diffuse reflection hazard distance, and will only be present for lasers capable of producing a hazardous diffuse reflection (these have a distance t associated with them). LSDZ area T is considered an exclusion zone, no one is allowed in it, and firing of lasers at any materials located within this diffuse reflection hazard area must be prohibited. Although a skin hazard can also exist in this area, it is a minor concern compared to the diffuse reflection hazard (See FIGURE 6-3).

6.1.4.1 LSDZ dimensions. The tables in APPENDICES A, B, and C list the applicable dimensions of the hazard distances for current laser devices. FIGURE 6-4 provides an example of an LSDZ or laser range danger fan (LRDF) for a training situation. The following paragraphs describe the LSDZ limits:

a. Existing Surface Danger Zones. Existing munitions surface danger zones for direct fire weapons are usually large enough to provide the required horizontal and vertical buffer zones for ground-to-ground laser operations provided the beam is terminated in the impact area (see FIGURES 6-5 and 6-6).

b. Distance of the Laser Surface Danger Zone. The following combination of NOHD and terrain features must be considered in controlling laser hazards:

1. When viewing the collimated beam with a telescope, the hazardous range is greatly increased. For example, a 10 km NOHD would be increased to 80 km for an individual looking back at the laser from within the beam with 13 power optics. Such large amounts of real estate are difficult to control. The solution is to use a backstop behind the target.

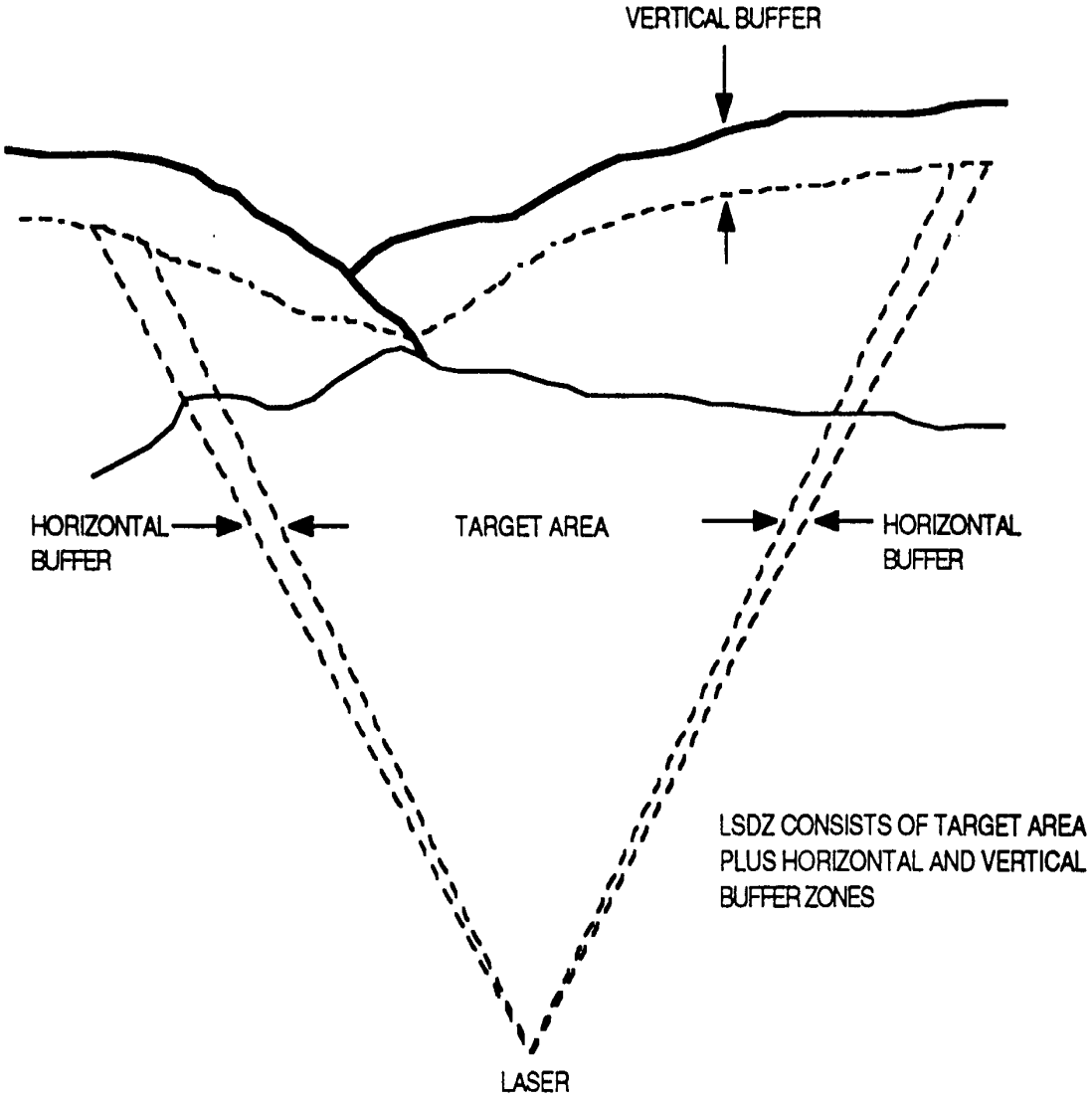
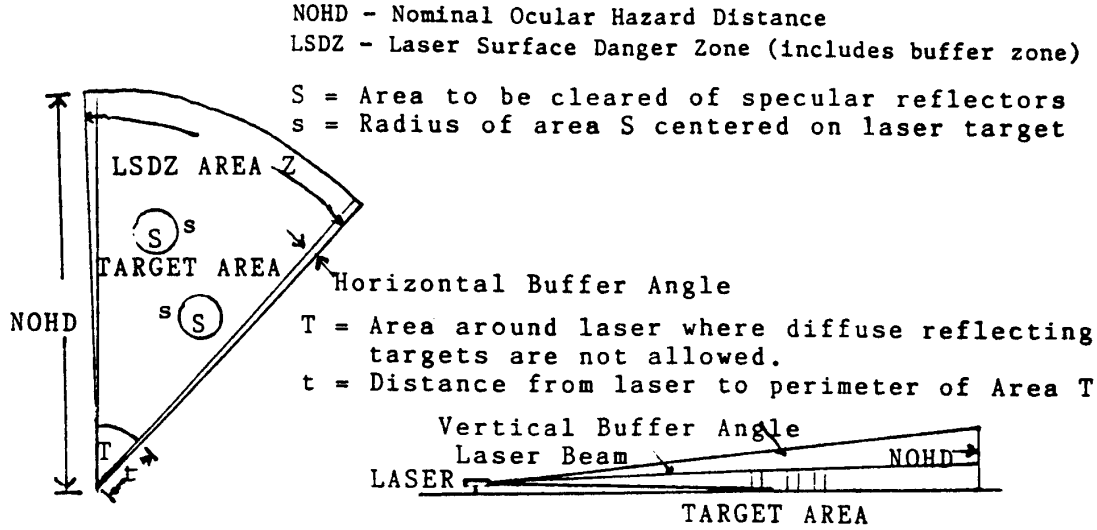
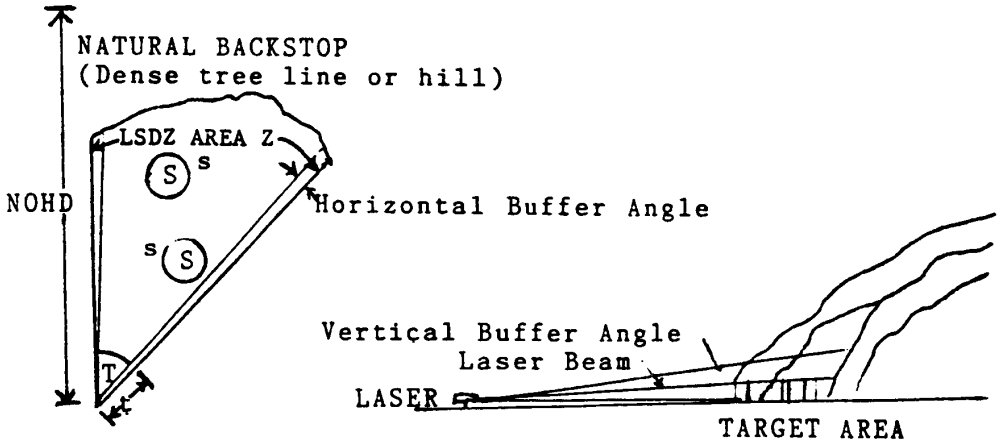


FIGURE 6-2. Laser Surface Danger Zone (LSDZ).



LSDZ FROM GROUND FIRED LASER - WITHOUT NATURAL BACKSTOP



LSDZ FROM GROUND FIRED LASER - WITH NATURAL BACKSTOP

FIGURE 6-3. LSDZ without and with natural backstop.

2. On the ground, this area normally extends to an adequate backstop or the NOHD. A laser operation at targets on the horizon is permitted as long as air space is controlled to the NOHD. In this case, the LSDZ extends downrange to the NOHD in the air space and to the skyline on the ground as seen from the laser position (see FIGURE 6-6). Operators and crews will conduct laser operations only at approved targets. Usually, when there are no natural backstops available (that is, mountains), the magnified NOHD-O (O indicates optics) may extend out to extremely long ranges (that is, 80 km for tank-mounted laser rangefinder (LRF)). This extreme situation would only create ocular hazards if:

A. There was a direct LOS to an observer on the ground, and

B. There is a possibility that the observer could be engaged in direct intrabeam viewing with unfiltered magnifying optics.

3. Unless the NOHD or NOHD-O has been exceeded, the hazard distance of the laser device is the distance to the back-stop. This hazard distance must be controlled. The terrain profile from the laser device's field of-view plays a very important role since the laser presents only a LOS hazard. The optimal use of natural backstops is the obvious key of minimizing laser range control problems.

c. Buffer Zones. The extent of horizontal and vertical buffer zones around the target area, as viewed from the firing area, depends on the aiming accuracy and stability of the laser device. The laser horizontal buffer zones could partially or completely be included in lateral safety or ricochet areas on ranges where the laser is used with live fire weapons. APPENDIX A, TABLE A-I, lists buffer zone values for currently fielded equipment.

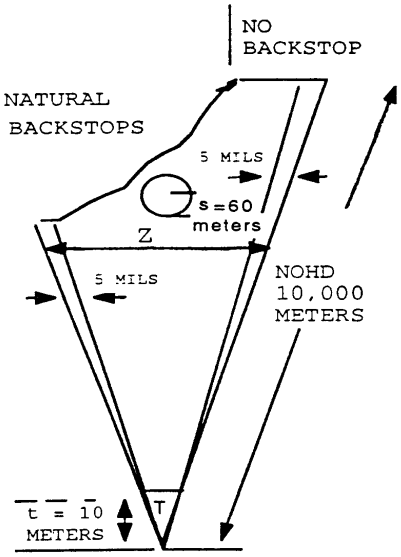
6.1.5 Range facilities evaluation.

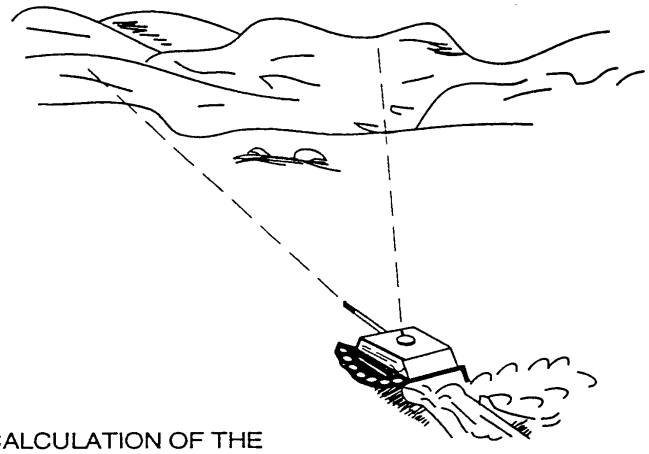
a. Range Location and Access. The range facilities are evaluated in terms of location relative to populated areas, military and civilian industrial sites, and water surface traffic. The methods used to control access to the potential laser hazard area (that is, fences, warning signs, airspace restrictions, water surface danger areas, and so forth) must be evaluated for adequacy. The locations of all occupied areas on the range, such as control towers, must be determined, as well as specific environmental factors; that is, the habitat of any endangered wildlife in the range area.

b. Types of Targets. Target areas are evaluated for types of targets currently in position. Vehicular targets, in particular, could have chrome bumpers, windshields, or other flat glass or chrome surfaces. Presence of these types of surfaces could generate a specular reflection when optical radiation is incident to the target. This hazard could even exist if the surface were bent or broken due to previous ordnance impact or explosion. Broken or bent specular surfaces could still have an adequately large flat surface remaining to generate a specular reflection. Unexploded ordnance areas in or surrounding the proposed target area could have an impact on the advisability of policing or masking existing specular surfaces.

EXAMPLE

M60A3 WITH STABILIZATION AND LASER RANGEFINDER FIRING THE MAIN GUN WHILE MOVING. IN THE COMMANDER'S JUDGEMENT, THE POSSIBILITY OF AN OBSERVER WITH MAGNIFYING OPTICS OBSERVING THE OPERATING LASER ON THE TANK FROM A DISTANT GROUND POSITION BEYOND THE NOHD IS VERY REMOTE. THE AIRSPACE DOWNRANGE IS RESTRICTED OUT TO 10 KILOMETERS.





CALCULATION OF THE LASER RANGE DANGER FAN (LDRF), ALSO CALLED LASER SURFACE DANGER ZONE (LSDZ):

1. Determine t, s, & NOHD from Table A-1. (t= 10 m, s= 60 m, NOHD = 10,000m)

2. Determine the buffer zone from Table A-1. for the moving tank. (Buffer zone = 5 mils)

3. Draw a Laser Range Danger Fan incorporating the natural backstops on the left and the target area

FIGURE 6-4. Example laser range danger fan/laser surface danger zone.

c. Terrain Features. Terrain features on and surrounding the range are evaluated for impact on laser safety. Useable terrain and vegetation backstops are identified and located on maps of the range area. Any mountain peaks outside the range are examined to verify that such obstructions as radio or television towers or park service observation towers do not extend into the laser buffer zone between the laser and the target. This consideration should only affect airborne laser systems when active target illumination commences before the aircraft enters the range boundaries.

d. Access Control. Roads or other access points to the range area should be evaluated to determine the probabilities of non-controlled personnel entering the target area or controlled range areas. Roadblocks should be established and posted at the area where access could occur.

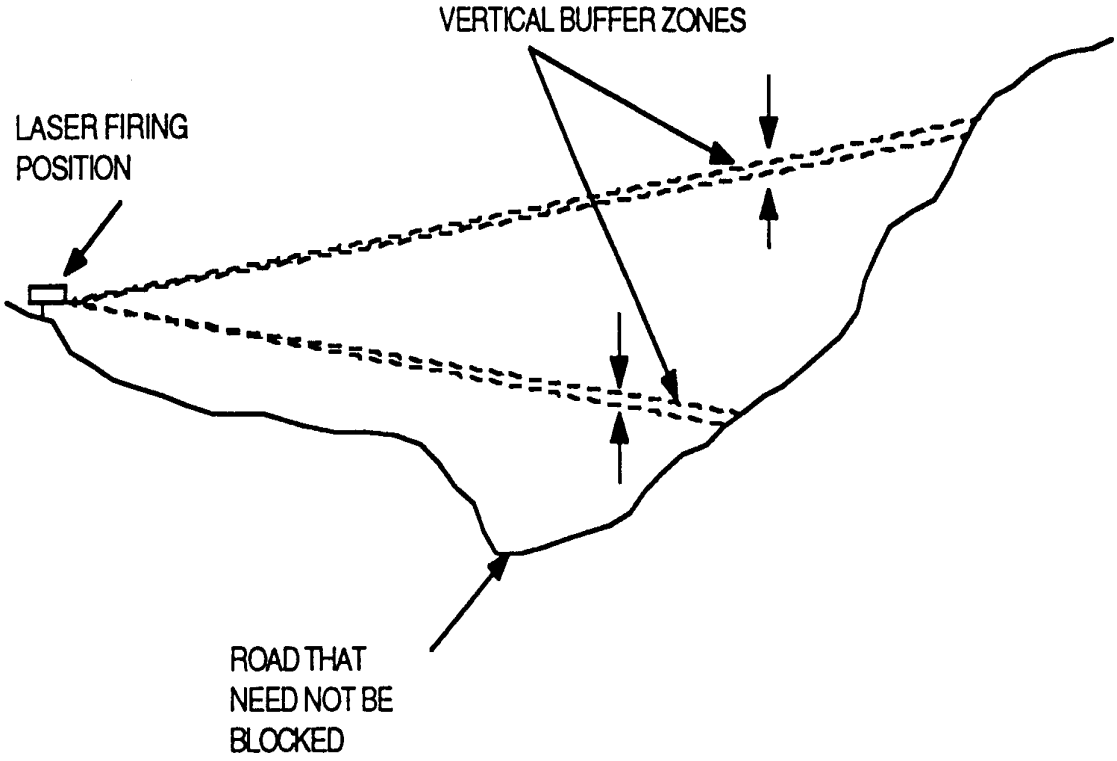


FIGURE 6-5. Vertical buffer zone.

e. Operations Over Water. Since water can become a flat specular reflector when it is calm, additional precautions are required when firing the laser over water. While in most applications, the reflectors contained in TABLE 6-I can be either covered or removed, water cannot always be avoided. Therefore, additional precautions are required when firing over water as discussed in APPENDIX G. See FIGURE 6-7.

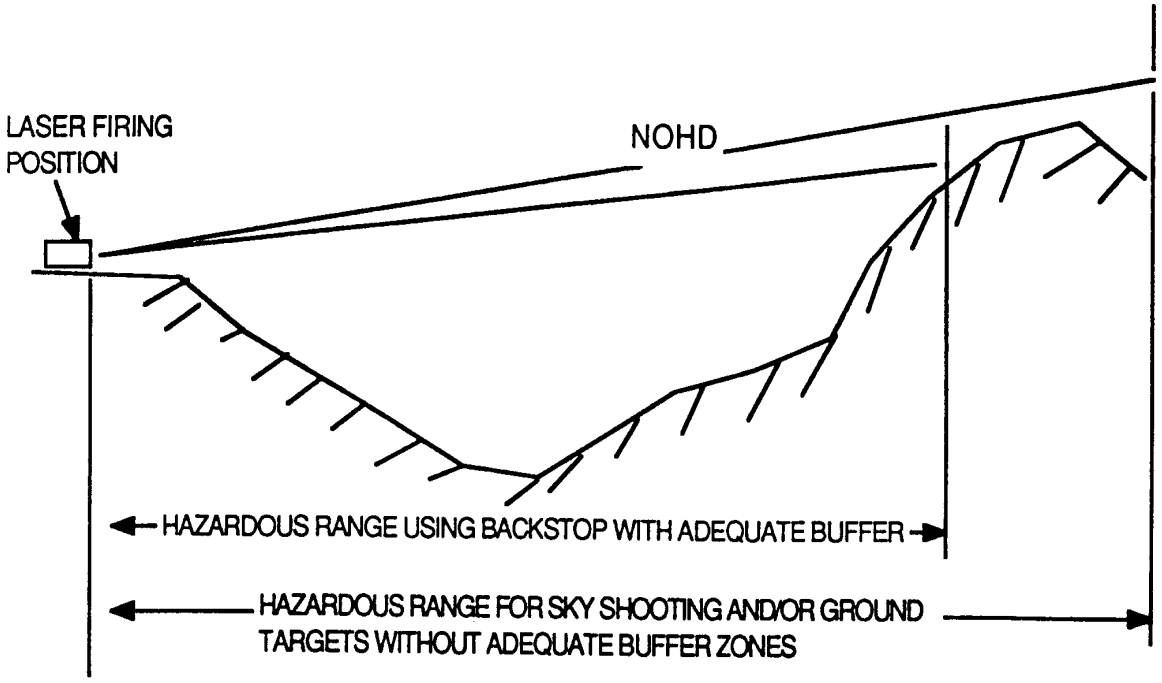


FIGURE 6-6. Effects of backstops.

6.1.6 Visual survey. A visual survey of the range area is often very useful. The survey should be conducted from actual firing locations and target locations. If the target is used for aerial operations, the range evaluator should whenever possible perform an aerial fly-over on the proposed or approved laser run-in headings. A pair of binoculars with an angular calibrated reticle can be used to scan the terrain features to estimate the natural buffer area. Suitable areas should be marked on a current map. Do not rely entirely upon the contour lines on the range map, since they may result in an erroneous estimation of the buffer area. Actual targets should be visually inspected for specular reflectors before their insertion onto the range to ensure that these surfaces are removed. Conversion of an impact area to a laser range area may require over-flights to observe any glints of sunlight reflecting from broken bits of glass or other reflectors laying on the ground.

6.1.7 Laser parameters. Laser system parameters may vary greatly with laser location, look angle, support structure and laser characteristics. The effects of these parameters are provided in the following paragraphs:

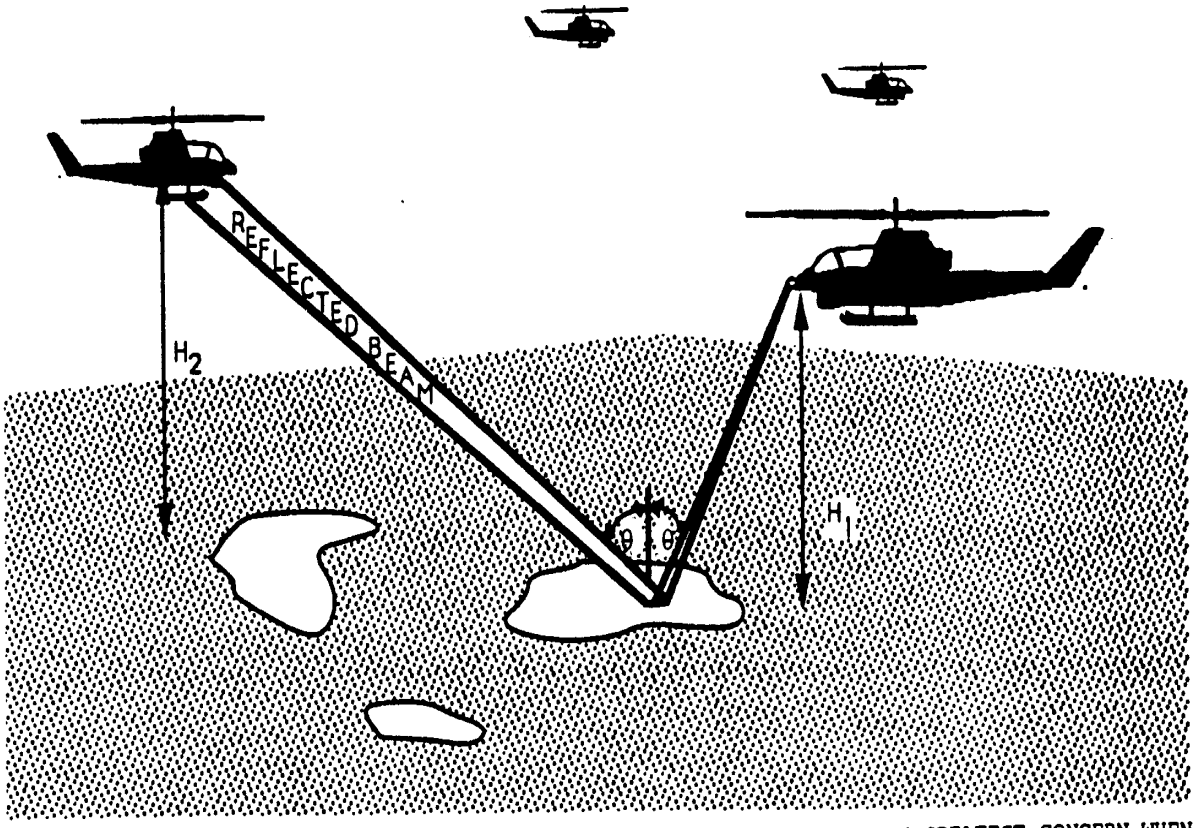
a. In addition to knowing the geometry of the range environment, knowledge of the specific laser system is essential. Perhaps the most important aspect to laser range safety is the assurance that the laser beam is terminated within a controlled area. When the distance to the backstop is less than the NOHD, the backstop determines the absolute hazard distance and the NOHD is of academic value. The buffer zone requirements are based on the pointing accuracy and stability of the system and therefore are dependent upon the laser system mounting; that is, a hand-held laser system has a larger buffer zone than a tripod mounted system. Some laser systems have a variety of mounting configurations. APPENDIX A, TABLE A-I, contains the minimum buffer zone requirements for currently fielded laser systems under their intended mounting configurations.

b. A controlled area is an area where the occupancy and activity of those within the area are subject to control and supervision for the purpose of protection from laser radiation hazards. The hazard zone or footprint will be the beam itself plus a buffer zone. This footprint is normally an ellipse. The minor axis depends on the laser to target range and the buffer zone angle for that particular laser. The major axis depends upon the altitude of the laser above the target in addition to the requirements for the minor axis. Therefore, the amount of surface area requiring control depends upon the elevation of the laser, range to target, and the specific laser system. When necessary, any of these factors can be changed to ensure that the laser beam is terminated within the controlled range boundary; that is, the footprint can be reduced in size by elevating the laser. Thus, we can have either a fairly large area to control that might extend out to the NOHD, or we can select target or laser locations that provide the required backstop.

