

# American National Standard

*American National Standard  
for Safe Use of Lasers Outdoors*

---



**Laser Institute  
of America**  
*Laser Applications and Safety*



**ANSI®**  
Z136.6 – 2015  
Revision of  
ANSI Z136.6-2005

**American National Standard  
for Safe Use of Lasers Outdoors**

Secretariat  
**Laser Institute of America**

Approved October 5, 2015  
**American National Standards Institute, Inc.**

**American  
National  
Standard**

An American National Standard implies a consensus of those substantially concerned with its scope and provisions. An American National Standard is intended as a guide to aid the manufacturer, the consumer, and the general public. The existence of an American National Standard does not in any respect preclude anyone, whether or not he or she has approved the standard, from manufacturing, marketing, purchasing, or using products, processes or procedures not conforming to the standard. American National Standards are subject to periodic review and users are encouraged to obtain the latest editions.

**CAUTION NOTICE:** This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken periodically to reaffirm, revise, or withdraw this standard no later than five years from the date of publication. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute.

Published by

**Laser Institute of America  
13501 Ingenuity Drive, Suite 128  
Orlando, FL 32826**

ISBN: 978-1-940168-07-4

Copyright © 2015 by Laser Institute of America.  
All rights reserved.

No part of this publication may be copied or reproduced in any form, including an electronic retrieval system or be made available on the Internet, a public network, by satellite, or otherwise, without the prior written permission of the publisher.

Printed in the United States of America.

**Foreword** (This introduction is not a normative part of ANSI Z136.6-2015, *American National Standard for Safe Use of Lasers Outdoors*.)

In 1968, the American National Standards Institute (ANSI) approved the initiation of the Safe Use of Lasers Standards Project under the sponsorship of the Telephone Group.

Prior to 1985, Z136 standards were developed by ANSI Committee Z136 and submitted for approval and issuance as ANSI Z136 standards. Since 1985, Z136 standards have been developed by the ANSI Accredited Standards Committee (ASC) Z136 for Safe Use of Lasers. A copy of the procedures for development of these standards can be obtained from the secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826, or viewed at [www.z136.org](http://www.z136.org).

The present scope of ASC Z136 is to protect against hazards associated with the use of lasers and optically radiating diodes.

ASC Z136 is responsible for the development and maintenance of this standard. In addition to the consensus body, ASC Z136 is composed of standards subcommittees (SSC) and technical subcommittees (TSC) involved in Z136 standards development and an editorial working group (EWG). At the time of this printing, the following standards and technical subcommittees were active:

SSC-1	Safe Use of Lasers (parent document)
SSC-2	Safe Use of Lasers and LEDs in Telecommunications Applications
SSC-3	Safe Use of Lasers in Health Care
SSC-4	Measurements and Instrumentation
SSC-5	Safe Use of Lasers in Educational Institutions
SSC-6	Safe Use of Lasers Outdoors
SSC-7	Eyewear and Protective Barriers
SSC-8	Safe Use of Lasers in Research, Development, and Testing
SSC-9	Safe Use of Lasers in Manufacturing Environments
SSC-10	Safe Use of Lasers in Entertainment, Displays, and Exhibitions
TSC-1	Biological Effects and Medical Surveillance
TSC-2	Hazard Evaluation and Classification
TSC-4	Control Measures and Training
TSC-5	Non-Beam Hazards
TSC-7	Analysis and Applications
EWG	Editorial Working Group

The nine standards currently issued are:

*ANSI Z136.1-2014, American National Standard for Safe Use of Lasers*

*ANSI Z136.2-2012, American National Standard for Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources*

*ANSI Z136.3-2011, American National Standard for Safe Use of Lasers in Health Care*

*ANSI Z136.4-2010, American National Standard Recommended Practice for Laser Safety Measurements for Hazard Evaluation*

*ANSI Z136.5-2009, American National Standard for Safe Use of Lasers in Educational Institutions