6.1.8 Laser footprint. Calculate the size of the beam that irradiates the ground or ground-based, sea-based, or airborne target (footprint). Normally, laser beams are circular, diverge equally in all directions, and produce cone shaped beams. The size of the beam depends on the initial beam diameter, divergence, and distance (slant range) from the source. The size of the footprint is the size of the beam plus a buffer zone (see FIGURE 6-8). For scanning systems, the size of the beam would include all positions in the scan. The shape of the footprint depends on the angle of the beam that intersects the ground (slant angle is determined from the range and altitude). The footprint is determined by the following:

a. Determine the buffer angle: If the assigned laser buffer angle is 5 milliradians and the beam divergence is less than 0.5 milliradians, use 5 milliradians for the buffered footprint angular width and ignore the beam divergence. This approach will only introduce an error of less than 5 percent. If this evaluation is overly restrictive (requires too much land), a system specific evaluation can be made for each laser system. The appropriate buffer angles for most systems are listed in APPENDIX A. To calculate a buffered footprint for other systems, when the beam divergence is equal to or greater than l.0 milliradian, the footprint will be the buffer angle plus the beam divergence. When the beam divergence is less than l.0 milliradian, the following will apply:

1. If the aiming accuracy for a stabilized laser is unknown, buffered footprint angular width will be five milliradians either side of the beam.



THE SPECULARLY REFLECTED BEAM FROM AN AIRBORNE LASER GENERALLY IS OF GREATEST CONCERN WHEN ORGINATING FROM STILL WATER. THE REFLECTED BEAM IS REDIRECTED UPWARD AT THE SAME ANGLE (θ) AS THE INCIDENT BEAM.

FIGURE 6-7. Example of airborne beam reflection.

2. If the aiming accuracy is known, the buffered footprint angular width will be five milliradians, or the absolute value of the aiming uncertainty (in milliradians) plus five times the beam divergence at the 1/e (.3679) point, whichever is less, either side of the laser beam. Aiming accuracy should be contained in the system specifications.

b. Determine Footprint Size. There are at least two approaches used to determine the size of the footprint. If the desired flight profiles are known, then the size of the footprint can be determined from these flight profiles. If the size of the range is the limiting factor, the boundaries of flight profiles can be determined which would keep the footprint within the range. These two approaches can be used independently or, typically, used together to maximize land use and minimize mission impact. The procedures for these two approaches are detailed in APPENDIX E.

6.1.9 Other considerations.

a. Moving Targets or Lasers. A moving target or laser will affect the size of the LSDZ and may indicate that the single pulse NOHD is more applicable than the multiple pulse NOHD, especially when evaluating specular reflections. This must be decided on a case by case basis. A common application of this includes evaluating reflection hazards when the angle of laser operations is rapidly changing, and therefore the probability of a multiple pulse exposure is small.

b. Operating Outside of Controlled Area. Targets should never be positioned outside the controlled area (including airspace). Airborne lasers should not be operated outside the controlled airspace if the potential for the beam striking an object outside the controlled area exists. If this risk is minimal, consider permitting laser operations from uncontrolled areas under controlled conditions. Ensure the regional Flight Service Center for the Federal Aviation Administration (FAA) and Coast Guard are notified before starting this operation so they can publish a Notice to Airmen and Mariners. The FAA regulation governing this is 7930.2B, Notices to Airmen (NOTAM). Ground laser systems should never be operated outside the controlled area. Air-to-Air, Air-to-Ground, Ground-to-Air, and Ground-to-Ground laser systems shall only be operated inside controlled airspace. If the potential for the beam striking an object outside the controlled area exists, laser operations shall not be permitted. For specific guidance, each service will refer to their respective service experts outlined in paragraph 1.2b. Units conducting Air-to-Air laser operations must obtain approval from U.S. Space Command before lasing above the horizon. See Appendix I.

6.1.10 Range control procedures and recommendations.

a. Objective. Laser range safety shall prevent exposure of unprotected personnel from laser radiation in excess of the MPE. This is accomplished by determining where the laser radiation is expected to be, restricting access of unprotected personnel, and removing reflective surfaces from this area.

b. Target Areas. Recommended target areas are those without specular (mirror-like) surfaces. Glossy foliage, raindrops, snow, and other natural objects are not considered to be specular surfaces that would create ocular hazards. Although snow is not considered to be a specular surface, if thawed and refrozen, hazardous reflections can be found, especially at low angles of incidence.

c. Sanitized Ranges. If the target areas have no flat specular surfaces, range control measures can be limited to the control of the area where the laser beam hits directly. For Air-to-Air operations, surface and airspace must be sanitized to ensure no air or surface contacts are located in the direction of the firing laser.

d. Laser Operation. Laser devices shall only be directed at safety approved targets and only from approved operating positions or on designated headings and altitudes.

e. Unprotected Personnel. Unprotected personnel must not be exposed to laser radiation greater than the MPE.

f. Signs. Local procedures should provide for the placement of laser warning signs at the boundaries of the controlled areas and the access points. This is normally a coordinated process between bioenvironmental engineers/industrial hygienists and/or laser safety officers, ground safety and/or ship's safety officer, and the range officer. These signs should be constructed in accordance with MIL-STD-1425. They are also available in the federal stock system (see FIGURE 4-3). If the hazard zone is within a designated range, access controls must be established.

g. Eyewear. Personnel within the LSDZ shall wear laser protective eyewear during laser operations. Eyewear must be approved for the wavelength of the laser system being used and must provide sufficient protection (see APPENDIX A, TABLE A-III and TABLE A-IV). If more than one type of laser is used, protective eye wear must provide adequate protection for all wavelengths involved (OD greater or equal to the largest minimum OD required for each wavelength).

h. Optical Devices. Magnifying daylight optical devices, without attenuation, may be used to view the target only if flat specular surfaces have been removed from the target area. Specular surfaces can be viewed only if appropriate laser safety filters are placed in the optical train of the magnifying optics.

i. Range Access Restrictions. Access restrictions to the laser range should include consideration of roadblocks or gates especially where the range is unmanned.

j. Laser Demonstrations. Personnel may safely view a diffuse reflection of an otherwise hazardous laser beam from a protected setting as shown on FIGURE 6-9. The laser-to-target distance is great enough to preclude a hazardous reflection from a dry diffuse target. Infrared viewers or night vision goggles are necessary to view the diffuse reflections from near-infrared lasers. Visible diffuse reflections can be seen with the unaided eye.

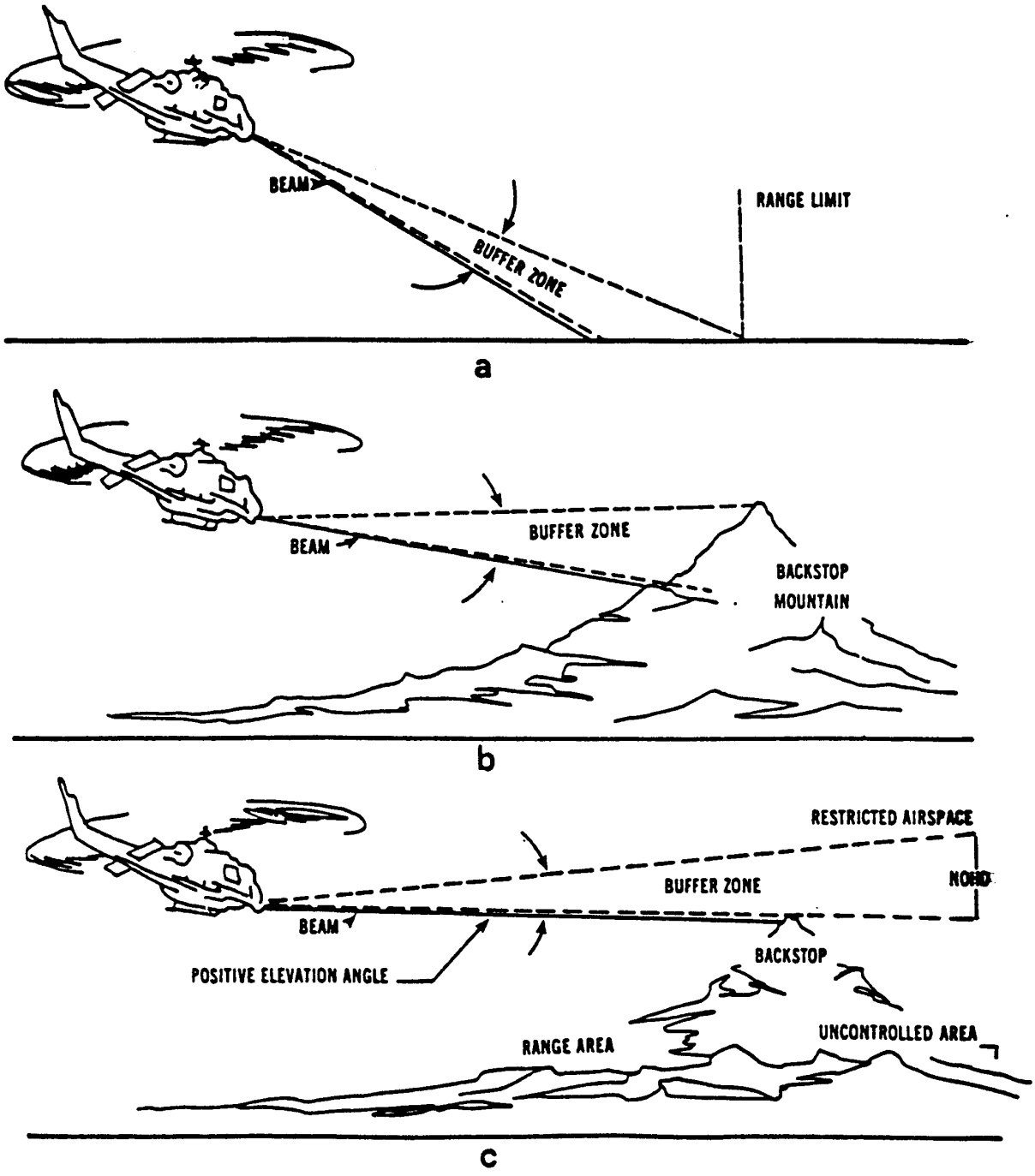


FIGURE 6-8. Examples of the use of natural backstops, buffer zones, and restricted air space.

LASER TRAINING RANGE

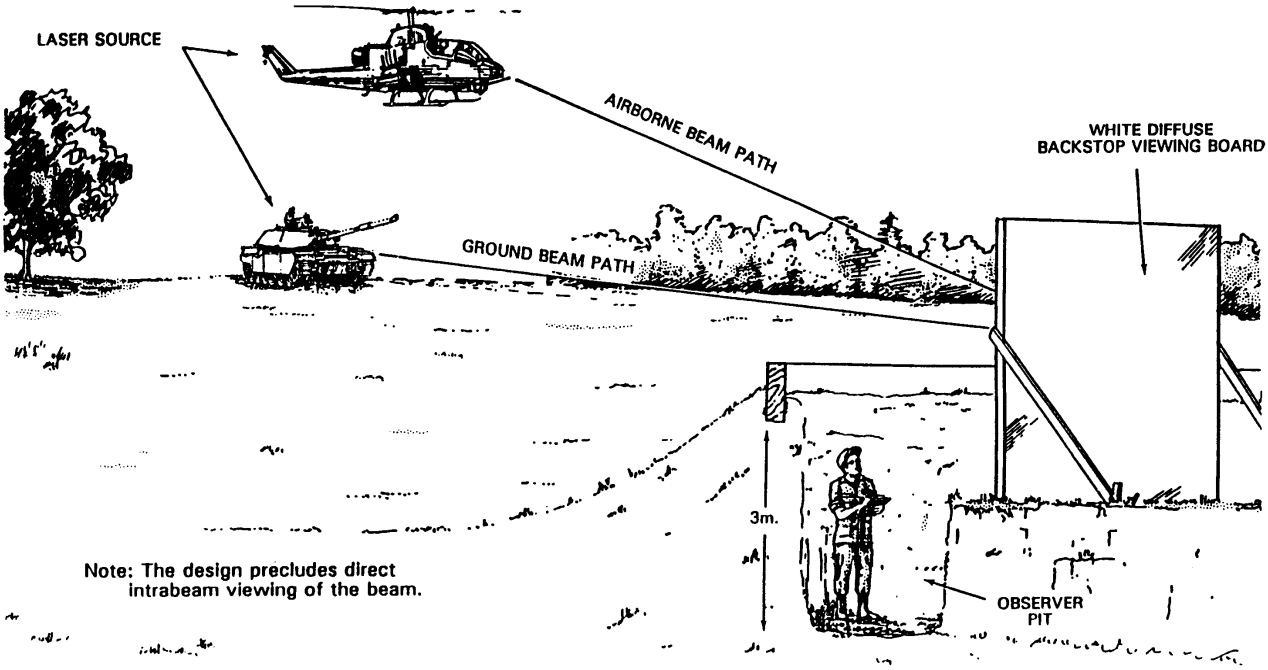


FIGURE 6-9. Supervised laser demonstration for military training.
(Modified from ANSI Z136.1, FIGURE 2D)

7. REQUIREMENTS FOR USER LEVEL LASER INSTRUCTIONS

7.1 User-level laser instructions.

7.1.1 Instruction. Utilizing the laser range safety evaluation, the range planner/LSO will determine the necessary information to:

a. Prepare or modify range laser safety directives.

b. Develop Standard Operating Procedures (SOP) for laser operations.

c. Brief personnel involved in laser operations to provide an understanding of the hazards of specific devices, and allay unfounded fears.

d. Prescribe the personal protective equipment to be used.

7.1.2 Directives. The laser range safety evaluation should be utilized to review and ensure that overall range safety regulations are current. Regulations should be developed or updated as necessary to take into account new laser systems, operating areas and targets.

7.1.3 Standard operating procedures (SOP). SOPs for specific laser devices should be prepared to inform laser users of the potential hazards from the laser devices under their control during the laser operation. Checklists for evaluating SOP are provided in APPENDIX F. An SOP should be prepared concerning procedures for a pre-sweep of the range before laser operation to ensure that unprotected personnel are not in the target area and to maintain radio communications, and so forth.

7.1.4 Safety briefing. In addition to instructions on particular devices or simulators, training material required for class room instructors and range personnel should include:

a. Principles of reflection or refraction of light.

b. Hazards of laser beams to humans and misconceptions about laser effects.

c. Safety standards or operational control procedures.

d. Preparation of range areas for laser use (that is, ensure that personnel have been alerted to the laser hazard and covered, removed, or has avoided the firing at specular surfaces).

7.1.5 Protective equipment. Eye protection requirements are listed in APPENDIX A, TABLE A-III.

7.2 Systems briefings. Laser indoctrination should be provided at the same time as the basic weapons systems instruction to students taking advanced individual training and to officers taking basic courses. The classroom instructors must be knowledgeable in operator and crew aspects of laser safety. Reference publications on subject lasers should be readily available. The instruction presented should be at the user level. (Complex scientific data or terminology should be avoided.) A training film, if available, should be included in the instruction program. Hazard data for lasers as incorporated into the technical manual on the related weapon system or on the laser component should be stressed. Proper channels for obtaining professional safety and medical assistance should be addressed during indoctrination.

8. NOTES

8.1 Intended use. The contents of this handbook are intended to serve as a guide to the safe use of lasers and laser systems used on military reservations and in military controlled areas.

8.2 Changes from previous issue. Marginal notations are not used in this review to identify changes with respect to the previous issue due to the extent of the changes.

8.3 Subject term (keyword) listing.

Apertures
Attenuation
Exclusion Zones
Hazard Zone
Lasers
Laser Radiation
Ocular Hazard Distance
Optical Density
Radiant Energy
Transmittance
Ultraviolet Radiation
Wavelength

8.4 International standardization agreement. Certain provisions of this handbook are the subject of international standardization agreement (STANAG 3606). When amendment, revision, or cancellation of this handbook is proposed which are inconsistent with the international agreement concerned, the preparing activity will take appropriate action through international standardization channels including departmental standardization offices to change the agreement or make other appropriate accommodations.

SUMMARY OF LASER SAFETY INFORMATION FOR FIRE CONTROL LASER SYSTEMS

A.1 SCOPE. This APPENDIX provides safety information for currently fielded laser fire control systems.

A.2 APPLICABLE DOCUMENTS. None.

A.3 FIRE CONTROL LASER SAFETY FEATURES

A.3.1 Fire control laser systems. Fire control laser systems are laser range finders (LRFs) and laser designators (LDs). These laser systems can be far more harmful to the eye than laser training devices such as the MILES and Air-to-Ground Engagement System/Air Defense (AGES/AD) laser simulators. Consequently, fire control lasers require control measures to prevent permanent blindness of an unprotected individual viewing the laser system from within the laser beam. A sample list of control measures for operators of fire control lasers is provided in APPENDIX G.

A.3.2 Current laser safety summary. TABLES A-I on the following pages summarize current laser safety information pertaining to the most common fire control laser systems likely to be encountered. The NOHDs for unaided viewing and while viewing the beam through an optical instrument such as a pair of binoculars (NOHD-O) are listed in TABLE A-I. The importance of NOHD is often over-valued since the laser beam is normally required to be terminated in a controlled area and the distance to the backstop defines the absolute hazard distance.

A.3.3 Ruby LRFs. The ruby LRFs on the tanks are the most hazardous lasers to the eye at close range. These lasers not only pose a hazard while viewing the laser from within the direct beam, but also from viewing the diffusely reflected laser radiation.

A.3.4 Reflectors. The entire buffered laser footprint must be cleared of specular reflectors. A specular reflector is one that is so smooth that one can observe one's image in it. A curved specular reflector does not create a significant risk to individuals at typical training distances from a target.

A.3.5 Buffer zones. Each buffer zone gives the minimum angular size of backstop behind the target that is used to terminate the beam. By ensuring that adequate backstop is present, laser energy is prevented from leaving the controlled area. Thus, if a moving target approaches the skyline within the buffer zone, laser operation should cease unless adequate airspace is controlled.

A.3.6 Eye protection. TABLES A-I summarizes the eye protection optical density (OD) requirements for worst-case exposure at the laser output (unaided) or when collected with an optical instrument (total). The final column reflects protective OD values for a single pulse entering the eye. The stated optical densities must be at the laser wavelength, otherwise the stated optical densities may offer very little protection. At longer distances away from the laser, the beam begins to spread out and become less harmful. Thus, required less optical density at further distances away from the laser.

Table A-I. NOHD (Atmospheric Attenuated), Range Safety Information, and Eye Protection Requirements for Fielded Military Laser Systems Evaluated and Approved by the DoD LSRB.

Device/Mounting		NOHD		NOHD-O			Buffer Zone (Buffer Angle) each side			Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in* safety filters OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
*****VEHICLE MOUNTED*****												
AN/VVG-1 (M551A1)[1]	694.3		9	32	47	67	2	not allowed	Clip-on 5	5.8	5.8	
AN/VVS-1 (M60A2)[1]	694.3		9	32	36	44	5	10	Clip-on 5	5.8	5.8	
AN/VVG-2 (M60A3)[1]	694.3		8	30	40	47	2	5	Clip-on 5	5.8	5.8	
red ESSLR	694.3		0.3	1.8			2	5				
green ESSLR	694.3		0	0	0	0	N/A	5				
AN/VVG-3 (M1)	1064		7	25	35	44	2	5	5	4.7	4.7	
AN/VVG-3 (LAV-105)	1064		8.2	32	41	50	2	5	5	4.7	4.7	
ESSLR	1064		0	0	0	0	N/A	N/A				
AVENGER (HMMWV)	10590	0	0	0	0	0	N/A	N/A		0	0	
AD LRF (LAV)	10600	0	0	0	0	0	N/A	N/A		4.0	4.7	
*****MAN TRANSPORTABLE*****												
AN/GAQ-T1 (LD82LB LDSS)	1064	12.5	-	38	43	52	5	N/A	Yes	4.6	5.5	
AN/GVS-5 (Handheld)	1064		2.7	13	21	27	10	N/A	5	3.7	4.4	
red filter (19dB)	1064		0.29	1.8	1.8	-	10	N/A				
yellow filter (29dB)	1064		0.056	0.55	0.55	-	10	N/A				
AN/PAQ-1 (LWLD) (Handheld LTD)	1064	7	3.5	15	33	43	10	N/A	4	4.2	5.8	
AN/PAQ-3 (MULE) (Tripod)	1064								5	3.9	5.6	
Designator - day		20	12	53	64	78	2	N/A				
Designator - night		20	12	53	64	78	5	N/A				
Rangefinder - day	1064	12	12	37	47	60	2	N/A				
Rangefinder - night		12	12	37	47	60	5	N/A				
Rangefinder w/ 12dB filter	1064	3.3	3.3	16	25	31	2	N/A				
AN/PAQ-3 (MULE) (Handheld)	1064								5	3.9	5.6	
Designator - day		20	12	53	64	78	10	N/A				
Designator - night		20	12	53	64	78	15	N/A				
Rangefinder - day	1064	12	12	37	47	60	10	N/A				
Rangefinder - night		12	12	37	47	60	15	N/A				
AN/PAQ-4,A,B,C (IR aiming light)	830	0		0	0	0	0	N/A		0	0	
AN/PEQ-1 (SOFLAM)	1064	9.6		35	45	54	10	N/A	5	4.0	5.3	
AN/PEQ-2 (ITPIAL) Aiming light &	850									2.0	2.0	
Illuminator		0.263		1.8	2.8	4.7	10	N/A				
Illuminator only		0.211		1.5	2.3	3.9	10	N/A				
Aiming light - high		0.078		0.56	0.88	1.5	10	N/A				
Aiming light - low		0		0	0	0	0	N/A				
AN/PVS-6 (MELIOS)	1540	0		0.007	0.019	0.037	0	0		0	0	
AN/PVS-X (MLRF)	1064		3	16	29	41	90 degrees - 3		Yes	3.7	3.7	
AN/TVQ-2 (GVLLD) (Tripod)	1064								Yes	3.8	5.5	
Designator		25	17	63	80	87	2	N/A				
Rangefinder		8	8	28.5	40	65	2	N/A				
Rangefinder w/ 8.5dB yellow filter		3.1	3.1	15	23	39	2	N/A				
CLD (compact laser designator)	1064	9.7		38	48	58	10	N/A	5	4.5	5.4	

1. Target must be 10 m away from the tank to avoid diffuse reflection hazard.

* see page A-4.

Table A-I. NOHD (Atmospheric Attenuated), Range Safety Information, and Eye Protection Requirements for Fielded Military Laser Systems Evaluated and Approved by the DoD LSRB.

Device/Mounting		NOHD		NOHD-O			Buffer Zone (Buffer Angle) each side			Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in* safety filters OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
*****MAN TRANSPORTABLE*****												
LLTD (laser light target designator)	1064	7		15	38	42	10	N/A		4.0	4.9	
*****AIRCRAFT MOUNTED*****												
Night Targeting System - NTS (AH-1W)	1064	15	9.2	48	59	69	5	5	Yes	3.5	5.2	
AN/AAS-33A TRAM (A-6E)	1064	14.6	9	47	58	67	N/A	5		4.6	5.8	3.0
AN/AAS-37 (OV-10D NOS)	1064	11.2	7.1	45	56	59	N/A	5		4.6	5.6	3.0
AN/AAS-38 & 38A (F/A-18A-F)	1064	17	10	50	63	73	N/A	5		4.3	5.4	3.0
AN/ASQ-153 PAVE SPIKE (F-4E)	1064	10	6.8	33	48	58	N/A	5		4.2	5.6	
AN/AVQ-25 PAVE TACK (F-111F)	1064	16	8.8	48	52	70	N/A	5		4.3	5.8	
F-117	1064	14	7.5	45	56	65	N/A	TBD	N/A	4.5	6.0	
LAAT (AH-1S & F)	1064	5	3.4	15	30	36	5	5	Yes	3.5	4.8	
LANTIRN (F-14/15/16)												
combat mode	1064	15	9	48	59	69	N/A	5[1]	N/A	4.5	5.6	
training mode	1540	0	0	0.18	0.32	0.58	0	N/A	N/A	0	1.2[3]	
secondary beam[2]	1064	0.35	0.35	2.4	3.8	5.44	N/A	N/A		1.1	2.0	
MMS-C (OH-58D)	1064									4.1	5.3	
Single pulse			23	56	72	85	5	5				
Multi-pulse		35		76	98	119	5	5				
NITE EAGLE UH-1N	1064	15	11	45	55	65	5	5		4.1	5.2	3.7
PAVE SPECTRE	1064	7.1	4.5	29	38	46	N/A	5	N/A	3.7	5.4	
TADS (AH-64)	1064	26	16	45	68	71	5	5	yes	4.0	5.5	
AN/AAQ-22 NTIS (UH-1N)	1064		0.72	4	6.1	8.6	5	5	N/A	4.0	4.0	
AC-130U LTD/RF												
Combat mode	1064	44		90	110	120	N/A	5		3.2	4.8	
Training mode	1064	2.9		16	22	28	N/A	5		1.2	2.9	
AC-130U LIA	807	0.10		0.67	1.10	1.60	N/A	5		3.2	4.7	
Magic Lantern (ML) (SH-2F/MH-53-E)	532	0.15		1.1	1.7	2.6	5	5		5.2	6.7	
*****SHIP MOUNTED*****												
Mast Mounted Sight	1540	0	0	0	0	0	0	0				
COMMERCIAL OFF THE SHELF (COTS) MILITARY LASER SYSTEMS**												
*****MAN TRANSPORTABLE*****												
AIM-1/D	800-850	0.075		0.46			10	10		1.7	1.7	
AIM-1/DLR	800-850	0.236		1.56	2.43	3.55	10	10		1.7	1.7	
LPL-30	800-850	0.09		0.68	1.1	1.6	10	10		1.7	1.7	

1. Air Force assigned buffer zone is 2 milliradians for LANTIRN. Navy F-14 LANTIRN and general policy is that aircraft be assigned a minimum buffer zone of 5 milliradians.
2. Air Force policy is to maintain aircraft separation of 1000 ft. Navy prohibits tandem or buddy aircraft lasing.
3. For F-15/16 this OD is 0, for the F-14 the OD used is 1.2.

Table A-I. NOHD (Atmospheric Attenuated), Range Safety Information, and Eye Protection Requirements for Fielded Military Laser Systems Evaluated and Approved by the DoD LSRB.

Device/Mounting		NOHD		NOHD-O			Buffer Zone (Buffer Angle) each side			Required Eye Protection		
	wave-length	multi-pulse	single pulse	7x50 binoc	8-cm optics	12-cm optics	static	moving	built-in* safety filters OD	unaided OD	aided OD	single pulse OD
	nm	kilometers		kilometers			milliradians					
COMMERCIAL OFF THE SHELF (COTS) MILITARY LASER SYSTEMS**												
*****MAN TRANSPORTABLE*****												
M-931	850	0.011		0.16	0.28	0.4	10	10		0.7	0.8	
GCP-1/1A GCP-1B	800-850	0.09 0.24		0.68 1.65	1.1 2.57	1.6 3.75	10 10	10 10		1.7 2.2	1.7 2.2	
NITE EYE	980	0.09		0.68	1.1	1.6	10	10		1.7	1.7	
HAVIS (M16 Aiming light)	850	0.012		0.1	0.17	0.25	10	10		1.1	1.1	
IZLID II	870	0.248		1.63	2.55	4.28	10	10		3.0	3.0	
TD-100 TD-100A	850 632.8 850 670	0.1					10	10		1.1 0.3 1.1 0.6	1.1 0.3 1.1 0.6	
*****AIRCRAFT MOUNTED*****												
AIM-1/MLR	800-850	0.085		0.68	1.1	1.6	5	5		1.7	1.7	
AIM-1/EXL	800-850	0.130		0.68	1.1	1.6	5	5		1.7	1.7	

* Assume that built-in safety filter only protects against the wavelength of the laser in which it is installed and that it does not always protect against other laser wavelengths.
** WARNING! THIS HAZARD DATA COULD CHANGE SINCE DOD HAS NO CONTROL OVER MANUFACTURING OF THESE PRODUCTS. HAZARD CHARACTERISTICS IN THIS TABLE ARE VALID AS OF THE DATE OF DOD EVALUATION; PERIODICALLY CHECK WITH THE MANUFACTURER TO ENSURE THAT CHARACTERISTICS HAVE NOT CHANGED SINCE THE DATE OF THE LAST DOD EVALUATION.

A.3.7 Description of fielded laser systems.

AC-130U Laser Target Designator/Range Finder LTD/RF is mounted on the AC-130U aircraft.

AH-1W Night Targeting System (NTS): This is a modification to the Marine Corps AH-1 Telescopic Sight Unit to include night targeting capability through the direct view optics using a Forward Looking Infrared (FLIR) and Laser Target Designator/Range finder system with camera and video tracker.

AIM-1: A Class 3b infrared diode aiming laser (830 nm - 850 nm wavelength) for use with night vision goggles. The AIM/MLR is mounted on Marine Corps XM-218, 50 caliber, M-60 and GAU-17B machine gun mounts. The AIM/EXL version is hard mounted on the AH-1 turret. AIM-1/D, AIM-1/DLR, AIM-1/MLR, AIM-1/EXL devices are integrated into the army AH-1F helicopter or used separately or mounted on army rifles. ANVIS night vision goggles provide adequate protection against these lasers. CAT'S EYES do not protect against laser radiation.

Air to Ground Engagement System/Air Defense (AGES/AD) is an extension of MILES to air defense simulation.

AN/AAQ-14: LANTIRN System, Low Altitude Navigation and Targeting Infrared System for Night. A two pod system containing a terrain following radar (TFR), forward-looking infrared (FLIR), laser designation, and later, a target recognition system. Originally designed for the F-15E and F-16 and the targeting pod now integrated with some USN F-14s.

AN/AAQ-22 Navigational Thermal Imaging System (NTIS): Turret mounted FLIR/Laser Range finder on the UH-1N helicopter.

AN/AAS-33A, Target Recognition Attack Multisensor (TRAM) laser system: This system is mounted on the A6-E Aircraft and has a laser target designator and forward-looking infrared (FLIR).

AN/AAS-37: Laser Range Finder Designator mounted on the Marine Corps OV-10 Observation Aircraft.

AN/AAS-38A NITE HAWK: Pod mounted on lower left side of F/A-18 aircraft contains a Forward Looking Infrared (FLIR) and laser target designator/Range finder (LTDR)

AN/GAQ-T1 LDSS: Laser Designator Simulator System.

AN/GVS-5 Laser Range Finder Infrared Observation Set (Hand held).

AN/PAQ-1 (LTD) Laser Target Designator: This is a lightweight, hand-held, battery operated laser device. Forward observers use the LTD to designate targets.

AN/PAQ-3 (MULE) Modular Universal Laser Equipment: This is a Marine Corps laser designator used with laser energy homing munitions. The MULE is man portable and is used only in a dismounted mode.

AN/PAQ-4, AN/PAQ-4A, pulsed AN/PAQ-4B and AN/PAQ-4C Infrared Aiming Light: These are Class 1 military exempt laser systems using an 830 nm wavelength laser diode.

AN/PEQ-1 SOFLAM: Special Operating Forces Laser Marker.

AN/PVS-6 MELIOS: MELIOS was developed for infantry forward observers to measure distance. MELIOS is a Class 3a restricted eye safe laser.

AN/TVQ-2 Ground/Vehicle Laser Locator Designator (G/VLLD): The G/VLLD is a principal ranging and laser designating device used by Army artillery forward observers with laser energy homing munitions. The G/VLLD is capable of designating stationary or moving vehicular targets and may be used in a stationary, vehicle mounted, or tripod supported dismounted mode. The primary vehicle mount is the Fire Support Team Vehicle (FISTV).

AN/VVG-1 Laser Range Finder mounted on the M55lAl Sheridan Vehicles.

AN/VVG-2 Laser Range Finder mounted on the M60A3 tank. Used with two filters, the green Eye Safe Simulated Laser Range Finder (ESSLR) filter and the red ESSLR filter. The green ESSLR is eye-safe, the red ESSLR is less hazardous than the system without filters (see APPENDIX B).

AN/VVG-3 M1 tank laser Range finder used with one eyesafe filter.

AN/VVS-1 Laser Range Finder mounted on the M60A2 tank.

AVENGER: Avenger air defense system, turret mounted laser range finder on a HMMWV.

COMPACT LASER DESIGNATOR (CLD): A small, lightweight laser designator and/or Range finder used by the Navy for target designation.

GCP-1: Ground Commander's Pointer: Small, lightweight Infrared aiming laser for use with night vision devices in target identification and night illumination. GCP-1 operates at a power of 30 mw with zoom beam from 30 degrees to 0.03 degrees (approximately 500 to 0.5 milliradians). Built-in sensor prevents operation in daylight; however, it does not sufficiently reduce power in dark conditions to prevent hazardous illumination of unprotected personnel within the NOHD. GCP-1A operates at 50 mw and does not incorporate the sensor.

Laser Augmented Airborne TOW (LAAT) mounted in the AH-1F COBRA Helicopter. The LAAT system consists of a laser range finder and receiver that is incorporated into the M65 tube launched, optically tracked, wire guided (TOW) telescopic sight unit.

LAV-105: Light Armored Vehicle-105 mm gun laser range finder.

LAV-AD: Light Armored Vehicle - Air Defense turret mounted CO2 laser Range finder.

LPL-30: A Class 3b infra-red diode aiming laser used by command to mark targets of choice to attacking forces equipped with the night vision goggles (NVG). ANVIS NVGs provide adequate protection against Class 3b lasers.

M55: Laser Tank Gunnery Trainer.

Mast Mounted Sight on the OH-58D that, in addition to thermal and optical sensors and imaging instrumentation, incorporates a laser Range finder and/or designator.

MINI LASER RANGE FINDER (MLRF): A lightweight, Hand held Neodymium YAG laser Range finder. The RCA MLRF listed in TABLE II is given the designation of AN/PVS-X to distinguish it from future MLRFs, which should not have off-axis radiation that would cause it to have such large buffer zone requirements as the AN/PVS-X.

MILES: Multiple Integrated Laser Engagement System. The MILES system uses low risk lasers and does not require service members to wear protective eyewear during the conduct of training with the MILES system.

NMMS: Navy Mast Mounted Sight. The Navy Mast Mounted Sight is mounted above deck for television and IR imaging and incorporates an eye-safe Class 1 LRF utilized to give range data for high priority targets such as mines, ships, and small water craft.

NITE EAGLE: FLIR/Laser Designator/Range finder turret adapted from the Aquilla system for the US Marine Corps UH-1N helicopters. In training and field testing, prohibit laser firing when the laser in flight is less than 1000 meters from the target. This is required to prevent loss of track and possibility of the beam wandering off the target during slew and reorientation of the laser as the system passes over the target.

NITE EYE: Illuminator for IR camera. Produced by Air Force Phillips Laboratory. Approved only for use with output power below 30 mw.

PAVE PENNY (AN/AAS-35): Laser tracker pod used on the A-10 and A-7 aircraft. Does not contain a laser.

PAVE SPECTRE (AN/AVQ-19): Laser tracking and designator used on C-130 gun ships.

PAVE SPIKE (AN/AVQ-12): Laser tracking and designator pod fitted on F-4 and F-111 aircraft.

PAVE TACK (AN/AVQ-26): Advanced optronics pod containing stabilized turret with FLIR, laser designator and tracker used on the F-4, RF-4, and F-111F aircraft.

SCOFT: SHILLELAGH Conduct of Fire Trainer.

TADS/PNVS: Target Acquisition and Designation System with Pilot Night Vision Sight mounted in the Apache Advanced Attack Helicopter.

TD-100: A day/night aiming laser. For daytime use this device uses a Class 2 helium neon visible laser and for nighttime the TD-100 uses a Class 3b infrared laser diode. Night vision goggles will provide adequate nighttime protection for personnel viewing the infrared laser.

A.3.8 Description of inactive lasers and associated systems. The following systems are not in the active inventory but are included for information:

PAVE ARROW (AN/AVQ-14): This was a laser tracker pod developed for use in conjunction with the PAVE SPOT laser designator used on O-2A FAC spotter planes, C-123, and was planned for use on the F-100. It was eventually merged with the PAVE SWORD program.

PAVE BLIND BAT: The PAVE BLIND BAT consisted of a laser target designator to illuminate targets for the PAVE WAY guided bombs. The PAVE BLIND BAT had an effective range of 18,000 ft and was developed for use by AC-130 gun ships to aid supporting fighter aircraft.

PAVE FIRE: Development of laser scanner to aid F-4 Phantoms in securing proper target bearing.

PAVE GAT: Development of a laser range finder for use on the B-52G.

PAVE KNIFE (AN/ALQ-10): The original laser designator pod developed by Aeronutronic-Ford and used in combat in Vietnam.

PAVE LANCE: Developmental effort to replace the PAVE KNIFE by improving night capability with the addition of a FLIR in place of the low light television (LLTV). Superseded by PAVE TACK.

PAVE LIGHT (AN/AVQ-9): Stabilized laser designator developed for the F-4 Phantom.

PAVE MACK: Development of laser seeker head for air to ground rockets. Project was also called LARS (Laser Aided Rocket System) and rockets were to be used in conjunction with Forward Air Controller (FAC) mounted PAVE SPOT designator.

PAVE NAIL (AN/AVQ-13): Modification of 18 OV-10 FAC aircraft with stabilized periscope night sight and laser designator. Program coordinated with PAVE PHANTOM and PAVE SPOT.

PAVE PHANTOM: Addition of an ARN-92 Loran and computer to the F-4D allowing aircraft to store targeting information for eight separate positions illuminated by OV-10 PAVE NAIL.

PAVE POINTED: Palletized gun direction system consisting of a laser designator and/or rangefinder and LLTV employed on a C-123 and forerunner of subsequent gunship fire control stems.

PAVE PRISM: Aerodyne Research effort to develop IR and active laser seekers for use on the ASRAAM air-to-air missile.

PAVE PRONTO: Modification of AC-130 gunships for night attack including an LLTV Electro systems night observation camera, AAD-4, or AAD-6 FLIR and AVQ-17 illuminator.

PAVE SCOPE: Target acquisition aids for jet fighter aircraft such as the Eagle Eye (LAD) AN/AVG-8, and TISEO.

PAVE SHIELD: Classified project undertaken by Aeronautical Research Associates.

PAVE SPOT (AN/AVQ-12): Stabilized periscope night vision sight developed by Varo for use on the O-2A FAC. The system was fitted with a Korad laser designator (ND:YAG).

PAVE STRIKE: A related group of air-to-ground strike programs include PAVE TACK and IR guided bombs.

PAVE SWORD (AN/AVQ-11): Laser tracker designed to pick up energy from targets illuminated by O-2A spotter planes. Used on F-4, and bore sighted with its radar set.

PAVE WAY: Code name for a wide variety of guided bomb projects, also refers to AN/AVQ-9 laser designator, developed by Martin Marietta for use on the F-4 Phantom.

OPTICAL SAFETY SUMMARY FOR WEAPON SIMULATORS AND LASER TRAINING SYSTEMS

B.1 SCOPE. This hazard information applies to Military exercises using weapon simulators and laser training systems such as the Multiple Integrated Laser Engagement System (MILES) and the Air to Ground Engagement System/Air Defense (AGES/AD).

B.2 APPLICABLE DOCUMENTS. Information in this section was obtained from documents referenced in Section 2 and from informal documents provided by each of the Service's safety specialists in Section 1.

B.3 OPTICAL SAFETY SUMMARY. The AGES/AD, Laser Air to Air Gunnery Systems (LATAGS), and Precision Gunnery Training System (PGTS) for TOW and Dragon missiles are an extension of and are similar to the MILES. The AGES/AD, LATAGS and PGTS systems emit infrared laser beams to simulate various air defense, airborne and ground weapons systems to improve realism during training. The AN/GVT-1 is a simulator of a target illuminated by a laser; it consists of an infrared laser emitter covered by a diffuser. Table B-1 provides cautionary distances within which the weapons may be pointed at the face of another person, with and without the use of optical viewing aids. Since optical aids; that is, binoculars, tend to concentrate this energy, these distances may be extended when unfiltered optical aids are used. In most cases, greater hazards exist during training exercises than from the infrared energy produced from the weapon simulators.

B3.2 MILES. The MILES is an ingenious system for scoring tactical exercises, dating from the early 1980s. This is accomplished through an infrared beam emitted from each weapon and detected by a target that can be a man or vehicle. These systems do not present a hazard during normal field exercises. However, the beam is quite concentrated upon leaving the transmitter and cautionary measures are advised at extremely close engagement ranges. Currently MILES transmitters exist and are used from the original MILES, the MILES II, and the MILES 2000. MILES transmitters used for the M16 before 1986 were Class 3a devices as are the MILES 2000 M16 laser transmitters. In 1986, the original MILES Small Arms Transmitter (SAT), was redesigned to be a Class 1 device. A person would be more likely to receive an eye injury from the impact of the blank fired at close range than from the infrared energy from the SAT. The MILES II, M16 rifle simulator is also a Class 1 device, but the other MILES II machine gun simulators are Class 3a. .

B.3.3 AGES/AD. The Air to Ground Engagement System/Air Defense (AGES/AD), Laser Air to Air Gunnery Systems (LATAGS), and Precision Gunnery Training System (PGTS) for TOW and Dragon missiles are an extension of and are similar to the Multiple Integrated Laser Engagement System (MILES). The AGES/AD, LATAGS and PGTS systems emit infrared laser beams to simulate various air defense, airborne and ground weapons systems to improve realism during training. The AN/GVT-1 is a simulator of a target illuminated by a laser; it consists of an infrared laser emitter covered by a diffuser. TABLE B-I lists cautionary viewing distance for an eye exposed from within the infrared laser beam for various versions of the AGES/AD, LATAGS and PGTS, and

AN/GVT-1 simulators. Since these systems are pointed toward the sky, aimed at a retroreflector mounted on a target in a restricted area, or contained within a diffuser, no optical radiation hazard exists during normal field exercises. Other potential hazards such as posed by the blast simulators must be considered.

B.3.4 TWGSS/PGS. Tank Weapon Gunnery Simulator System/Precision Gunnery System (TWGSS/PGS) with modified telescope has a MILES type transmitter (SAAB version). The Target Acquisition and Designation System (TADS), Mast Mounted Sight (MMS) simulators, and the Hellfire Ground Support Simulator (HGSS) (all of which use a 1.54 nm Erbium laser and 904 nm laser diode) comprise the AGES II simulator system. AGES II is used on the KIOWA 50 caliber gun and rocket simulators and on the wirestrike modification to the APACHE which includes a 20 mm area weapon system (AWS) simulator.

B.3.5 Schwartz Electro-optic Controller Gun. The controller gun is used with the Tank Weapon Gunnery Simulation System/Precision Gunnery System (TWGSS/PGS) transmitter. The controller gun can simulate the kill codes of various MILES weapon simulators and reactivate troops or weapons systems during training exercises. This is a Class 1 device and does not present a laser hazard.

B.3.6 JAVELIN FTT. The JAVELIN Field Tactical Trainer (FTT) is a man portable training system for the shoulder fired JAVELIN antitank tactical weapon system. The FTT is similar in appearance to the actual JAVELIN without the explosive parts. The FTT is a key controlled trainer used during force-on-force training, gunner range qualification, and verification of operating skills in developing JAVELIN gunners. The FTT consists of the Simulated Round (SR) and an instructor station which monitors and records the functions of the SR. The SR includes a laser for simulation of target hits with a MILES compatible laser/detector system for scoring hits.

B.3.7 ISMT/IST. The Indoor Simulated Marksmanship Trainer (ISMT) and Infantry Squad Trainer (IST) use Class 1 lasers (780 nm) in modified weapons to trace the aim point and calculate the location of simulated shots hitting a display screen. These lasers are commercially sold and registered with the FDA.

TABLE B-I. Cautionary Distances for Eye Exposure to Weapon Simulators and Laser Training Devices.

Device/Simulator	Unaided Viewing (m)	Optically Aided Viewing (7 X 50 Binoculars) (m)
MILES I/II Large Gun Simulators	10	0
MILES I SAT pre 1986 Blank Fire	0	0
MILES I SAT pre 1986 Dry Fire	7	0
MILES I SAT post 1986	0	0
MILES 2000 SAT	10	40
MILES 2000 ULT	10	40
MILES SWLTU	10	0
M55 Trainer (0.25 s viewing)	0	0
SCOFT	13	160
Schwartz Electro-optic Controller Gun	0	0
AGES/AD TOW	10	0
AGES/AD-Chapparal	0	0
AGES/AD Vulcan	10	0
AGES/AD 2.75" Rocket	10	0
AGES/AD 20 mm Gun	10	0
AGES/AD Stinger	10	0
AN/ASQ-193 LATAGS	0	438
PGTS	0	154
AGES II TADS, Mast Mounted		
Sight and HGSS		
Erbium Laser	0	0
GaAs Laser	0	260
AGES II OH58D Kiowa Warrior		
50 - Caliber	8	22
Rocket	6	10
AGES II APACHE 30-mm AWS	10	50
TWGSS/PGS	0	5
Controller Gun(Schwartz E-O)	0	30
Javelin FTT	15	
AN/GVT-1 Simulated Laser Target		
With Diffuser	0	0
Without Diffuser	2760	15,000
ISMT/IST	0	0

SAMPLE CONTENT FOR LASER SAFETY SOP FOR TRAINING WITH PORTABLE FIRE CONTROL LASERS

C.1 SCOPE. This APPENDIX provides suggested input to laser safety SOP.

C.2 APPLICABLE DOCUMENTS. This section is not applicable to this APPENDIX.

C.3 WARNING.

WARNING

Laser rangefinders and designators can cause irreparable blindness if used improperly. Exposure of the eye to either the direct beam or a beam reflected from a flat mirror-like surface can cause an eye injury at a great distance. These lasers will not pose a skin or diffuse reflection viewing hazard. The following control measures will prevent such an exposure when training operators with portable fire control lasers in one-sided exercises:

a. Laser operators shall periodically read and always follow this safety SOP.

b. Never point the laser at any unprotected personnel or flat mirror-like surfaces such as glass.

c. Operate only on laser-approved ranges established in accordance with this handbook

d. The laser will not be operated or experimented with outside the range area unless it is specifically authorized. The laser exit port will be covered by an opaque dust cover and the laser disabled by removal of the battery when the laser is located outside the range area.

e. Positively identify the target and buffer areas before laser operations.

f. Since the target area must be clear of specular reflectors, laser eye protection is not required for laser operators even when viewing the target area with binoculars. However, personnel should never enter the laser hazard area during lasing operations without appropriate laser eye protection. Such eye protection shall have curved lenses.

g. No special precautions are necessary for firing during rain, fog, or snowfall. Certain ranges may be closed for operation if water begins pooling either on the ground or on snow.

h. Report immediately to your supervisor any suspected injury or defective equipment (such as misalignment of the laser beam with the pointing telescope) so appropriate action may be taken.

i. The SOP must also include general information such as responsibilities, emergency procedures, and the meaning of operational and warning signals.

EQUATIONS FOR LASER HAZARD EVALUATION

D.1 SCOPE. This APPENDIX contains equations for laser hazard evaluation to conform to range safety constraints.

D.2 APPLICABLE DOCUMENTS. These equations derive from Chapter 2 of this handbook.

D.3 APPLICATION OF EQUATIONS.

D.3.1 Introduction. The information provided in this APPENDIX may be used in addition to the Service-specific laser evaluation techniques. The equations provided here are the means to determine minimum laser altitude above Mean Sea Level (MSL) that will satisfy the safety constraints for use of an airborne laser system on a particular range and at a specified distance from the target. Equations are provided to determine positions of ground based lasers that will satisfy the safety constraints on a given range. Many ranges have a sloping terrain that yields a laser footprint plus buffer zone resembling an ellipse. This footprint will be a more elongated ellipse for airborne lasers illuminating a downward sloping terrain and a truncated ellipse for lasers illuminating an upward sloping terrain. The use of these equations in the case of shipboard laser systems would provide pessimistic results. The lack of terrain features to act as a backstop in an open ocean environment, when combined with the longer NOHD of a more powerful shipboard laser system causes the curvature of the earth to play a significant role in shipboard laser evaluations. The optical horizon from an elevation of 80-ft MSL is approximately 9.5 nmi. Since at a range of l9 nmi (the approximate NOHD for unaided viewing of some proposed shipboard laser systems), the propagated beam could not possibly be below 80-ft MSL, the use of optical aids aboard other surface vessels would not increase the probability of exposure. It would increase the extent of damage should an exposure occur. It would also require coordination with those responsible for the air space and coordination of satellite space with Space Command, Cheyenne Mountain, Colorado. The goal of airborne laser and ground laser safety evaluations on many ranges is to determine the aircraft flight profile required to keep the laser beam plus its buffer within the confines of the target restricted area, that is, the LSDZ.

E.3.2 Hazard evaluation.

a. Buffered Footprint Definition. The buffered footprint is the projection of the laser beam and its associated buffer zone on the ground surrounding the intended target. The footprint configuration and size are determined by the range from the laser aperture to the target, the incidence angle of the laser beam LOS on the target or range area plane and the assigned buffer angle. FIGURES D-1 and D-2 show the geometry of the buffered footprint. The footprint of this laser is an ellipse whose width is typically quite small and a simple function of the distance to the target. The spreading of the beam along the ground in the direction of the laser LOS is of primary concern and changes drastically as a function of the aircraft's height above and distance to the target.

b. Hazard Evaluation Without Specular Reflections. This evaluation should be done for each aircraft heading and should account for slope of the terrain.

(1) Single Laser Aircraft Heading. Provided that the laser target and surrounding area are clear of specular reflectors, the mathematical model used to evaluate range safety must assure that the laser beam and its associated buffered footprint fall within the prescribed boundaries of the controlled and restricted ground space. The following paragraphs describe the equations used for this model. FIGURE D-1 shows an aircraft laser illuminating a small target area with the associated buffer zones fore and aft. FIGURE D-2 shows an airborne laser illuminating a large target area with near and far buffer zones assigned as if the laser were always aimed at the nearest and farthest targets. The plan views of these buffered footprints are shown on FIGURES D-3 and D-4. When using TABLES D-I through D-V to determine buffered footprint widths and lengths, refer to the rectangle in FIGURE D-4 to visualize dimensions in the footprint tables which are listed as forward, aft, and width.

(2) Multiple Laser Aircraft Headings. If the laser attack will be from several bearings (for example 45 degrees to 135 degrees), the LSDZ will be a summation of all possible buffered footprints as shown on FIGURE D-5. If the attack bearings are not specified or attack from any direction is desired, the LSDZ will be a circle with a radius equal to the longest forward or aft buffered footprint dimension for the possible altitudes or slant ranges. This is shown on FIGURE D-6.

(3) Examples (Level Ground). The following examples are provided as an application of the conditions described above.

(A) EXAMPLE 1 (Level ground): Referring to TABLE D-I, for a PAVE SPIKE laser fired from 200 - 1000 feet above ground level (AGL) at ranges from 1 to 4 miles, the longest buffered footprint dimensions on level ground are 8500 feet forward, 5960 feet aft and 130 feet wide. The areas within these distances of target must be restricted as the LSDZ.

(B) EXAMPLE 2 (Level ground): Referring to TABLE D-V, for any PAVE SPIKE or PAVE TACK laser fired from 200 feet - 1000 feet above ground level at ranges from 1 mile to 4 miles, the longest buffered footprint dimensions on level ground are 37,600 feet forward, 9190 feet aft, and 243 feet wide. The areas within these distances of the target must be restricted as the LSDZ.

(4) Terrain Not Level. Actual procedures vary case by case; the following are presented as common conditions:

(A) Target on rising terrain or hills behind target (Natural Backstop). The condition of targets on rising terrain sometimes lengthens the near boundary and makes the far boundary less restrictive than the level ground condition. Hills behind the targets can act as natural backstops and reduce the size of the forward footprint as rising terrain did, see FIGURES D-7, D-8, and D-9.

(B) Falling terrain in target area or hills in foreground. This condition will result in longer forward buffered footprints and more restrictive conditions.

(1) Foreground distances. The height, MSL, or above ground level (AGL) of the laser in reference to the target must be determined for all distances between the laser and target.

(2) Distance beyond target. The downward sloping ground beyond the target can greatly extend the forward footprint as shown on FIGURES D-10 and D-11. If flight profiles are not limited, the forward footprint could be as long as the NOHD.

c. Specular Reflections.

(1) Still Water and Other Flat Specular Surfaces. Determine if the reflection from still water can enter uncontrolled air space, or hit a hill or ship's structure within the NOHD and beyond the restricted boundaries. This is shown on FIGURE D-12. If this is or other specular reflectors appear to be a problem, limit the flight profiles, move the target, or restrict more land or airspace. If still water cannot be avoided or flat specular reflecting surfaces in the area of the foot print cannot be removed, then the aircrew, personnel in other aircraft, ground and shipboard personnel and the surrounding community need to be considered for this condition. If the reflectivity of the specular surface is known, the effective NOHD (distance from laser to reflector plus distance of reflected beam to end of hazard zone) can be reduced by (approximately) the square root of the reflection coefficient. See APPENDIX F for some reflection coefficients. For each altitude of the aircraft and distance from the specular reflector a new sphere or linear distance must be calculated for the specular reflection into the surrounding area or air space. Use the worst case results.

d. Aircrew. Present policy for most services requires aircrews to wear laser protective eyewear when: flying in multiple ship formations, targets are not clear of specular surfaces or ground based lasers are used against aircraft. If the target area is not clear of specular surfaces, and the aircrews lase from distances less than one half the NOHD, aircrews are at risk of eye damage if laser protective eyewear is not used. Possible exposure situations to aircrews from specular reflectors are shown on FIGURES D-13 and D-14.

e. Ground Personnel, Shipboard personnel, Other Aircraft and Surrounding Community. If flat specular surfaces are near the target, the laser beam can be redirected in any direction as shown on FIGURES D-15 and D-16. The LSDZ should then be extended to a hemisphere or portion of a hemisphere with a distance from the specular reflector equal to the NOHD minus the minimum lasing distance from the laser to specular reflector. As with the cases described above, natural backstops and terrain may alter the shape of this area. Airspace over the range or personnel on ships superstructure or land based high structures may be at an unacceptable risk.

f. Hazard Distances from various reflective surfaces. This can be calculated from the information in APPENDIX F.

E.3.3 Footprint determinations. If the range is small and therefore is the controlling factor, we usually determine the flight profiles from the land size as follows:

a. Determine desired target location.

b. Draw outline of controllable restricted range area.

c. Measure distance from target to range boundaries.

d. Use footprint tables or calculate flight profiles that would not cause the LSDZ to exceed the range boundaries. For both ground-based lasers and airborne lasers, the problem can be broken into two constraints; the first being that the buffered footprint does not exceed the available controlled area between the target and the laser (near boundary). Likewise, the second constraint is that the buffered footprint does not exceed the available controlled area beyond the target (far boundary).

e. Ground Based Lasers. Determine the ability to keep the buffered laser footprint vertically and horizontally within the restricted boundaries.

1. Vertical Buffer Far Boundary. Addressing the far boundary constraint first, FIGURE D-17 shows the geometry of the problem. Determine the available buffer above and below the target out to the edge of the backstop.

α = buffer angle plus beam divergence either side of laser LOS. For systems listed in TABLE A-I, the beam divergence is extremely small compared to the buffer angle and hence the beam divergence may be ignored.

δ = Available vertical buffer angle between laser LOS to target and laser LOS to backstop.
h = altitude of laser
al = altitude of far target
bl = altitude of far boundary
dl = horizontal distance on surface from laser to furthest target
A = distance from target to far boundary of LSDZ (backstop)

The angle δ may be calculated from the following equation.

$$\delta = \arctan((bl - h)/(dl + A)) + \arctan((h - al)/(dl))$$

As long as the angle δ remains greater than angle α, the beam is safely contained vertically within the designated LSDZ.

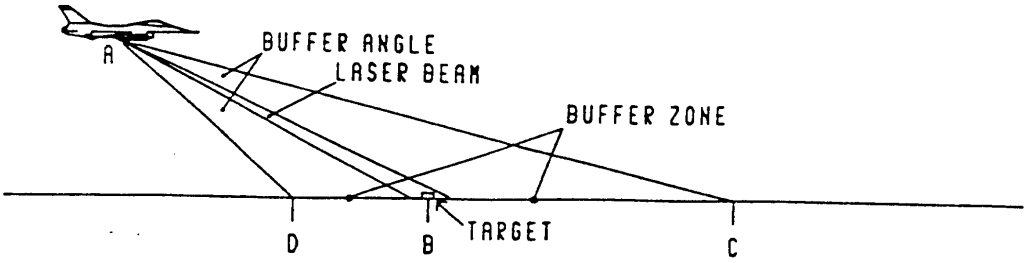


FIGURE D-1. Laser footprint with single target - side view.

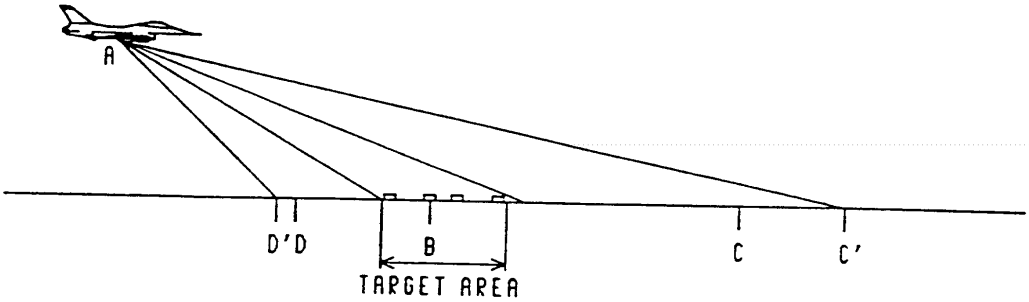


FIGURE D-2. Laser footprint with multiple targets-side view

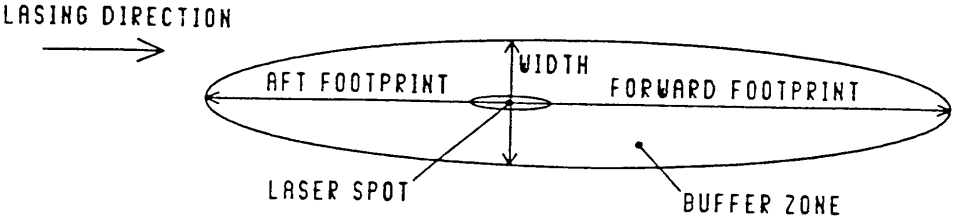


FIGURE D-3. Laser footprint top view

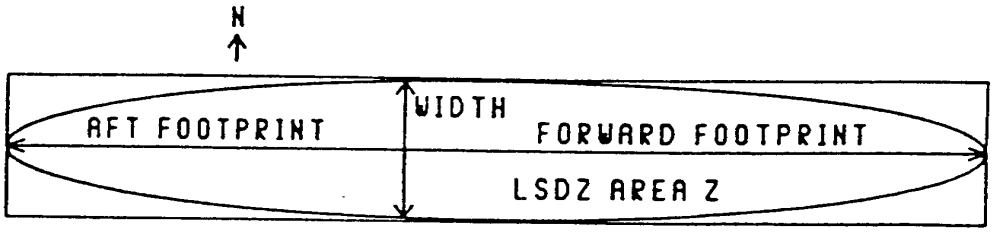


FIGURE D-4. LSDZ - attack bearing 90 degrees

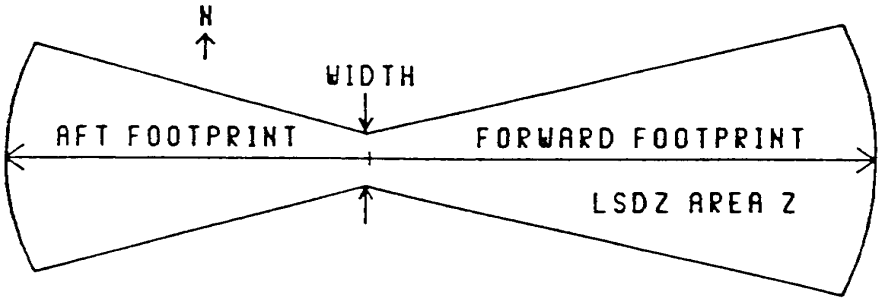


FIGURE D-5. LSDZ - attack bearing 70 degrees to 100 degrees

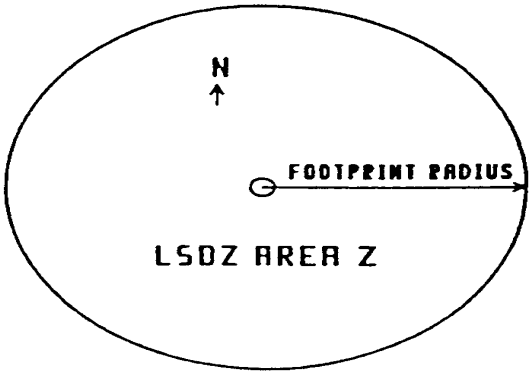


FIGURE D-6. LSDZ - attack from any direction.

Table D-I. Laser Footprint Table For: Pave Spike (Using Vacuum NOHD)
Table based on: Flat terrain, Buffer = 2.5 mrad, Divergence = 0.35 mrad
NOHD= 10000 meters (32900 feet or 5.4 nautical miles)
Table values are FOOTPRINT dimensions (feet and meters)

FOOTPRINT FORWARD - distance beyond target
FOOTPRINT AFT - distance from target toward aircraft.
FOOTPRINT WIDTH - total width at target.
NOTE: -99 Indicates an impossible alt./range combination.

SLANT RANGE (nautical miles, feet, and meters)

ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	1180 ft 359 m	5850 ft 1780 m	14600 ft 4440 m	8500 ft 2590 m	2420 ft 737 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	850 ft 259 m	2980 ft 909 m	5970 ft 1820 m	9580 ft 2920 m	13600 ft 4150 m	18000 ft 5490 m	22500 ft 6900 m	27500 ft 8380 m	32500 ft 9900 m
200	FORWARD	537 ft 164 m	2360 ft 719 m	5880 ft 1790 m	8500 ft 2590 m	2420 ft 731 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	457 ft 139 m	1,700 ft 518 m	3570 ft 1090 m	5960 ft 1820 m	8780 ft 2680 m	11900 ft 3640 m	15400 ft 4700 m	19200 ft 5840 m	23100 ft 7040 m
300	FORWARD	348 ft 106 m	1480 ft 450 m	3540 ft 1080 m	6720 ft 2050 m	2420 ft 737 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	312 ft 95 m	1190 ft 362 m	2550 ft 777 m	4330 ft 1320 m	6480 ft 1970 m	8940 ft 2730 m	11700 ft 3560 m	0 ft 0 m	0 ft 0 m
400	FORWARD	257 ft 78 m	1070 ft 328 m	2530 ft 171 m	4720 ft 1440 m	2420 ft 737 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	237 ft 72 m	913 ft 278 m	1980 ft 604 m	3400 ft 1040 m	5130 ft 1560 m	7150 ft 2180 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
500	FORWARD	204 ft 62 m	845 ft 258 m	1970 ft 600 m	3630 ft 1110 m	2420 ft 738 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	191 ft 58 m	742 ft 226 m	1620 ft 494 m	2800 ft 852 m	4250 ft 1290 m	5950 ft 1810 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
600	FORWARD	169 ft 52 m	696 ft 212 m	1610 ft 491 m	2950 ft 900 m	2420 ft 738 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	160 ft 49 m	625 ft 190 m	1370 ft 418 m	2380 ft 724 m	3620 ft 1100 m	5100 ft 1550 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
700	FORWARD	144 ft 44 m	592 ft 180 m	1360 ft 416 m	2490 ft 758 m	2420 ft 738 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	138 ft 42 m	539 ft 164 m	1190 ft 362 m	2070 ft 630 m	3160 ft 963 m	4450 ft 1360 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
800	FORWARD	126 ft 38 m	515 ft 157 m	1180 ft 361 m	2150 ft 655 m	2420 ft 738 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	121 ft 37 m	475 ft 145 m	1050 ft 319 m	1830 ft 557 m	2800 ft 854 m	3960 ft 1210 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	WIDTH	33 ft 10 m	65 ft 20 m	98 ft 30 m	130 ft 40 m	163 ft 50 m	195 ft 59 m	228 ft 69 m	260 ft 79 m	293 ft 89 m

Table D-II. Laser Footprint Table For: Pave Spike (Including Atmospheric Attenuation for Lasing from Altitudes below 1 km MSL Only)
Table based on: Flat terrain, Buffer = 2.5 mrad, Divergence = .35 mrad
NOHD= 8200 meters (26896 feet or 4.4 nautical miles)
Table values are FOOTPRINT dimensions(feet and meters)

FOOTPRINT FORWARD - distance beyond target.
FOOTPRINT AFT - distance from target bard aircraft.
FOOTPRINT WIDTH - total width at target.
N0TE: -99 indicates an impossible alt./range combination.

		SLANT RANGE (nautical miles, feet, and meters)								
ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	1180 ft 359 m	5850 ft 1780 m	8670 ft 2640 m	2590 ft 790 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	850 ft 259 m	2980 ft 909 m	5970 ft 1820 m	9580 ft 2920 m	13600 ft 4150 m	18000 ft 5490 m	22600 ft 6900 m	27500 ft 8380 m	32500 ft 9900 m
200	FORWARD	537 ft 164 m	2360 ft 719 m	5880 ft 1790 m	2590 ft 790 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	457 ft 139 m	1700 ft 518 m	3570 ft 1090 m	5960 ft 1820 m	8780 ft 2680 m	11900 ft 3640 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
300	FORWARD	348 ft 106 m	1480 ft 450 m	3540 ft 1080 m	2590 ft 790 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	312 ft 95 m	1190 ft 362 m	2550 ft 777 m	4330 ft 1320 m	6480 ft 1970 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
400	FORWARD	257 ft 78 m	1070 ft 328 m	2530 ft 771 m	2590 ft 790 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	237 ft 72 m	913 ft 278 m	1980 ft 604 m	3400 ft 1040 m	5130 ft 1560 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
500	FORWARD	204 ft 62 m	845 ft 258 m	1970 ft 600 m	2590 ft 790 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	191 ft 58 m	742 ft 226 m	1620 ft 494 m	2800 ft 852 m	4250 ft 1290 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
600	FORWARD	169 ft 52 m	696 ft 212 m	1610 ft 491 m	2590 ft 790 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	160 ft 49 m	625 ft 190 m	1370 ft 418 m	2380 ft 724 m	3620 ft 1100 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
700	FORWARD	144 ft 44 m	592 ft 180 m	1360 ft 416 m	2490 ft 758 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	138 ft 42 m	539 ft 164 m	1190 ft 362 m	2070 ft 630 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
800	FORWARD	126 ft 38 m	515 ft 157 m	1180 ft 361 m	2150 ft 655 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	121 ft 37 m	475 ft 145 m	1050 ft 319 m	1830 ft 557 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	WIDTH	33 ft 10 m	65 ft 20 m	98 ft 30 m	130 ft 40 m	163 ft 50 m	195 ft 59 m	228 ft 69 m	260 ft 79 m	293 ft 89 m

Table D-III. Laser Footprint Table For: Pave Tack (Using Vacuum NOHD)
Table based on: Flat terrain, Buffer = 2 mrad, Divergence = 0 mrad
NOHD= 16000 meters (52480 feet or 8.6 nautical miles)
Table values are FOOTPRINT dimensions(feet and meters)

FOOTPRINT FORWARD - distance beyond target.
FOOTPRINT AFT - distance from target bard aircraft.
FOOTPRINT WIDTH - total width at target.
NOTE: -99 indicates an impossible alt./range combination.

		SLANT RANGE (nautical miles, feet, and meters)								
ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	841 ft 256 m	3900 ft 1190 m	10500 ft 3190 m	23000 ft 7010 m	22100 ft 6740 m	16000 ft 4880 m	9950 ft 3030 m	3870 ft 1180 m	0 ft 0 m
	AFT	658 ft 201 m	2380 ft 724 m	4870 ft 1480 m	7950 ft 2420 m	11500 ft 3500 m	15400 ft 4690 m	19600 ft 5960 m	24000 ft 7300 m	28600 ft 8710 m
200	FORWARD	393 ft 120 m	1680 ft 512 m	4060 ft 1240 m	7800 ft 2380 m	13300 ft 4040 m	16000 ft 4880 m	9950 ft 3030 m	3870 ft 1180 m	0 ft 0 m
	AFT	348 ft 106 m	1320 ft 401 m	2810 ft 857 m	4750 ft 1450 m	7080 ft 2160 m	9740 ft 2970 m	12700 ft 3870 m	15900 ft 4850 m	19300 ft 5890 m
300	FORWARD	257 ft 78 m	1070 ft 327 m	2520 ft 769 m	4700 ft 1430 m	7720 ft 2350 m	11700 ft 3570 m	9950 ft 3030 m	3870 ft 1180 m	0 ft 0 m
	AFT	237 ft 72 m	911 ft 278 m	1980 ft 602 m	3390 ft 1030 m	5120 ft 1560 m	7130 ft 2170 m	9400 ft 2860 m	11900 ft 3630 m	14600 ft 4450 m
400	FORWARD	190 ft 58 m	786 ft 240 m	1830 ft 557 m	3360 ft 1020 m	5440 ft 1660 m	8130 ft 2480 m	9950 ft 3030 m	3870 ft 1180 m	0 ft 0 m
	AFT	179 ft 55 m	696 ft 212 m	1520 ft 464 m	2630 ft 803 m	4010 ft 1220 m	5620 ft 1710 m	7460 ft 2270 m	9500 ft 2900 m	11700 ft 3580 m
500	FORWARD	151 ft 46 m	621 ft 189 m	1430 ft 437 m	2620 ft 798 m	4200 ft 1280 m	6220 ft 1900 m	8720 ft 2660 m	3870 ft 1180 m	0 ft 0 m
	AFT	144 ft 44 m	563 ft 172 m	1240 ft 378 m	2150 ft 656 m	3290 ft 1000 m	4640 ft 1410 m	6180 ft 1880 m	7910 ft 2410 m	9810 ft 2990 m
600	FORWARD	126 ft 33 m	513 ft 156 m	1180 ft 359 m	2140 ft 653 m	3420 ft 1040 m	5040 ft 1540 m	7030 ft 2140 m	3870 ft 1180 m	0 ft 0 m
	AFT	121 ft 37 m	473 ft 144 m	1040 ft 318 m	1820 ft 555 m	2790 ft 852 m	3950 ft 1200 m	5280 ft 1610 m	6780 ft 2070 m	8430 ft 2570 m
700	FORWARD	107 ft 33 m	437 ft 133 m	1000 ft 305 m	1810 ft 553 m	2890 ft 880 m	4240 ft 1290 m	5880 ft 1790 m	3870 ft 1180 m	0 ft 0 m
	AFT	104 ft 32 m	408 ft 124 m	902 ft 275 m	1580 ft 481 m	2430 ft 740 m	3440 ft 1050 m	4610 ft 1400 m	5930 ft 1810 m	7390 ft 2250 m
800	FORWARD	94 ft 29 m	381 ft 116 m	870 ft 265 m	1570 ft 479 m	2500 ft 761 m	3660 ft 1110 m	5060 ft 1540 m	3870 ft 1180 m	0 ft 0 m
	AFT	91 ft 28 m	358 ft 109 m	795 ft 242 m	1390 ft 424 m	2140 ft 654 m	3050 ft 928 m	4090 ft 1250 m	5270 ft 1610 m	6580 ft 2000 m
	WIDTH	24 ft 7 m	49 ft 15 m	73 ft 22 m	97 ft 30 m	122 ft 37 m	146 ft 44 m	170 ft 52 m	194 ft 59 m	219 ft 67 m

Table D-IV. Laser Footprint Table For: Pave Tack (Including Atmospheric Attenuation for Lasing from Altitudes below 1 km MSL Only)
Table based on: Flat terrain, Buffer = 2 mrad, Divergence = 0 mrad
NOHD= 12000 meters (39360 feet or 6.5 nautical miles)
Table values are FOOTPRINT dimensions(feet and meters)

FOOTPRINT FORWARD - distance beyond target.
FOOTPRINT AFT - distance from target toward aircraft.
FOOTPRINT WIDTH = total width at target.
NOTE: -99 indicates an impossible alt./range combination

		SLANT RANGE (nautical miles, feet, and meters)								
ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	841 ft 256 m	3900 ft 1190 m	10500 ft 3190 m	15100 ft 4590 m	8980 ft 2740 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	658 ft 201 m	2380 ft 724 m	4870 ft 1480 m	7950 ft 2420 m	11500 ft 3500 m	15400 ft 4690 m	19600 ft 5960 m	24000 ft 7300 m	28600 ft 8710 m
200	FORWARD	393 ft 120 m	1680 ft 512 m	4060 ft 1240 m	7800 ft 2380 m	8980 ft 2740 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	348 ft 106 m	1320 ft 401 m	2810 ft 857 m	4750 ft 1450 m	7080 ft 2160 m	9740 ft 2970 m	12700 ft 3870 m	15900 ft 4850 m	19300 ft 5890 m
300	FORWARD	257 ft 78 m	1070 ft 327 m	2520 ft 769 m	4700 ft 1430 m	7720 ft 2350 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	237 ft 72 m	911 ft 278 m	1980 ft 602 m	3390 ft 1030 m	5120 ft 1560 m	7130 ft 2170 m	9400 ft 2860 m	11900 ft 3630 m	0 ft 0 m
400	FORWARD	190 ft 58 m	786 ft 240 m	1830 ft 557 m	3360 ft 1020 m	5440 ft 1660 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	179 ft 55 m	696 ft 212 m	1520 ft 464 m	2630 ft 803 m	4010 ft 1220 m	5620 ft 1710 m	7460 ft 2270 m	9500 ft 2900 m	0 ft 0 m
500	FORWARD	151 ft 46 m	621 ft 189 m	1430 ft 437 m	2620 ft 798 m	4200 ft 1280 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	144 ft 44 m	563 ft 172 m	1240 ft 378 m	2150 ft 656 m	3290 ft 1000 m	4640 ft 1410 m	6180 ft 1880 m	0 ft 0 m	0 ft 0 m
600	FORWARD	126 ft 38 m	513 ft 156 m	1180 ft 359 m	2140 ft 653 m	3420 ft 1040 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	121 ft 37 m	473 ft 144 m	1040 ft 318 m	1820 ft 555 m	2790 ft 852 m	3950 ft 1200 m	5280 ft 1610 m	0 ft 0 m	0 ft 0 m
700	FORWARD	107 ft 33 m	437 ft 133 m	1000 ft 305 m	1810 ft 553 m	2890 ft 880 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	104 ft 32 m	408 ft 124 m	902 ft 275 m	1580 ft 481 m	2430 ft 740 m	3440 ft 1050 m	4610 ft 1400 m	0 ft 0 m	0 ft 0 m
800	FORWARD	94 ft 29 m	381 ft 116 m	870 ft 265 m	1570 ft 479 m	2500 ft 761 m	2900 ft 885 m	0 ft 0 m	0 ft 0 m	0 ft 0 m
	AFT	91 ft 28 m	358 ft 109 m	795 ft 242 m	1390 ft 424 m	2140 ft 654 m	3050 ft 928 m	4090 ft 1250 m	0 ft 0 m	0 ft 0 m
	WIDTH	24 ft 7 m	49 ft 15 m	73 ft 22 m	97 ft 30 m	122 ft 37 m	146 ft 44 m	170 ft 52 m	194 ft 59 m	219 ft 67 m

Table D-V. Laser Footprint Table For: Any Laser System with Beam Divergence < 0.5 mrad
Table based on: Flat terrain. Buffer = 5 mrad, Divergence = 0 mrad
N0HD= 100000 meters (328000 feet or 54.0 nautical miles)
Table values are FOOTPRINT dimensions(feet and meters)

FOOTPRINT FORWARD - distance beyond target.
FOOTPRINT AFT - distance from target toward aircraft.
FOOTPRINT WIDTH - total width at target.
NOTE: -99 indicates an impossible alt./range combination.

		SLANT RANGE (nautical miles, feet, and meters)								
ALTITUDE (feet)	FOOTPRINT	1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	2650 ft 808 m	18800 ft 5740 m	188000 ft 57200 m	304000 ft 92600 m	298000 ft 90700 m	292000 ft 88900 m	285000 ft 87000 m	279000 ft 85200 m	273000 ft 83300 m
	AFT	1420 ft 432 m	4590 ft 1400 m	8690 ft 2650 m	13300 ft 4060 m	18300 ft 5580 m	23500 ft 7180 m	28900 ft 8820 m	34400 ft 10500 m	40000 ft 12200 m
200	FORWARD	1090 ft 332 m	5300 ft 1620 m	15300 ft 4650 m	37600 ft 11500 m	95900 ft 29200 m	292000 ft 88900 m	285000 ft 87000 m	279000 ft 85200 m	273000 ft 83300 m
	AFT	801 ft 244 m	2830 ft 863 m	5710 ft 1740 m	9190 ft 2800 m	13100 ft 4000 m	17400 ft 5300 m	21900 ft 6680 m	26700 ft 8130 m	31600 ft 9630 m
300	FORWARD	685 ft 209 m	3090 ft 941 m	7950 ft 2420 m	16500 ft 5040 m	31200 ft 9500 m	56500 ft 17200 m	104000 ft 31500 m	207000 ft 63200 m	273000 ft 83300 m
	AFT	559 ft 170 m	2050 ft 624 m	4250 ft 1290 m	7010 ft 2140 m	10200 ft 3110 m	13800 ft 4200 m	17600 ft 5380 m	21800 ft 6630 m	26100 ft 7950 m
400	FORWARD	499 ft 152 m	2180 ft 663 m	5380 ft 1640 m	10600 ft 3230 m	18600 ft 5670 m	30500 ft 9300 m	48300 ft 14700 m	75300 ft 22900 m	118000 ft 36000 m
	AFT	429 ft 131 m	1600 ft 488 m	3380 ft 1030 m	5660 ft 1730 m	8360 ft 2550 m	11400 ft 3480 m	14800 ft 4500 m	18400 ft 5600 m	22200 ft 6770 m
500	FORWARD	393 ft 120 m	1680 ft 512 m	4060 ft 1240 m	7800 ft 2380 m	13300 ft 4040 m	20900 ft 6380 m	31500 ft 9590 m	46000 ft 14000 m	66000 ft 20100 m
	AFT	348 ft 106 m	1320 ft 401 m	2810 ft 857 m	4750 ft 1450 m	7080 ft 2160 m	9740 ft 2970 m	12700 ft 3870 m	15900 ft 4850 m	19300 ft 5890 m
600	FORWARD	324 ft 99 m	1370 ft 417 m	3260 ft 995 m	6170 ft 1880 m	10300 ft 3140 m	15900 ft 4850 m	23400 ft 7120 m	33100 ft 10100 m	45800 ft 14000 m
	AFT	293 ft 89 m	1120 ft 341 m	2400 ft 733 m	4090 ft 1250 m	6140 ft 1870 m	8500 ft 2590 m	11100 ft 3390 m	14000 ft 4270 m	17100 ft 5220 m
700	FORWARD	276 ft 84 m	1150 ft 352 m	2730 ft 832 m	5110 ft 1560 m	8420 ft 2570 m	12800 ft 3910 m	18500 ft 5660 m	25900 ft 7880 m	35100 ft 10700 m
	AFT	253 ft 77 m	971 ft 296 m	2100 ft 640 m	3600 ft 1100 m	5420 ft 1650 m	7530 ft 2300 m	9910 ft 3020 m	12500 ft 3820 m	15400 ft 4880 m
800	FORWARD	240 ft 73 m	999 ft 304 m	2340 ft 714 m	4350 ft 1330 m	7120 ft 2170 m	10800 ft 3280 m	15400 ft 4690 m	21200 ft 6470 m	28400 ft 8650 m
	AFT	222 ft 68 m	858 ft 262 m	1860 ft 568 m	3210 ft 977 m	4850 ft 1480 m	6770 ft 2060 m	8930 ft 2720 m	11300 ft 3450 m	13900 ft 4250 m
	WIDTH	61 ft 19 m	122 ft 37 m	182 ft 56 m	243 ft 74 m	304 ft 93 m	365 ft 111 m	425 ft 130 m	486 ft 148 m	547 ft 167 m

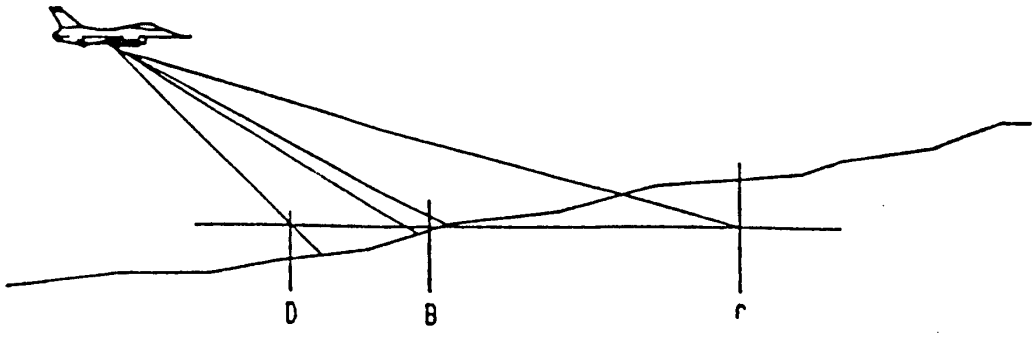


FIGURE D-7. LSDZ with rising terrain.

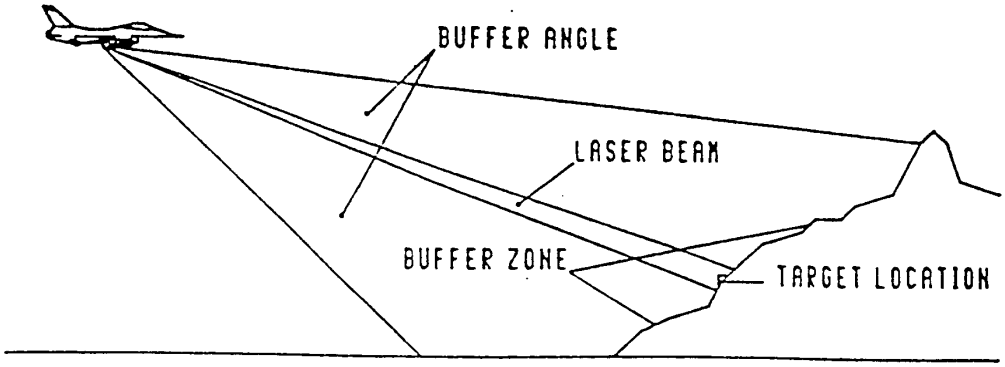


FIGURE D-8. Use of natural backstops to control laser beam.

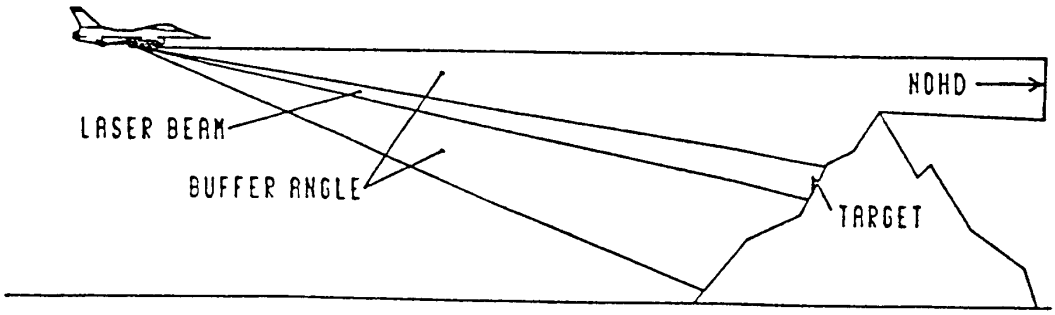


FIGURE D-9. Insufficient backstop to control laser beam.

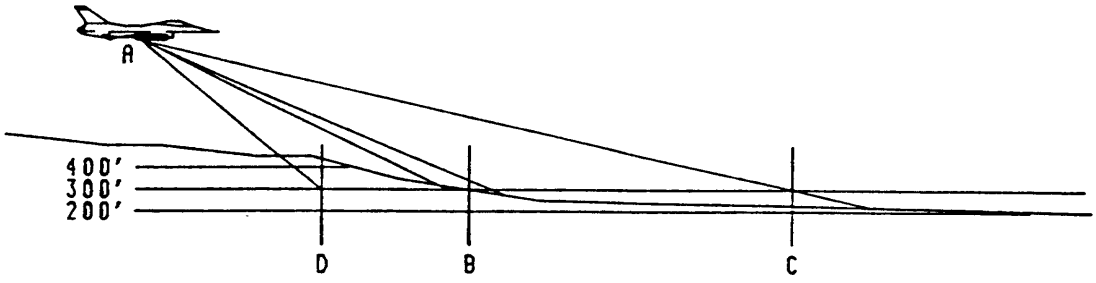


FIGURE D-10. LSDZ with terrain sloping down. Range less than NOHD

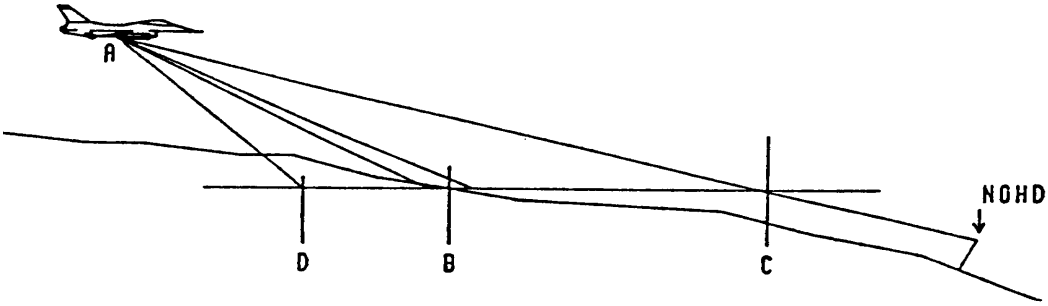


FIGURE D-11. LSDZ with terrain sloping down. Range greater than NOHD.

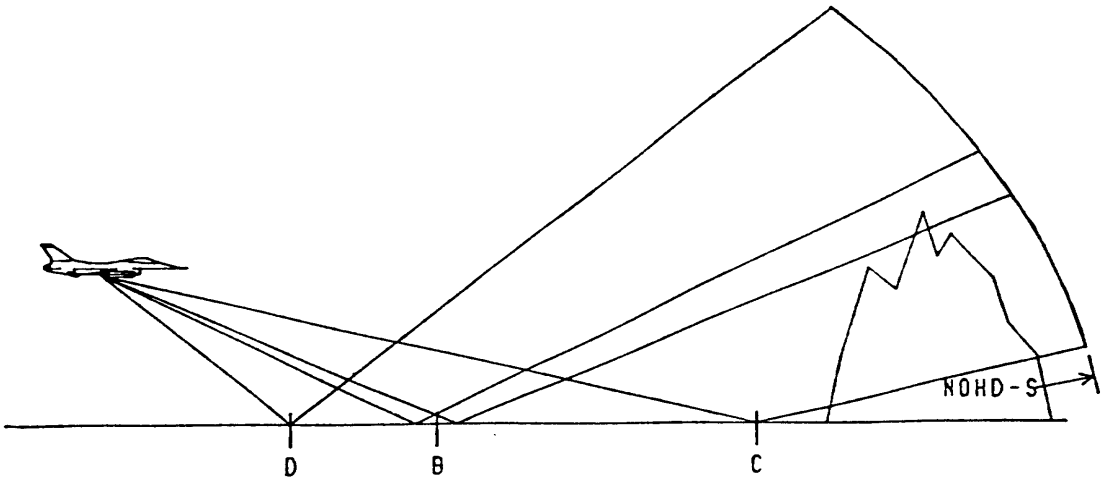
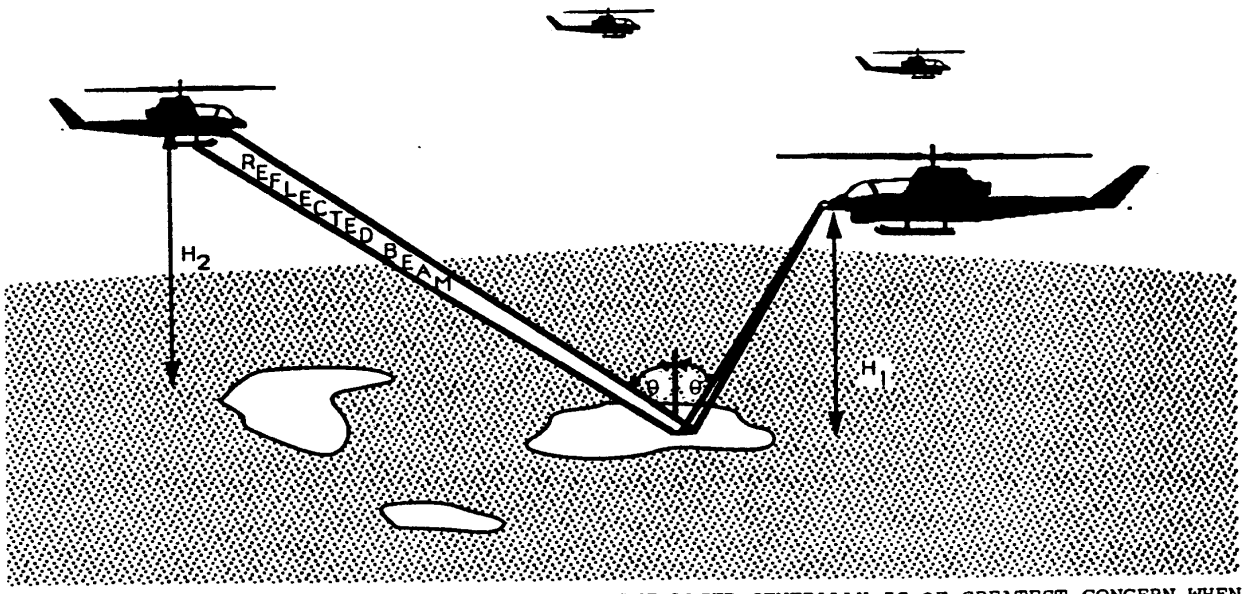


FIGURE E-12. Reflections from still water with LDZ.



THE SPECULARLY REFLECTED BEAM FROM AN AIRBORNE LASER GENERALLY IS OF GREATEST CONCERN WHEN ORGINATING FROM STILL WATER. THE REFLECTED BEAM IS REDIRECTED UPWARD AT THE SAME ANGLE (θ) AS THE INCIDENT BEAM.

FIGURE D-13. Example of airborne laser beam reflection.

2. Vertical Buffer Near Boundary, similar to the near boundary:

α = buffer angle plus beam divergence either side of laser LOS. For systems listed in TABLE A-I, the beam divergence is extremely small compared to the buffer angle and hence the beam divergence may be ignored.

γ = vertical angle from either side of laser LOS to near edge of LSDZ (backstop) between the laser and the target.

h = altitude of laser
as = altitude of nearest target
bs = altitude of near boundary
ds = horizontal distance on surface from laser to nearest target
B = distance from target to near boundary of LSDZ (backstop)

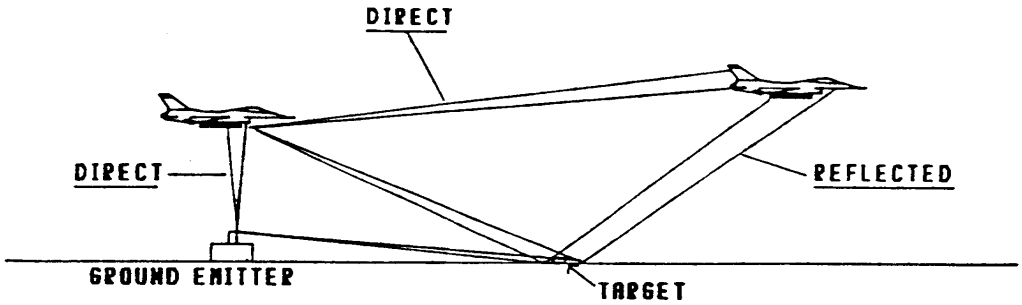


FIGURE D-14. Potential exposure modes.

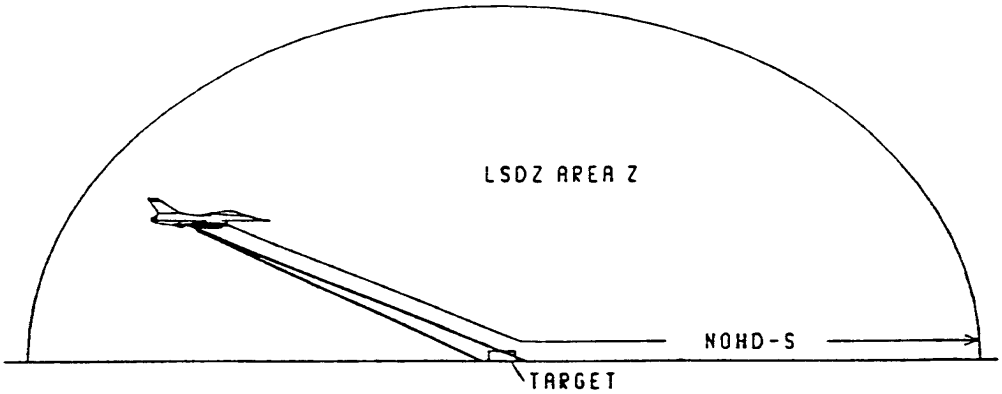


FIGURE D-15. Reflections from flat specular surface - side view.

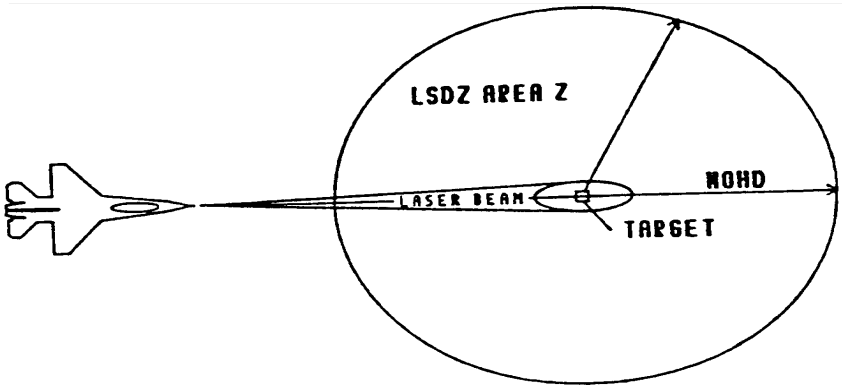


FIGURE D-16. Reflections from flat specular surface - top view.

The vertical angle γ may be calculated from the following equation.

$$\gamma = \arctan((h-bs)/(ds-B)) + \arctan((as-h)/ds))$$

As long as the angle γ remains greater than angle α, the beam is safely contained vertically within the designated LSDZ.

3. Horizontal Buffer. See FIGURE E-15. Available buffer to the left and right of the target out to the backstop may be calculated as follows:

$$AB = \arctan((FPN-EBN)/(FPE-EBE)) - \arctan((FPN-TN)/(FPE-TE))$$

Where:

AB	= available buffer angle in radians left and right of target out to the backstop.
FPN	= laser firing position north coordinate in meters
EBN	= edge of backstop north coordinate in meters
FPE	= laser firing position east coordinate in meters
EBE	= edge of backstop east coordinate in meters
TN	= edge of target north coordinate in meters
TE	= edge of target east coordinate in meters

As long as the angle AB is greater than angle α and is negative for the right edge of the backstop and positive for the left edge of the backstop, the beam is safely contained horizontally within the designated LSDZ.

b. Airborne Laser with Target on Level Ground

a. Aircraft minimum altitude to keep buffered footprint within far and near boundaries of LSDZ, see FIGURE D-16.

Minimum laser altitude (h) relative to target to keep buffered laser footprint within the far boundary when at slant range (R) from target is

$$h = R\sin(\arcsin((R/A)\sin(\alpha)) + \alpha)$$

Minimum altitude relative to target to keep buffered laser footprint within the near boundary when at slant range R from target is

$$h = R\sin(\arcsin((R/B)\sin(\alpha)) - \alpha)$$

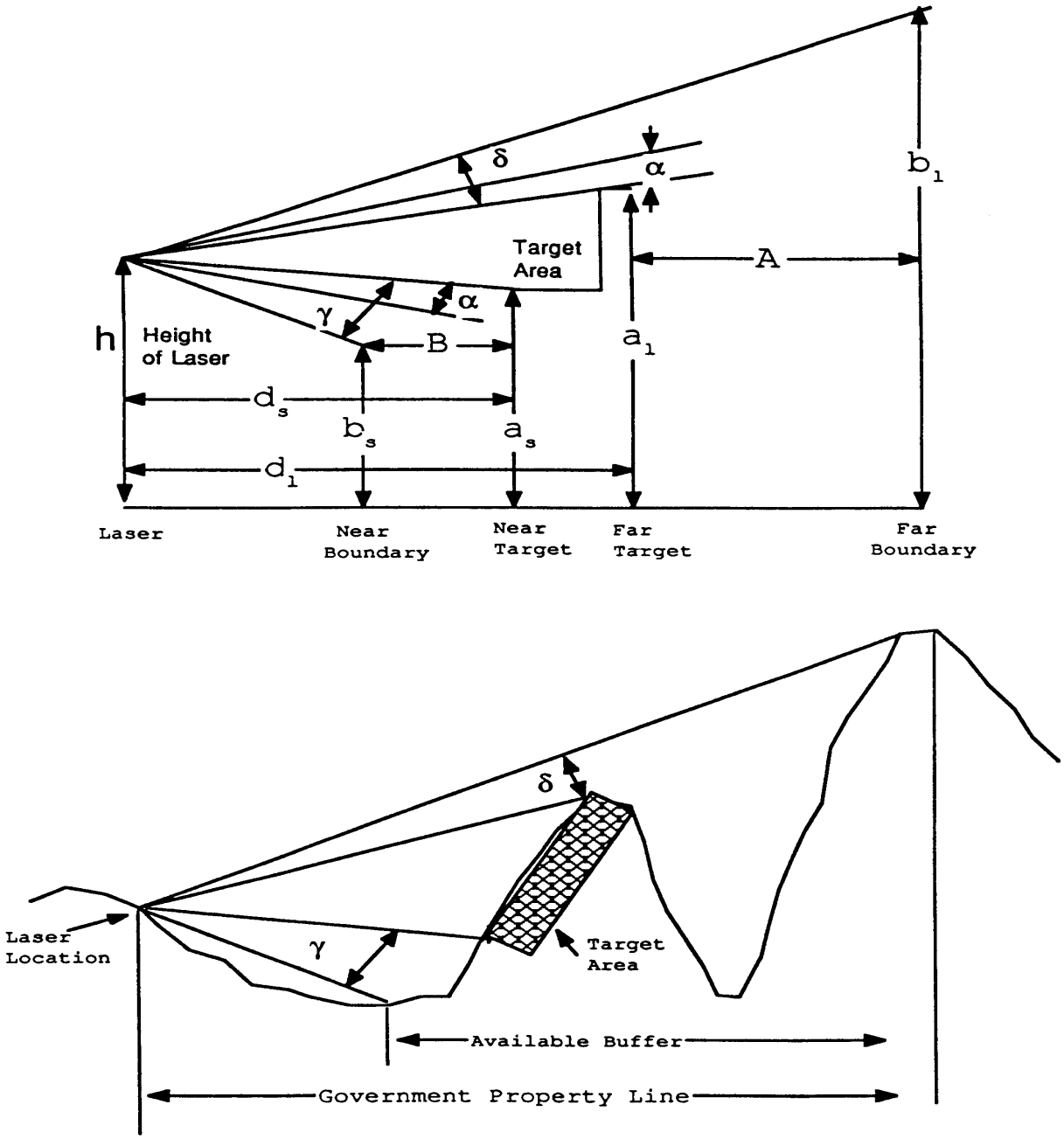
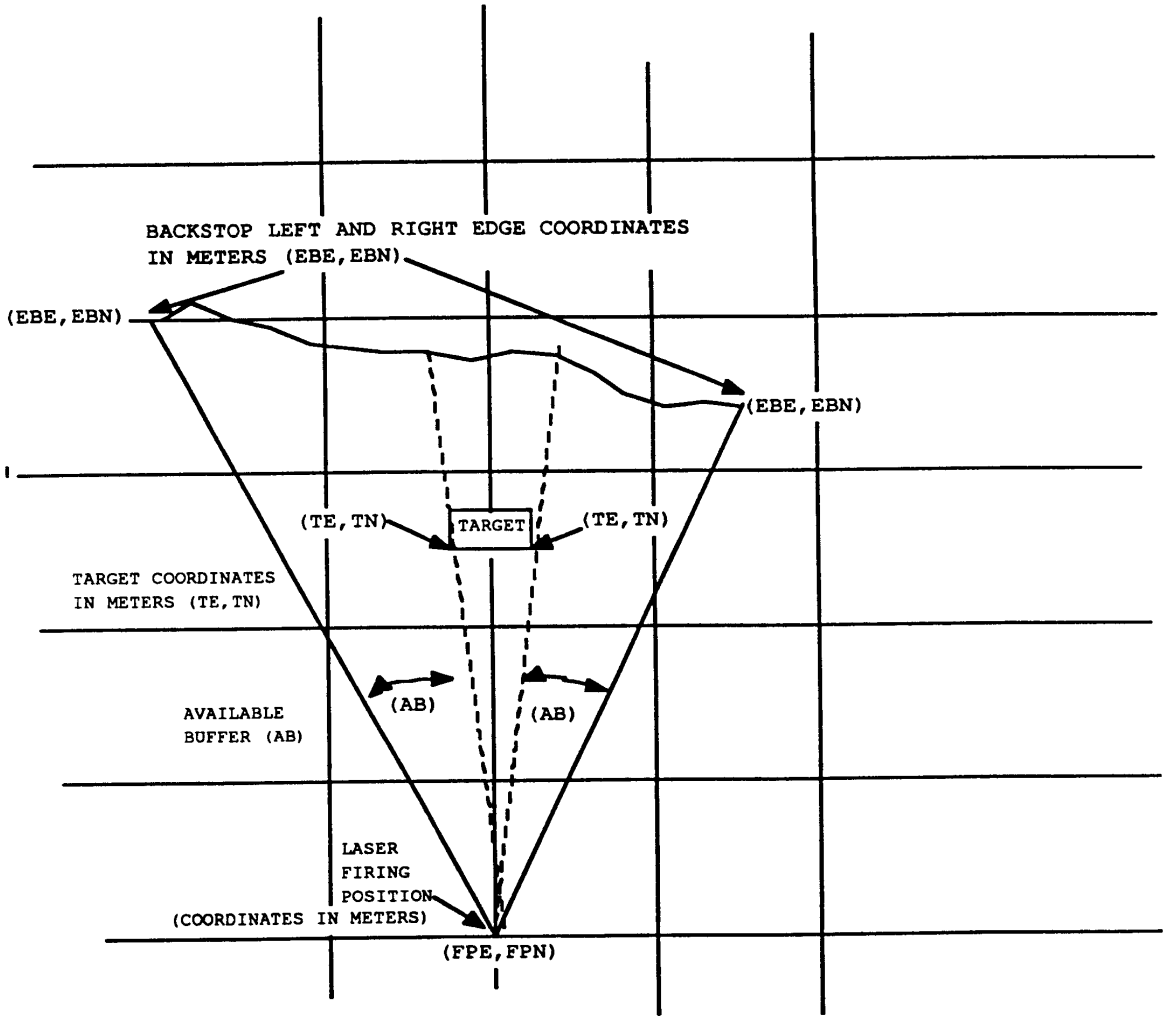


FIGURE D-17. Vertical buffer and LSDZ geometry.



AB = arctan ((FPN - EBN)/FPE-EBE))- arctan ((FPN - TN)/(FPE - TE))

To safely contain the laser beam, the available buffer must be larger than the allowed buffer for the laser in use (see Table A-1 for allowed buffer zones for specific lasers.).

FIGURE D-18. Calculation of available buffer versus allowed buffer.

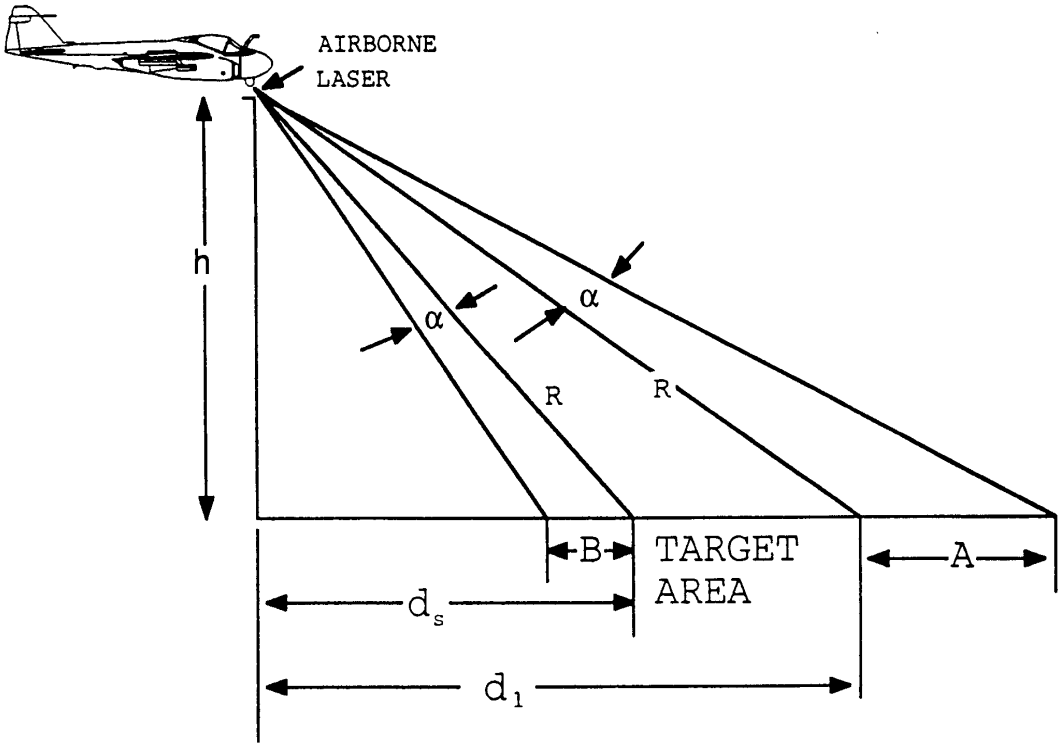


FIGURE D-19. Airborne laser buffer geometry - level ground.

Where:
R = slant range from laser to target
α = buffer angle plus beam divergence either side of laser LOS. For systems listed in TABLE A-I of APPENDIX A, the beam divergence is extremely small compared to the buffer angle and hence the beam divergence may be ignored.
A = distance from target to far boundary of LSDZ
B = distance from target to near boundary of LSDZ
h = altitude of laser relative to target surface
HL = altitude of laser above Mean Sea Level
HT = height of target above Mean Sea Level

Choose whichever h is the higher number and assign it as the safe altitude for lasing at range R. If altitude is altitude above mean sea level then the required laser altitude is:

$$HL = h + HT$$

Repeat this calculation for every nautical mile (or fraction of a mile depending on the risk) starting at about 12 nautical miles up to and beyond the target. Then plot the results. Remember as you pass over the target that the far and near boundary definitions reverse. A typical flight profile is plotted in FIGURE E-17.

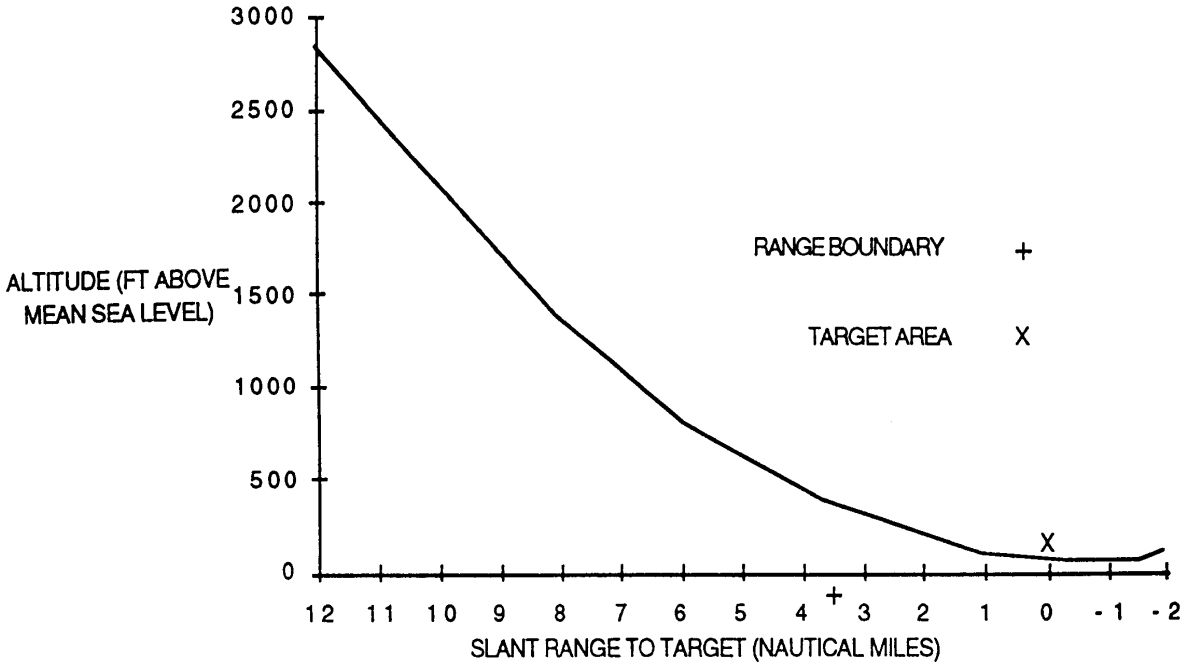
b. Left and Right Hand LSDZ. The width of the right hand and left hand LSDZ width (see FIGURE 21) are calculated as follows:

$s = R \times \alpha$
s = left hand LSDZ width or right hand LSDZ width
R = slant range from laser to target
α = assigned buffer angle plus beam divergence either side of the laser LOS. For systems listed in TABLE II the beam divergence is small compared to the buffer angle and may be ignored.

c. Airborne Laser with Target on Sloping Ground. Altitudes to keep buffered laser footprint within near or far boundary LSDZ can be calculated as follows:

(1) Buffered Footprint. See FIGURE E-18.

HT = altitude of target above mean sea level
h = altitude of laser above target
HL = altitude of laser above mean sea level = h + HT



SLANT RANGE TO TARGET nmi	MINIMUM LASING ALTITUDE ft MSL
12	2850
11	2500
10	2100
9	1750
8	1400
7	1100
6	850
5	650
4	450
3	300
2	150
1	100

SLANT RANGE FROM TARGET nmi	MINIMUM LASING ALTITUDE ft MSL
0	10
- 1	50
- 2	112

FIGURE D-20. Example laser aircraft flight profile.

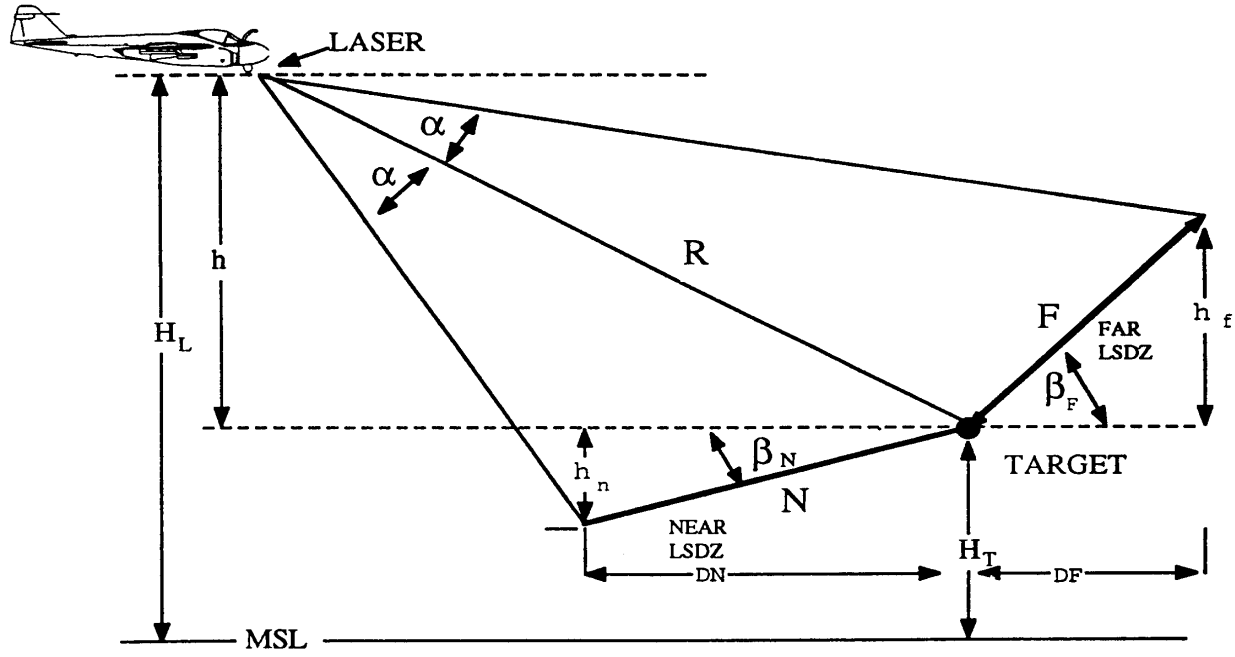


FIGURE D-21. Laser target on sloping terrain.

hn = height of near boundary above or below target
hf = height of far boundary above or below target
DN = horizontal distance from target to near boundary
DF = horizontal distance from target to far boundary
N = slant range distance from near edge of near target to edge of near boundary = square root of the sum of the squares of hn and DN
F = slant range distance from far edge of far target to edge of far boundary = square root of the sum of the squares of hf and DF
β_F = declination or elevation angle from horizontal between edge of far target and edge of far boundary = arctan(hf/DF) (positive number for far boundary higher than the target and negative number for far boundary lower than target)
β_N = declination or elevation angle from horizontal between edge of near target and edge of near boundary = arctan(hn/DN) (positive number for near boundary lower than target and negative number for near boundary higher than target)
hn = height of near boundary above or below target
R = slant range from laser to target

α = assigned buffer angle plus beam divergence. For systems listed in TABLE A-I the beam divergence is small compared to the buffer angle and hence may be ignored.

(2) For far target:

$h = R\sin(\arcsin((R/F)\sin(\alpha)) - \beta_F + \alpha)$

and

$HL = R\sin(\arcsin((R/F)\sin(\alpha)) - \beta_F + \alpha) + HT$

(3) For near target:

$h = R\sin(\arcsin((R/N)\sin(\alpha)) - \beta_N - \alpha)$

and

$HL = R\sin(\arcsin((R/N)\sin(\alpha)) - \beta_N - \alpha) + HT$

Choose whichever h is the higher number and assign it as the safe altitude for lasing at range R. Repeat this calculation for every nautical mile (or fraction of a mile depending on the risk) starting at about 12 nautical miles up to and beyond the target. Then plot the results. Remember as you pass over the target that the far and near boundary definitions reverse. A typical flight profile is plotted on FIGURE D-17.

(4) Left and Right Hand LSDZ.

The width of the right hand and left hand LSDZ are calculated as follows:

$s = R \times \alpha$

s = left hand LSDZ width or right hand LSDZ width

R = slant range from laser to target

α = assigned buffer angle plus beam divergence either side of the laser LOS. For systems listed in TABLE A-I, the beam divergence is small compared to the buffer angle and may be ignored.

DOD LASER RANGE SURVEY CHECKLISTS

E.1 SCOPE. This appendix provides pre-survey, survey and survey report checklist examples that may be used by tailoring or adding items as needed for local situations such as training operations, research, development or testing.

E.2 APPLICABLE DOCUMENTS. This section is not applicable to this appendix.

E.3 CHECKLISTS. Sample checklists are enclosed.

LASER RANGE PRE-SURVEY CHECKLIST

RANGE/AREA NAME:_____ DATE:_____

LOCATION (GRID COORDINATES)_____
ADDRESS:_____ PLANNED SURVEY
DATE:_____
_____ LAST SURVEY DATE:_____
PHONE:(DSN)_____ PERFORMED BY:_____
(COMM)_____ RANGE POC:_____
USER POC'S:_____
_____

DATA COLLECTION

DOCUMENTS
- RANGE SOP_____
- RANGE LASER DIRECTIVES_____
- OLD SURVEY REPORT_____

MAPS OF
- RANGE BOUNDARIES_____
- TOPOGRAPHY_____
- RESTRICTED AIR SPACE_____
- TGT LOCATIONS_____
- LASER OPERATING LOCATIONS_____

TYPES OF LASER OPERATIONS
- AIRBORNE LASER OPERATIONS_____
- GROUND BASED LASER OPERATIONS_____
- SHIP MOUNTED LASER OPERATIONS_____

SYSTEMS TO BE USED ON RANGE

TRAM_____	LTD_____	MULE_____	LANTIRN_____	NOS _____
LD-82_____	GVLLD___	M60A2____	PAVE TACK____	GVS-5_____
M60A3____	M1A1_____	M551A1____	PAVE SPIKE____	MILES_____
TADS_____	LAAT_____	CLD_____	PAVE KNIFE____	F/A-18_____
MMS_____	OTHERS (LIST)_____			

TARGET NAME	GRID COORDINATES
1._____	_____
2._____	_____
3._____	_____
4._____	_____
5._____	_____
6._____	_____
7._____	_____
8._____	_____

9._____ _____
10._____ _____

LASER OPERATOR/FIRING GRID COORDINATES

POSITIONS FOR TARGET #?

1._____ _____
2._____ _____
3._____ _____
4._____ _____
5._____ _____
6._____ _____
7._____ _____
8._____ _____
9._____ _____
10._____ _____

FORWARD OBSERVER POSITIONS GRID COORDINATES
FOR TARGET #?/LASER #?
1._____ _____
2._____ _____
3._____ _____
4._____ _____
5._____ _____
6._____ _____
7._____ _____
8._____ _____
9._____ _____
10._____ _____

A. Does the range have established run in headings for aircraft?

Yes ____ No ____

If Yes, what are they?

_____

_____

_____

B. Will more targets be added?
Yes ____ No ____
If yes, where? (grid coordinates)
_____
_____

C. Are there manned positions on the range?
Yes ____ No ____
If so, where? (grid coordinates)
_____
_____
_____

D. Are there any conditions off the range that need to be addressed?
Yes ____ No ____
If yes, what?
_____
_____
_____
_____

E. Any other changes _____
_____
_____
_____
_____

F. Comments _____
_____
_____
_____
_____
_____

REVIEW OF RANGE SOP and/or LASER SAFETY INSTRUCTION

Does SOP or Laser Safety Instruction specify:

(a) Permissible aircraft flight profiles and run-in headings for specified targets or target areas. Yes__ No__

(b) Permissible ships headings and safe firing zones for specified targets or target areas. Yes__ No__

(c) Permissible ground based laser operating positions and/or areas for specified targets or target areas. Yes__ No__

(d) Hazard areas to be cleared of non-operating personnel (road blocks if required). Yes__ No__

(e) Operating personnel locations (indicating those requiring eye protection). Yes__ No__

(f) Types of surveillance to be used to ensue a clear range. Yes__ No__

(g) Radio frequencies for communication where appropriate.
_____

(h) Firing log/schedule is kept by the range officer in accordance with DOD safety and health record keeping regulations. Yes__ No__

(i) Laser systems will not be activated until the target has been positively identified. Yes__ No__

(j) All Class 3 and 4 lasers shall not be directed above the horizon unless coordinated with all DOD components including US Space Command ((DSN 268-4543, (719)474-4543)) and regional service rep to FAA when lasing outside restricted air space. Has coordination been completed? Yes__ No__

(k) For ground based lasers, all unprotected personnel must remain behind the laser operator. Are these instructions in place? Yes__ No__

(l) Requirement that personnel in other aircraft in the restricted cone around the laser line of sight have eye protection of the proper wavelength and Optical density as specified in Appendix A of the DoD Laser Range Safety Manual for the specific system or as approved by the laser safety specialists for that DOD component. Yes__ No__

(m) Are there specific written requirements for prebriefing all participants in laser exercises to ensure that remote or wingman laser designators are not located within the field of detection of weapons systems or sensors (for example, laser guided munitions, laser spot trackers, NVGs). All tactics must be planned to ensure that the angle between the laser designator and laser guided munitions is such that the munitions cannot home on the laser source or scattered radiation from the laser platform. Yes__ No___

RANGE LASER SITE SURVEY

1. Laser Safety Officer

_____

Address

_____

Phone (A/V)

_____

2. Is there a Laser Safety Officer on range during laser operations? Yes ____ No ____

3. Have all of the range personnel involved with laser operations had laser safety training?
Yes ____ No ____

4. Is there a medical surveillance program in place? Yes ____ No ____

5. For lasers not listed in Appendix A, have all of the lasers being used on the range been evaluated by the specific service agency in Chapt 1 para 1.2b? Yes ____ No ____

5. a. Does the range laser safety officer have

(1) safety dataYes ____ No ____
(2) procedural information from operational manuals Yes ____ No ____
(3) data on completed recommended actions in the evaluation report from the service agency? Yes____ No ____

5. b. Has the range laser safety officer been provided with adequate planned tactics to ensure laser employment in compliance with range instructions? Yes____ No____

6. Is the range adequately controlled to prevent unauthorized entry? Yes ____ No ____

7. Are laser warning signs posted at the range boundaries and at the entrance?
Yes ____ No ____

8. Where necessary, are there barricades with laser warning signs? Yes ____ No ____

9. If necessary, are the laser warning signs multilingual? Yes ____ No ____

10. Are the targets made of a non-reflecting material for the laser wavelengths being used on the ranges? Yes ____ No ____

11. Are the target and target areas free of specular reflectors? Yes ____ No ____

12. Is there a protective eyewear training, inspection and replacement program in place?
Yes ____ No ____

13. Are all of the personnel who must be on the range during laser operations equipped with the proper eye protection? Yes ____ No ____

14. Is a laser operations log or schedule containing the date, time, and heading of all laser operations being kept? Yes ____ No ____

15. Is there two-way communication between the range laser safety officer, laser system operators, and range personnel? Yes ____ No ____

16. Describe the surveillance of the range.
_____
_____
_____

RANGE SURVEY REPORT

Note: This report may require sign-off by the Service Laser Safety Authority.

RANGE/AREA NAME:
SURVEY SUMMARY
Date Survey was completed_____
Applicable Regulations _____
Range controlled by _____
Survey completed by (Name/Organization)
_____
Dates of operations for which survey is valid_____
Other Pertinent Information_____

SURVEY RESULTS

1. Degree of compliance with applicable regulations
_____
_____

2. Safety deficiencies that must be corrected before approving range for laser use:

_____
_____
_____

RECOMMENDED ACTIONS

1. Corrective actions for existing deficiencies
_____
_____
_____

2. Ground Laser Restrictions - Description of Laser Surface Danger Zones (LSDZ)
_____
_____
_____

3. Aircraft Mounted Lasers - Description of Laser Surface Danger Zones (LSDZ)
_____
_____
_____

4. Recommended operating procedures/range regulations

_____
_____
_____

5. Recommended Laser Eye Protection

_____
_____
_____

6. Controls for protection from reflected laser beams

_____
_____
_____

7. Recommended Training

_____
_____
_____

8. Recommended pre-briefs for

(1) laser users _____
_____

(2) laser range personnel _____
_____

SPECULAR REFLECTION

F.1 SCOPE. This appendix provides guidance information on specular reflection hazards.

F.2 APPLICABLE DOCUMENTS. Willem P. Van De Merwe and Wesley J. Marshall, "Hazardous Ranges of Laser Beams and Their Reflections from Targets", Applied Optics, Vol. 25, No.5, 1 March 1986.

F.3 SPECULAR REFLECTION CHARACTERISTICS.

F.3.1 Introduction. The amount of laser energy reflected from a specular surface and the divergence of the reflected laser beam are dependent on:

a. Reflectivity and/or index of refraction of the material at the laser wavelength.

b. Polarization of the laser beam.

c. Angle of incidence of the laser beam.

d. Size of the specular reflector relative to the size of the laser spot on the reflector. A specular reflector cross section that is smaller than the cross section of the incident laser beam will only reflect a proportional amount of the laser energy. With small size reflectors, diffraction effects may also be present, resulting in a larger divergence of the laser beam.

e. Number of reflective surfaces. Normally a pane of glass will reflect from both the front and back surface. However, the reflected beams are seldom co-linear.

f. Curvature of the reflecting surface. Curved specular reflectors (See TABLE 6-I) will diverge most laser beams so they generally present no hazard beyond a few meters from the reflector. For this reason, personnel in laser restricted areas should wear laser eye protection with curved lenses.

F.3.2 Flat reflectors. A flat specular surface is one that retains a collimated reflected beam. Examples are:

a. Standing water.

b. Flat glass.

c. Flat Plexiglas.

d. Imaging optical systems.

e. Corner cube reflectors.

f. Flat mirror-like chrome bumpers.

F.3.3 Hazardous ranges of reflected laser beam. The amount of reflected laser energy and the resultant hazard distance from a specular reflector are dependent on the factors provided in F.3.1.

a. Reflection from Reflector Larger Than Cross Section of Incident Laser Beam. FIGURES 6-7 and F-1 show possible laser reflection hazards from standing water. FIGURE F-2 shows the possible laser reflection hazard from specularly reflecting objects in random orientations. Shown on FIGURE F-3 is a worst case example of reflectance from both the front and back surfaces of a flat glass plate. FIGURES F-4 and F-5 show values of reflectance for fresh and salt water surfaces. In ascertaining the hazardous range of the reflective laser energy, the second surface reflections are usually ignored for distances beyond a few meters from the reflector. Neglecting second surface reflections, the following equation may be used to determine the hazardous range of reflected laser energy in situations similar to FIGURE F-7.

$$NOHR = H2/\cos(\theta) = NOHD \times (\%P \times R\| + \%N \times R\perp)^{1/2} - H1/\cos(\theta)$$
$$= NOHD \times [\%P(\tan^2(\theta-\theta'))/(\tan^2(\theta+\theta')) + \%N(\sin^2(\theta-\theta'))/(\sin^2(\theta+\theta'))]^{1/2} - H1/\cos(\theta)$$

where:

NOHR = Nominal Ocular Hazard Distance from Reflector
H1 = altitude of laser
H2 = altitude of observer viewing reflected laser beam
θ = angle incident and reflected laser beam makes with a line perpendicular to the reflecting surface (angle of incidence) = arctan(D1/H1) for a flat reflector on flat ground.
D1 = horizontal distance from laser to reflector
θ' = angle of refracted beam in a reflecting media = $\arcsin(\theta/n)$
n = index of refraction of reflecting media
%P = fraction of laser beam polarized parallel to the plane of incidence
%N = fraction of laser beam polarized perpendicular to plane of incidence
NOHD = Nominal Ocular Hazard Distance (See TABLE II for typical distances)
R|| = Parallel polarization reflection coefficient = $(\tan^2(\theta-\theta'))/(\tan^2(\theta+\theta'))$
R⊥ = Perpendicular polarization reflection coefficient = $(\sin^2(\theta-\theta'))/(\sin^2(\theta+\theta'))$

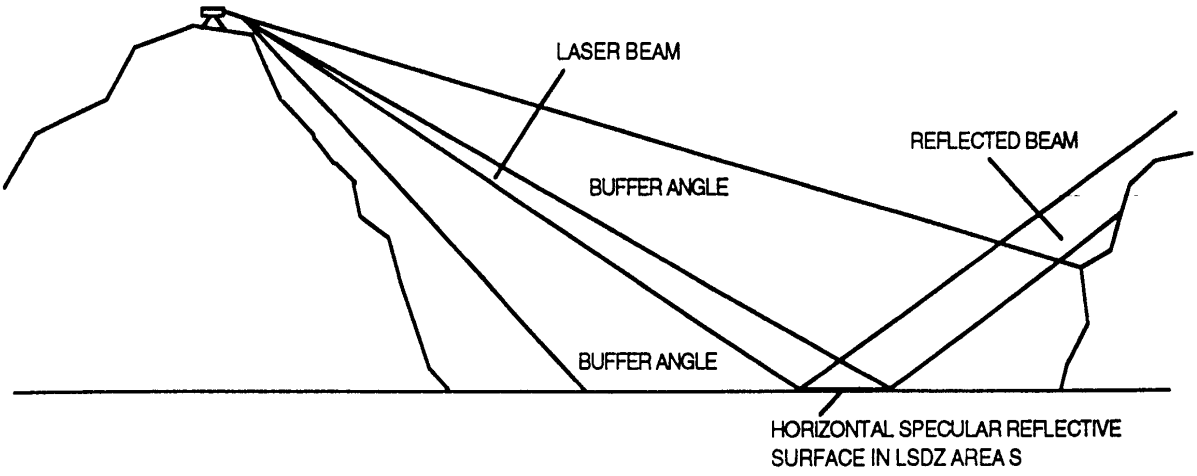


FIGURE F-1. LSDZ with specular reflections from standing still water.

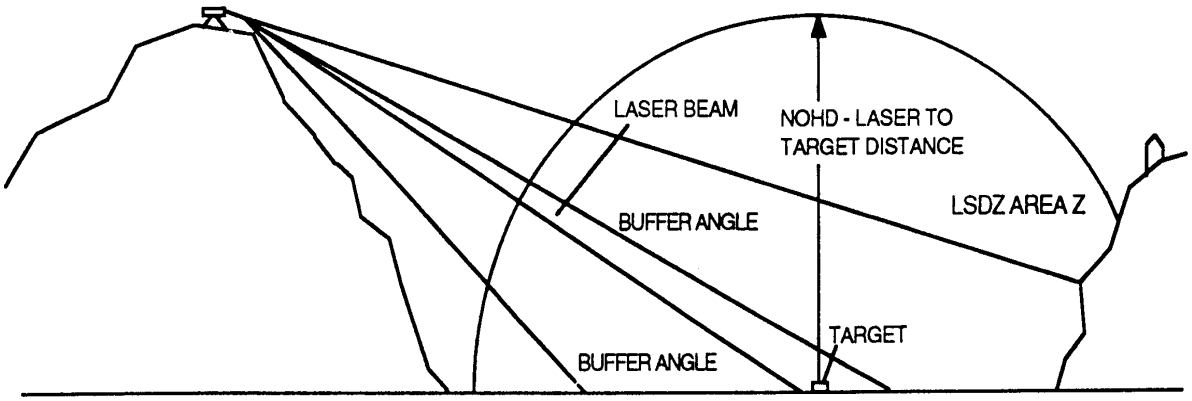


FIGURE F-2. LSDZ with specular reflective target - side view.

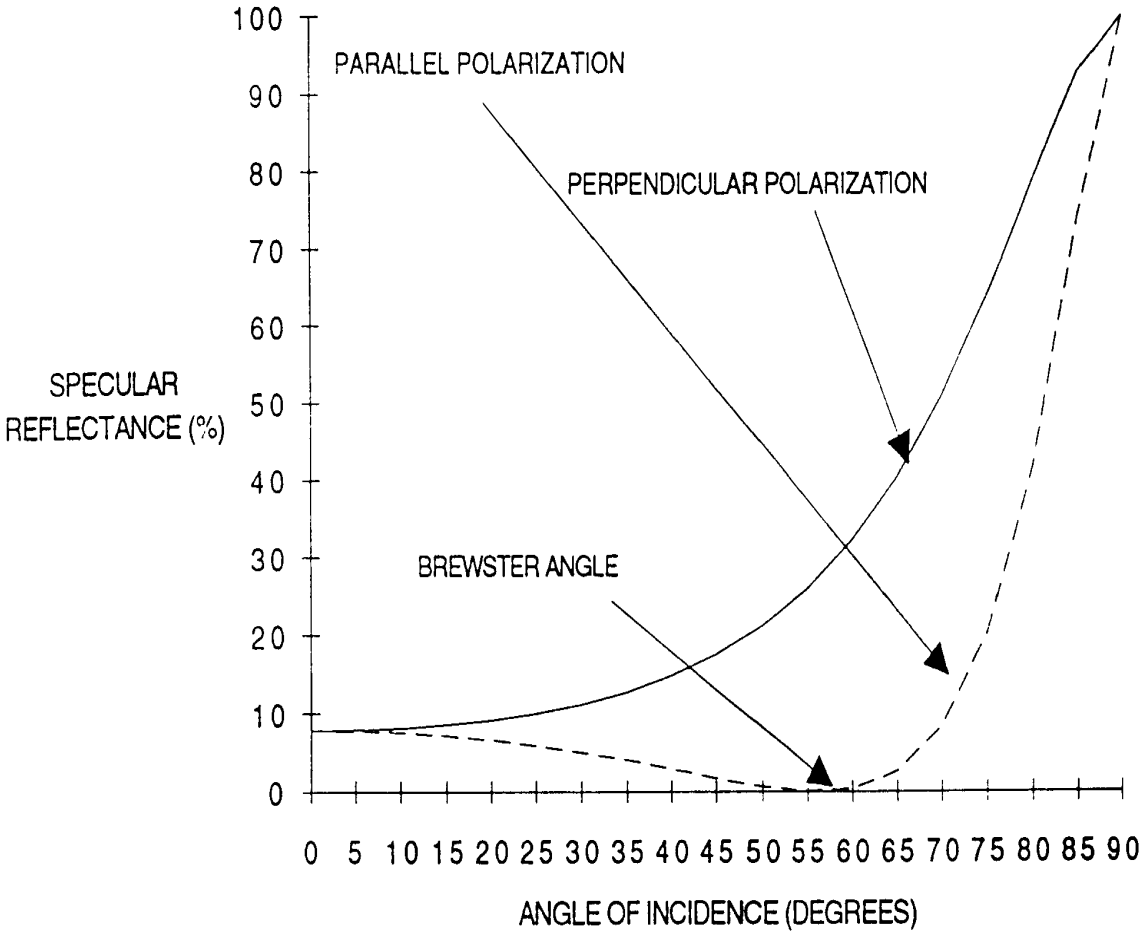


FIGURE F-3. Specular reflectance from both surfaces of plate glass
(index of refraction = 1.5)

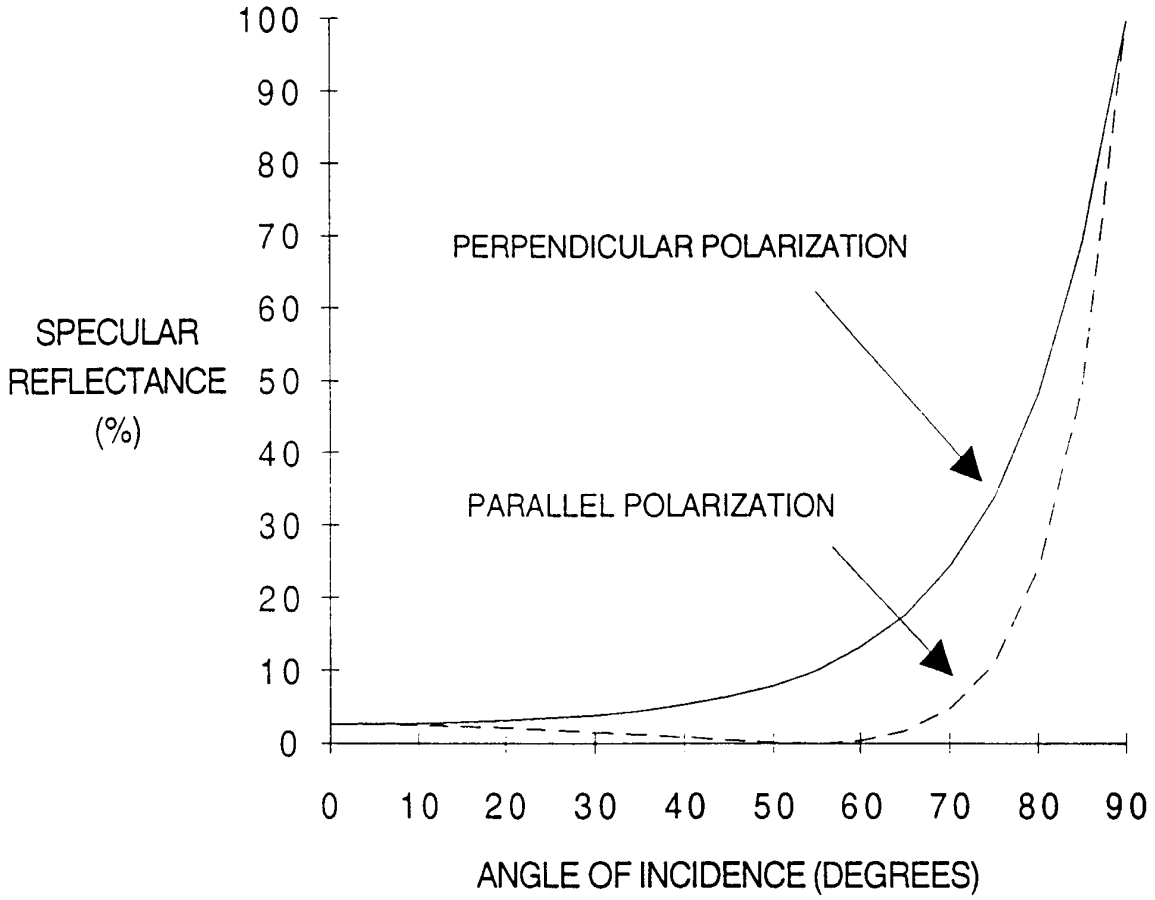


FIGURE F-4. Specular reflectance from sea water (index of refraction = 1.378).

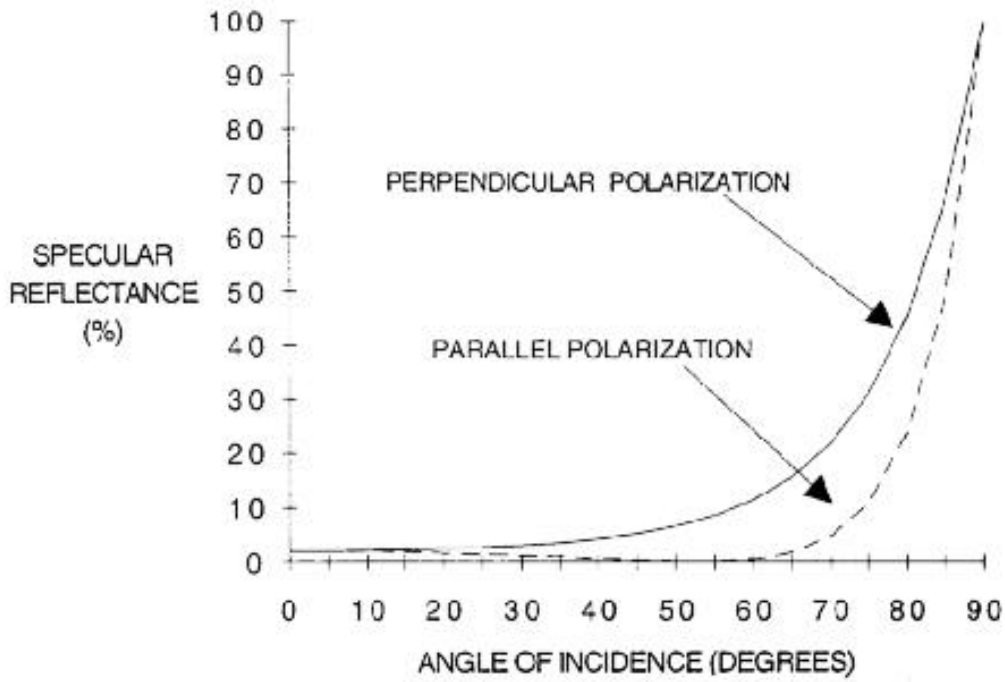


FIGURE F-5. Specular reflectance from fresh water(index of refraction =1.33).

If the fractions of the laser beam polarization are not known, choose the highest reflectivity for the given angle of incidence. Typical values are given in TABLES F-I through F-III. Calculate the value of NOHR for various values of D1 and θ. Choose the worst case NOHR to restrict airspace, ships, vehicles or projecting landmasses.

b. Reflection from Reflector Smaller than Incident Laser Beam Cross Section. Reflective objects that are smaller in cross section than the incident laser beam will pose less of a reflection hazard since only a proportional amount of laser radiation will be reflected. Small reflectors will also cause diffraction effects. For a detailed explanation of this, see references in the applicable document section of this appendix. Ignoring diffraction effects and second surface reflection, the hazard distance from reflectors smaller than the incident laser beam cross section is given by the following equation:

$$NOHR = H2/\cos(\theta) = NOHD \times (\%P \times R\| + \%N \times R\perp)^{1/2}(RA/LA)^{1/2} - H1/\cos(\theta)$$
$$= NOHD \times [\%P(\tan^2(\theta-\theta'))/(\tan^2(\theta+\theta'))+\%N(\sin^2(\theta-\theta'))/(\sin^2(\theta+\theta'))]^{1/2} \times (RA/LA)^{1/2} - H1/\cos(\theta)$$

Where:

RA = cross sectional area of the reflector
LA = cross sectional area of the incident laser beam
NOHR = Nominal Ocular Hazard Distance from Reflector
H1 = altitude of laser
H2 = altitude of observer viewing reflected laser beam
θ = angle incident and reflected laser beam makes with a line perpendicular to the reflecting surface (angle of incidence)= arctan(D1/H1) for a flat reflector on flat ground.
D1 = horizontal distance from laser to reflector
θ' = angle of refracted beam in a reflecting media = $\arcsin(\theta/n)$
n = index of refraction of reflecting media
%P = fraction of laser beam polarized parallel to plane of incidence
%N = fraction of laser beam polarized perpendicular to plane of incidence
NOHD = Nominal Ocular Hazard Distance (See TABLE II for typical distances)
R|| = Parallel polarization reflection coefficient = $(\tan^2(\theta-\theta'))/(\tan^2(\theta+\theta'))$
R⊥ = Perpendicular polarization reflection coefficient = $(\sin^2(\theta-\theta'))/(\sin^2(\theta+\theta'))$

If the fractions of the laser beam polarizations are not known, choose the highest reflectivity for the given angle of incidence. Typical values are given in TABLE F-I through F-III. Calculate the value of NOHR for various values of D1 and θ. Choose the worst case NOHR to restrict airspace, ships, vehicles or projecting land masses. TABLE F-IV gives the reflectivity of shiny metal.

TABLE F-I. Reflectivity of glass at various angles of incidence.

MATERIAL - GLASS APPROX. INDEX OF REFRACTION AT WAVELENGTHS .3 TO 2 MICRONS = 1.55

ANGLE OF INCIDENCE (DEGREES)	REFLECTIVITY PERPENDICULAR POLARIZATION	REFLECTIVITY PARALLEL POLARIZATION
0	0.0465	0.0465
10	0.0484	0.0447
20	0.0545	0.0391
30	0.0664	0.0299
40	0.0877	0.0175
50	0.1254	0.0046
60	0.1935	0.0012
70	0.3199	0.0400
80	0.5574	0.2334
90	1.0	1.0

TABLE F-II. Reflectivity of fresh water at various angles of incidence.

MATERIAL - FRESH WATER APPROX. INDEX OF REFRACTION AT WAVELENGTHS .3 TO 2 MICRONS = 1.33

ANGLE OF INCIDENCE (DEGREES)	REFLECTIVITY PERPENDICULAR POLARIZATION	REFLECTIVITY PARALLEL POLARIZATION
0	0.0201	0.0201
10	0.0210	0.0191
20	0.0241	0.0164
30	0.0305	0.0117
40	0.0426	0.0057
50	0.0660	0.0006
60	0.1139	0.0044
70	0.2180	0.0473
80	0.4552	0.2387
90	1.0	1.0

TABLE F-III. Reflectivity of sea water at various angles of incidence.

MATERIAL - SEA WATER APPROX. INDEX OF REFRACTION AT WAVELENGTHS .3 TO 2 MICRONS = 1.378

ANGLE OF INCIDENCE (DEGREES)	REFLECTIVITY PERPENDICULAR POLARIZATION	REFLECTIVITY PARALLEL POLARIZATION
0	0.0253	0.0253
10	0.0264	0.0241
20	0.0302	0.0207
30	0.0378	0.0151
40	0.0521	0.0078
50	0.0790	0.0010
60	0.1324	0.0037
70	0.2433	0.0467
80	0.4826	0.2403
90	1.0	1.0

TABLE F-IV. Reflectivity of Shiny Metal

MATERIAL - SHINY METAL (SILVER) AT ALL ANGLES OF INCIDENCE

WAVELENGTH (Microns)	REFLECTIVITY
.45	.88
.50	.90
.55	.915
.60	.927
.65	.935
.70	.941
.80	.951
.90	.96
1.0	.965
2.0	.979

SEPARATE TARGET (SEPTAR) AND SHIP'S TOWED TARGET OPERATIONS

G.1 SCOPE. This appendix provides safety guidance on SEPTAR and ship towed target operations.

G.2 APPLICABLE DOCUMENTS

US Navy

E0410-BA-GYD-010, Technical Manual Laser Safety

NATO

STANAG 3606, Evaluation and Control of Laser Hazards

G.3. GUIDANCE

G.3.1 SEPTAR operations. SEPTARs may be used for A-6E TRAM, OV-10D NOS, F-111F PAVE TACK, and PAVE SPIKE laser operations in open restricted areas provided that:

a. A two nautical mile (nmi) SEPTAR operating area is established with a 1-, 2-, 3-, 4-, or 5-nmi buffer zone around the operating area (See FIGURE H-1) as appropriate for the flight profiles in TABLES H-I through H-V.

b. No laser operations within 10 nmi of land are allowed when the laser line-of-sight (LLOS) is directed toward land.

c. All specular reflectors on the SEPTAR must be removed or covered prior to laser operations.

d. Every person required to be within the operations areas or buffer zone must wear laser protective goggles of adequate protection at 1.06 micron wavelength during laser operations.

e. The target must be positively identified on the operator's monitor before to lasing.

f. Laser operations shall cease if either the pilot or system operator is dissatisfied with target tracking.

g. Lasing shall cease if unprotected or unauthorized aircraft enter the operations area or buffer zone from 0 feet to 1800 feet above mean sea level (MSL) or between the lasing aircraft and the target.

h. Lasing shall cease if unprotected or unauthorized surface craft enter the operations area or buffer zone.

i. The aircraft must be at or above the flight profiles in TABLES G-I through G-V for the assigned buffer zone.

j. A log of the date and time of all laser firings must be kept.

G.3.2 Ship's towed target operations. Ship's towed target operations as shown on FIGURE G-1 shall abide by the following:

a. The target shall be towed no closer than one thousand feet from the towing ship.

b. All laser operations shall be conducted on incoming headings of 60 degrees to 90 degrees and 260 degrees to 300 degrees relative to towing ship's heading. If lasing back at the target is required, after passing over it, the outgoing heading shall be in the zones specified above for the incoming headings (see FIGURE G-2).

c. Laser operation shall not be initiated until the laser operator has identified the target under the reticle on the display, and the pilot has identified the target through the optical gun sight.

d. Laser operation must cease if the system is not properly tracking the target.

e. Laser operation shall cease immediately after weapon release for conventional ordnance or immediately after weapon impact for laser-guided ordnance.

f. Laser operation shall cease whenever friendly ships are within 48,000 feet of the target along the LLOS and 700 feet either side of the LLOS, unless the use of laser protective eyewear by onboard personnel is assured.

g. Laser operations shall cease whenever friendly aircraft operating below 6,000 feet altitude are within 31,000 feet of the target along the LLOS and 700 feet either side of the LLOS, unless the use of laser protective eyewear by onboard personnel is assured.

h. Optical aids used to view the target during laser operations must be equipped with proper protective filters when the viewer is within the boundaries cited and along the LLOS out to the optical aids nominal ocular hazard distance for the specific laser and specific optical aid.

i. Viewing of the target with optical aids from the towing ship, or from other ships and aircraft outside of the laser-beam hazard-control zone described above is permitted.

j. Targets shall be non-specular.

k. A log of the date, time, and heading of all laser firings must be kept.

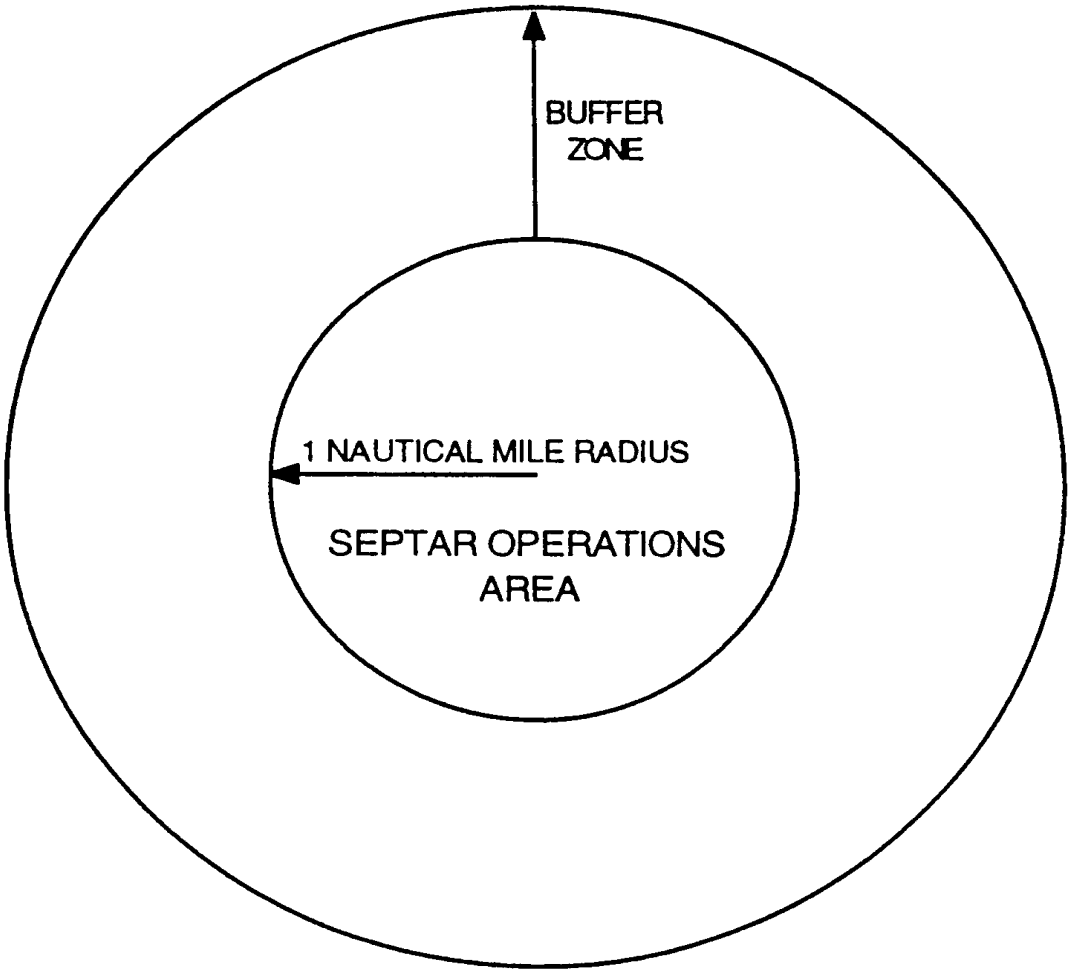
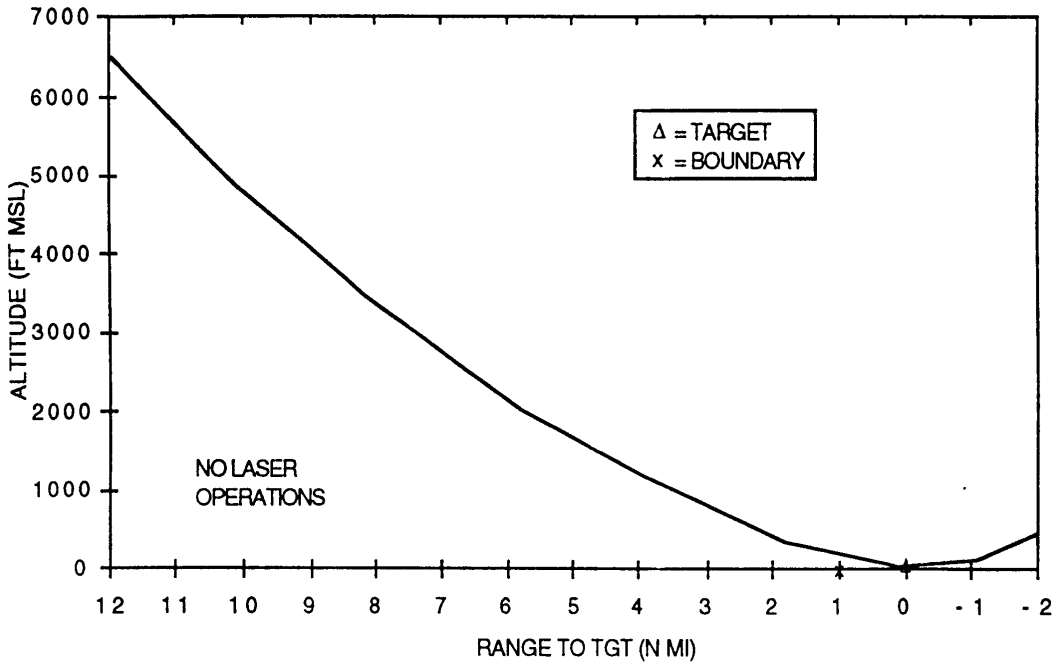
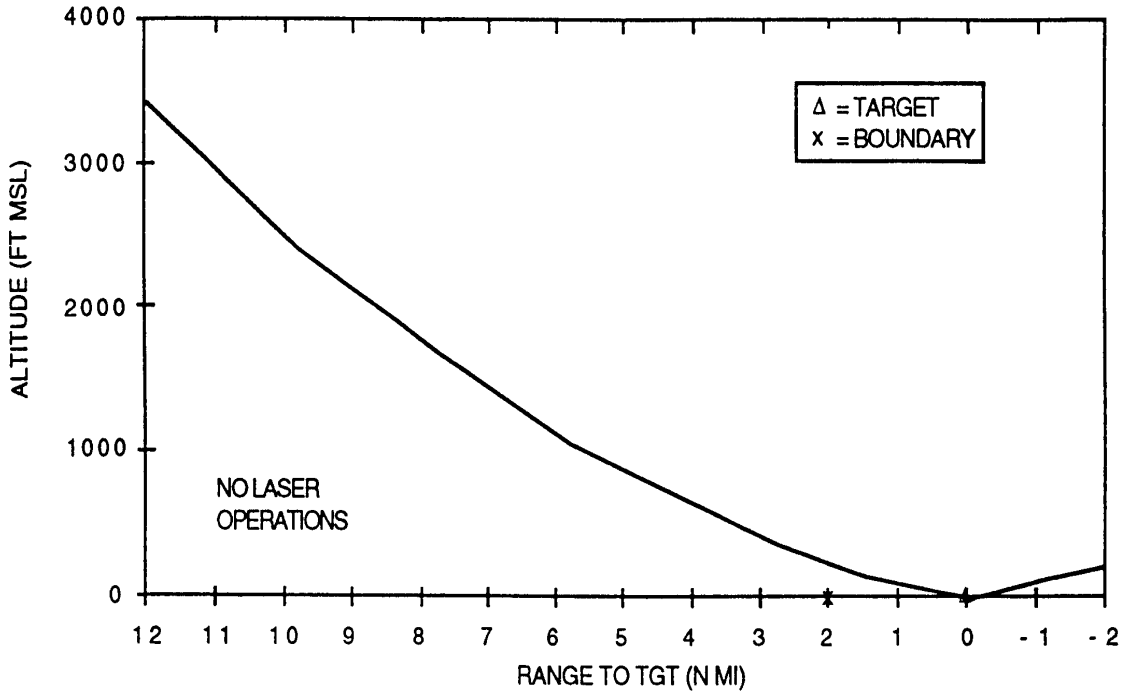


FIGURE G-1. SEPTAR operations area and buffer zone.



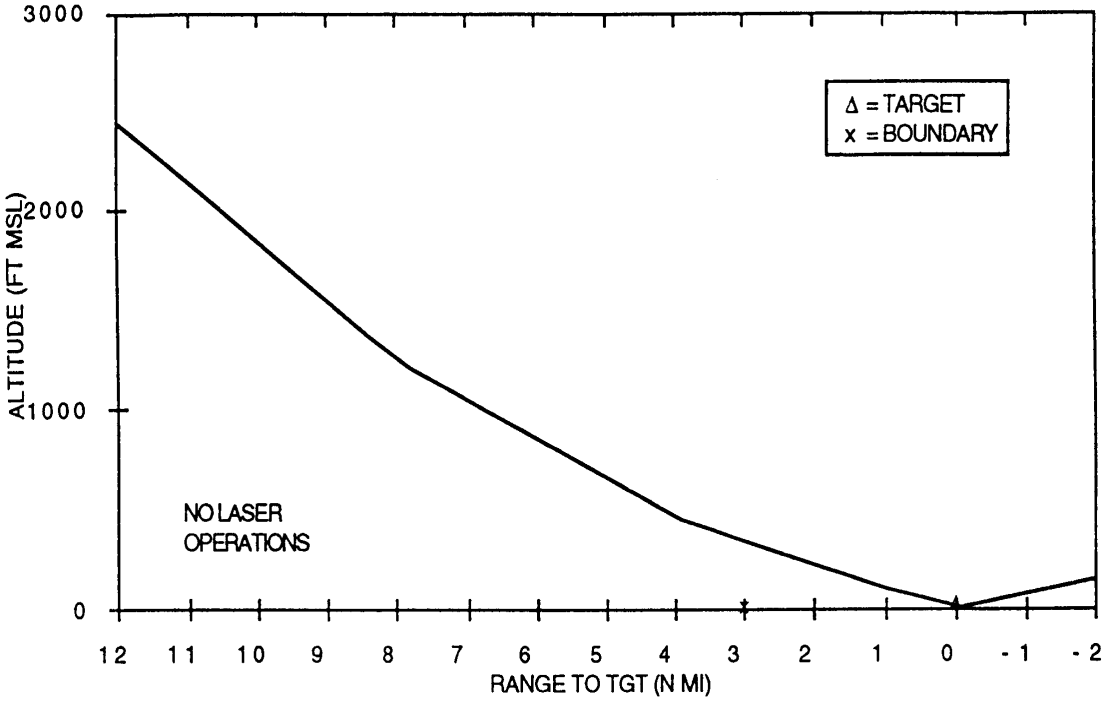
RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)	RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
12	6550	0	50
11	5650	1	150
10	4850	2	450
9	4050		
8	3350		
7	2750		
6	2150		
5	1650		
4	1250		
3	850		
2	450		
1	250		

TABLE G-I. Flight profile against SEPTAR. One NMI buffer zone around one nautical mile operation area - 0 degrees to 360 degrees.



RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)	RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
12	3450	0	50
11	3050	1	150
10	2550	2	250
9	2150		
8	1850		
7	1450		
6	1150		
5	950		
4	650		
3	450		
2	250		
1	150		

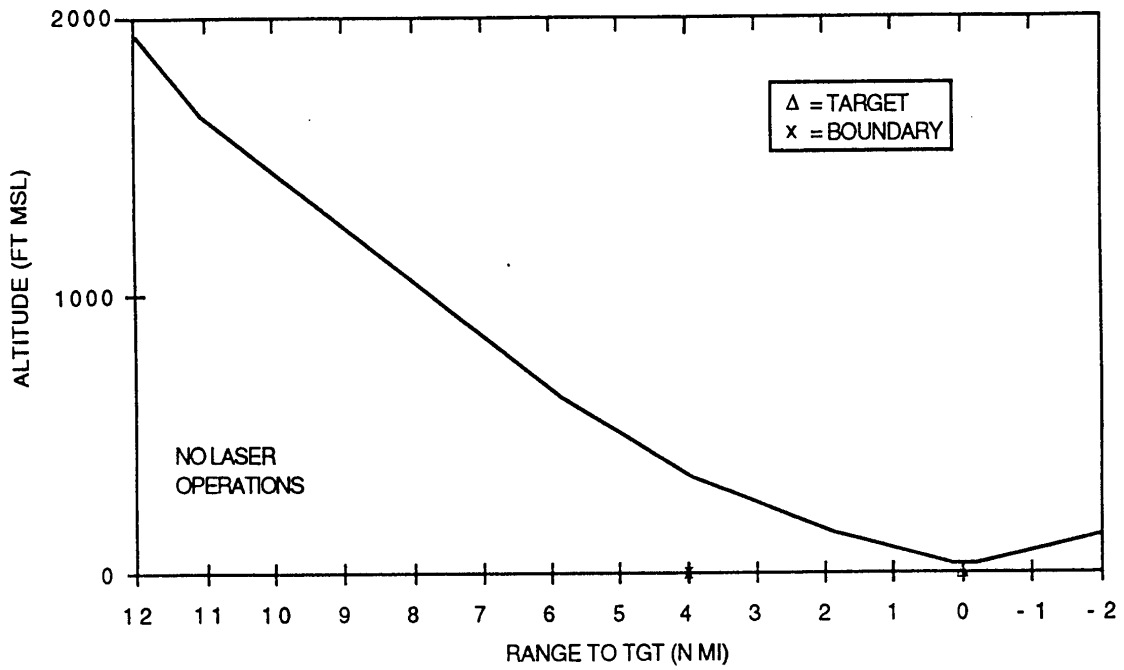
TABLE G-II. Flight profile against SEPTAR. Two NMI buffer zone around one nautical mile operation area - 0 degrees to 360 degrees.



RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
12	2450
11	2150
10	1850
9	1550
8	1250
7	1050
6	850
5	650
4	450
3	350
2	250
1	100

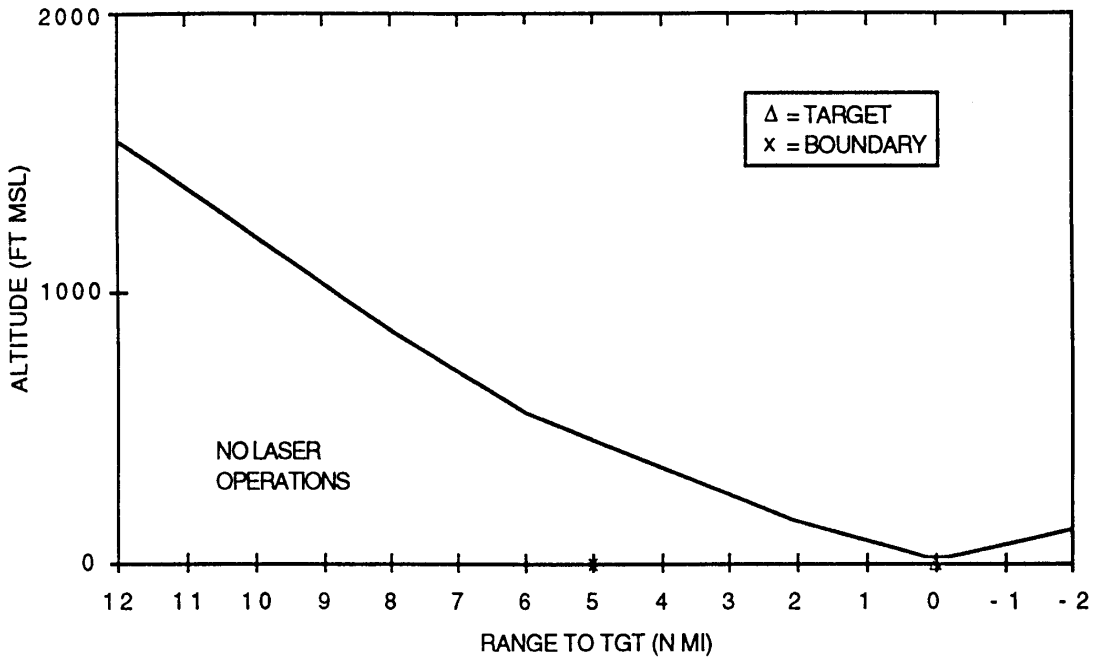
RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
0	50
1	100
2	150

TABLE G-III. Flight profile against SEPTAR. Three NMI buffer zone around one nautical mile operation area - 0 degrees to 360 degrees.



RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)	RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
12	1950	0	50
11	1650	1	100
10	1450	2	150
9	1250		
8	1050		
7	850		
6	650		
5	550		
4	350		
3	250		
2	150		
1	100		

TABLE G-IV. Flight profile against SEPTAR. Four NMI buffer zone around one nautical mile operation area - 0 degrees to 360 degrees.



RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
12	1550
11	1350
10	1250
9	1050
8	850
7	750
6	550
5	450
4	350
3	250
2	150
1	100

RANGE TO TARGET (N MI)	MINIMUM ALTITUDE (FT)
0	50
1	100
2	150

TABLE G-V. Flight profile against SEPTAR. Five NMI buffer zone around one nautical mile operation area - 0 degrees to 360 degrees.

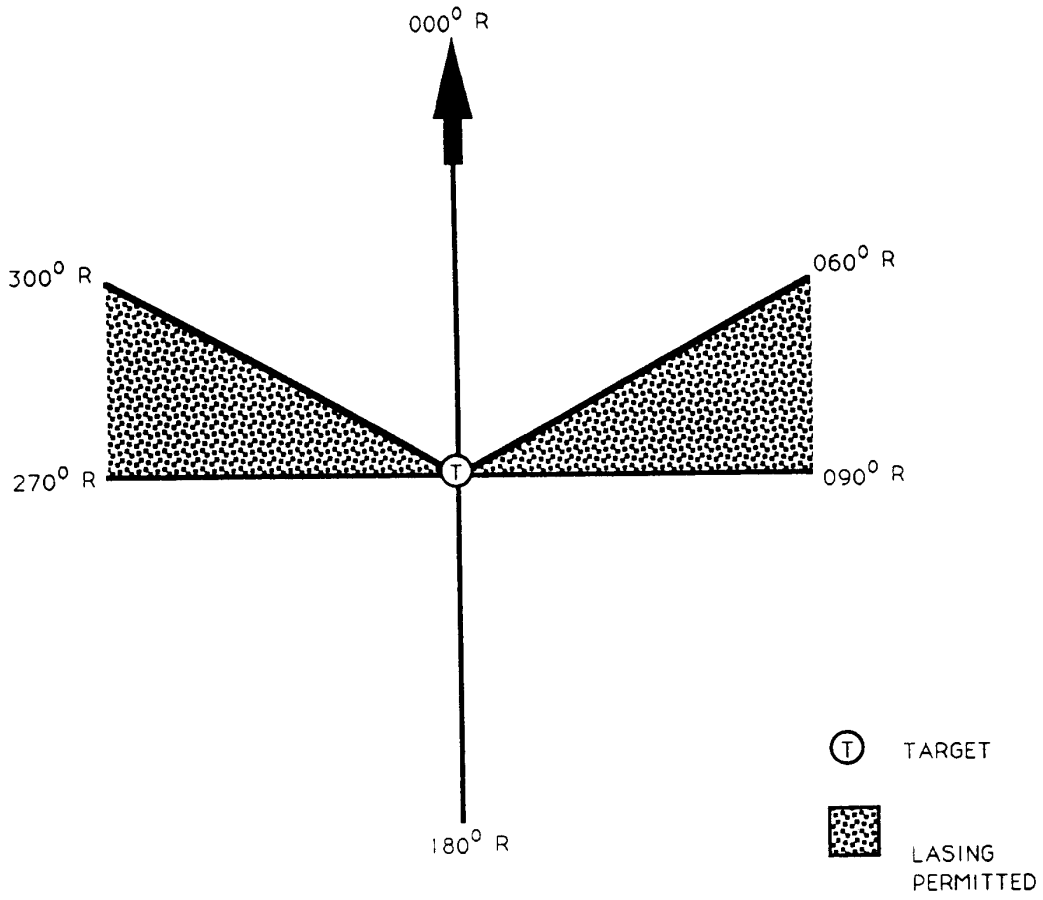


FIGURE G-2. Zones relative to towing ship's heading in which laser operations are permitted for A-6E TRAM, OV-10D NOS, F111-pave tack, and pave spike.

SATELLITE SAFETY PROCEDURES FOR SPACE DIRECTED LASERS

H.1 SCOPE. These guidelines establish the Space Control Center (SCC) Laser Clearinghouse (LCH) procedures.

H.2 REFERENCES

USCINCSPACE OPLAN 3400.90 pg. iii (classified secret)

Joint Strategic Capability Plan, para g(2) (a)7. USCINCSPACE will: "Disseminate information relating to, and provide measures for protecting vital US and allied space systems from interference by collision, directed energy, anti-satellite, nuclear detonation, sabotage, or electronic warfare."

Derivation and Use of the SPADOC Laser Clearinghouse Threshold Curve, June 1983, SAIC. (classified secret)

H.3 DEFINITIONS. Definitions of terms are included as Attachment 1.

H.4 APPLICABILITY

a. The Commander in Chief, United States Space Command (USCINCSPACE) is the executive agent for Laser Clearinghouse and, acting through the SCC, is directed by the Joint Strategic Capability Plan to authorize the emission of laser radiation from all DoD or DoD-sponsored lasers that have the potential of interfering with, degrading, or damaging any US or foreign satellite.

b. These guidelines apply to all space directed DoD laser facilities, either land based, sea based, airborne, or space based; mobile or fixed, including those owned, operated, or controlled by DoD components or by agencies or contractors under the auspices of DoD components. (NOTE: U. S. SPACECOM Laser Clearinghouse is only concerned with lasers which are intentionally directed towards space, that is, lasers used for atmospheric research, satellite analysis, astronomical research, Ballistic Missile Defense testing, and so forth). These guidelines apply to US non-DoD satellite owner/operators (O/Os) by agreement with the SCC. These guidelines do not apply to allied or foreign satellite O/Os. (If there is an interest in lasing a non-US satellite, contact the SCC for special procedures.)

c. These guidelines specify the responsibilities and procedures for:

(1) Evaluating a laser's damage potential.

(2) Scheduling emissions of laser energy from DoD sources into space to avoid interference or damage to US or foreign satellite payloads.

(3) Responding to accidental laser illumination events.

H.5 CONCEPT OF OPERATIONS

a. USCINCSPACE is tasked by the Joint Chiefs of Staff, the Joint Strategic Capability Plan, to provide the capability and act as the focal point to authorize laser emissions into space by DoD components which may result in interference or damage to US or foreign satellite payloads. This task is performed under the direct operational control of the SCC Space Control Director (SCD) located inside Cheyenne Mountain Air Station (CMAS), Colorado Springs, Colorado. The SCC SCD, based on authority delegated by USCINCSPACE, is the focal point for space control operations which includes the Laser Clearinghouse program.

b. The Combat Analysis Section (JCCDOA) will maintain a database of all known DoD laser facilities. Each DoD laser facility will initially notify JCCDOA of its laser(s) parameters. JCCDOA will determine the laser's damage potential and either grant a blanket waiver for the laser or coordinate to determine safe laser firing times.

c. Facilities operating a non-waived laser will request permission from SCC to emit space directed laser energy. The SCC in turn will provide the facility with Predictive Avoidance (PA) safe firing windows. The PA windows provide the laser facility with safe laser start/stop times insuring no satellite payload(s) will be unintentionally illuminated. The SCC will monitor changes in space activity and may update issued PA windows. The SCC may request data from DoD lasers in support of accidental illumination analysis. The SCC will notify the National Military Command Center (NMCC) or alternate agencies and DoD satellite O/Os, as appropriate, of accidental laser illumination. Laser facilities will monitor their operations and report any anomalies to the SCC which could have led to an accidental illumination.

H.6 JCCDOA RESPONSIBILITIES

a. Send each laser facility a LCH introductory package upon initial contact.

b. Upon receipt of the LCH Information Sheet (attachment 2), determine if a laser has the potential of damaging or interfering with satellite payloads. Interference and/or damage potential is determined using SCC's laser threshold data. The laser facility will be notified of the results by use of a LCH Waiver Response letter (attachment 3). JCCDOA shall reevaluate a laser's waiver status upon notification from a laser facility of a laser parameter change or when laser threshold data changes. JCCDOA shall provide initial guidance to laser facilities on proper message formats.

c. Develop, maintain, and operate new LCH software as required. Maintain SCC's threshold comparison procedures as new sensor technology is developed and/or more refined analysis techniques are employed. All waivers issued to lasers will be reevaluated whenever the waiver procedures or thresholds are modified.

d. Maintain a current database of all DoD laser facilities.

e. Receive and respond to LCH PA Requests by providing PA safe firing windows using the LCH PA Windows message (AUTODIN traffic is preferred, and all message formats are described in SPADOC ICD 2025 and 3225).

f. SCC will compute and transmit the LCH safe firing windows to the requesting site not later than four hours before the site firing begins.

g. After generating PA safe firing windows, the SCC will keep a watch for space events that could alter previously issued windows. If such an event occurs, the SCC will ask the laser operator to suspend laser firing using established communications. The SCC will recalculate the PA safe firing windows and send the new windows to the laser site. When the new windows are received, the laser site may continue operations.

h. If an Accidental Illumination Report is received, or if an accidental illumination is suspected, SCC will analyze the event to determine, as accurately as possible, the illumination source and vulnerable targets.

(1) Upon notification or suspicion of an accidental illumination, SCC will:

(A) Find all satellite payloads visible to the laser (within a cone about the beam).

(B) Contact the O/O's of those satellite systems identified as vulnerable and request information pertaining to system anomalies.

(C) Send an LCH Accidental Illumination Report to the involved satellite O/O's and laser site operators within 24 hours, if necessary.

(2) Upon sufficient cause to suspect an accidental illumination event, SCC will:

(A) Review PA window requests to identify active lasers.

(B) Determine which laser site(s) were visible to the affected satellite(s) during the period of interest.

(C) Send a LCH Activity Request to suspected laser sites within 1 hour. The laser site(s) should respond within 24 hours with a LCH Activity Report.

(D) Analyze all information and if necessary, send a LCH Accidental Illumination Report to the NMCC or alternates within 8 hours and to the involved satellite O/Os and laser site operators within 8 hours.

H.7 LASER FACILITY RESPONSIBILITIES

a. Send a LCH Information Sheet to JCCDOA for every new laser facility or for every new laser at a facility approximately 30 days prior to the first intended space directed emissions. JCCDOA's response to the waiver request is a LCH Waiver Response. If JCCDOA determines the laser at the facility is powerful enough to interfere with or damage satellite payloads, the site must request LCH PA safe firing windows from the SCC.

b. Notify JCCDOA whenever a laser's parameters are changed using the LCH Information Sheet. JCCDOA will reevaluate and update the waiver status.

c. If required, request LCH PA safe firing windows from SCC using the LCH PA Request message no later than 48 hours prior to the start of actually firing the laser.

d. Notify the SCC as soon as possible whenever planned laser testing is postponed or canceled.

e. Obtain permission to use a satellite as a target from a satellite O/O if a satellite payload is the intended target.

f. Submit within one hour of detection a LCH Accidental Firing message to SCC if the facility believes it illuminated the wrong satellite or operated outside of safe firing windows supplied by the SCC.

g. Respond within 24 hours of receipt of a LCH Activity Request with a LCH Activity Report. With this report, identify space directed laser emissions for lasers, regardless of waiver status.

h. When operations are classified, communications with the SCC will be via the communication channels necessary for the classification level.

Attachments:

1. Definitions for Space Directed Laser Emissions

2. Laser Clearinghouse Information Sheet

3. United States Space Command Sample Waiver Response

ATTACHMENT 1. DEFINITIONS FOR SPACE DIRECTED LASER EMISSIONS

Accidental Illumination - Laser illumination of a satellite payload which was not the intended target, and/or the operation of a laser outside of LCH/PA windows provided by the SCC.

Beam Divergence Half Angle - A parameter which describes the angular spread of a laser beam measured from the beam's center out to the point where intensity falls to 37 percent of its original value. Typically measured in radians.

Damage - Any physical impairment, either temporary or permanent, of the normal operating capability of a satellite.

DoD Components - A term meaning collectively the Office of the Secretary of Defense, the Joint Chiefs of Staff, the Unified and Specified Commands, the Military Departments, and the Defense Agencies (including national laboratories).

Jitter Angle - The factor which accounts for the mechanical pointing inaccuracies of the laser. The angle, from beam center, in which the beam is located with 96.6 percent probability (2 sigma).

Laser Clearinghouse - A function within USCINCSPACE/SCC which maintains the laser facility data base, receives laser facility emission requests determines waiver status, sends approval/ denial/restrictions to the laser facilities, and processes accidental illumination information.

Laser Damage Threshold - A predetermined level of laser intensity designed to protect satellite sensor material from damage.

Laser Facility - The laser device, supporting system and equipment, tracking mechanism, personnel, building and platform.

Output Aperture Diameter - The beam diameter at the emitter aperture (meters).

Predictive Avoidance Windows - Time intervals generated by SCC allowing a laser to safely conduct space-directed operations without fear of accidentally illuminating satellites.

Payload - The portion of a satellite that contains instrumentation and recording devices, transmitters and receivers, and related support equipment.

Radiant Intensity - The strength of a laser emission at the facility in units of power per solid angle, usually in watts per steradian.

Relative Intensity (IREL) - Accounts for thermal blooming. This factor is defined as the ratio of the actual (experimental) intensity compared to that obtained by a perfect beam (theoretical).

Satellite - Any man-made object in earth orbit.

Satellite Owner/Operator - The agency, unit, company, or other organization responsible for the operation of an orbiting satellite and its command, control, communication, and data utilization.

SCC - Space Control Center (formerly SPADOC) located inside Cheyenne Mountain in Colorado Springs, Colorado.

Strehl Beam Quality Factor - Measures the imperfections within the laser. The factor is equal to the square root of the theoretical power divided by the observed power at a given point.

Target - The satellite which is the intended object of laser illumination.

USCINCSPACE - Commander-in-Chief United States Space Command.

USSPACECOM - United States Space Command.

Waiver - Written permission from JCCDOA granting a laser facility permission to freely operate a space directed laser without the need for safe firing windows.

ATTACHMENT 2. LASER CLEARINGHOUSE INFORMATION SHEET

Orbital Safety Officer - CMOC/JCCDOA

FAX: (719) 474-3182 Voice: ((DSN 268-4543, (719)474-4543))

Laser Site:

Section 1: Point of Contact

Name:

Mailing Address:

Commercial Phones:

DSN Phones:

Secure Phones & Type:

FAX:

AUTODIN Routing Indicator and Plain Language Address:

Section 2: Project Data

Project Name:

Project Start Date:

Project Completion Date:

Typical Laser Target (check all that apply)

__Look-Angle __Missile __Star __Satellite

For missile targets contact LCH.

Section 3: Site Geodesics

Fixed Site:

Lat_____deg

Long_____deg

Alt_____kin

Section 4: Laser Parameters

CONTINUOUS WAVE LASERS

Firing Mode		Prime
1	2	3
Output Power (Watts)		
Wavelength (Meters)		
Divergence Half-Angle (Radians)		
Operating Time (Seconds)		
*Output Aperture		
Diameter (Meters)		
*Jitter Angle (Degrees)		
*Strehl Beam Quality (Percent)		

*Relative Intensity (Percent)

* To be used by our on-line software, please provide these if you know them. Other parameters are required for waiver analysis.

PULSED LASERS

Firing Mode	Prime	
1	2	3
Pulse Width (Seconds)		
Pulse Repetition Frequency (Hertz)		
Pulse Energy (Joules)		
Divergence Half-Angle (Radians)		
Wavelength (Meters)		
Operating		
Time (Seconds)		
*Output Aperture Diameter (Meters)		
*Output Power at Output Aperture (Watts)		

*Jitters Angle (Degrees)

*Strehl Beam Quality (Percent)

*Relative Intensity (Percent)

* To be used by our on-line software, please provide these if you know them. Other parameters are required for waiver analysis.

ATTACHMENT 3. UNITED STATES SPACE COMMAND SAMPLE WAIVER RESPONSE

FROM: CMOC/JCCDOA
Suite 9-101A
1 NORAD Rd.
Cheyenne Mountain AFS, CO 80914-6020

SUBJ: SPADOC Laser Clearinghouse Waiver Response

TO: Laser Site

1. I have evaluated the laser from your fax of 29 DEC. The laser described below is not waived and will require predictive avoidance screening. Please contact me at least 48 hours prior to any lasing so we can compute your open window times.

Type: Pulsed

Wavelength:	XXX Meters
Pulse Energy:	XXX Joules
Divergence:	XXX Radians (half-angle)
Pulse Rep. Freq.	XXX Hertz
Pulse Width:	XXX Seconds

2. Let me know if I can be of further assistance. I can be reached at U.S. Space Command (DSN 268-4543, (719)474-4543).

Orbital Safety Officer

CONCLUDING MATERIAL

Lead Standardization Activity:

Army - EA

Preparing Activity:

Navy - EC
Project No. 4240-0671

Custodians:

Navy - EC
Army - EA
Air Force - 10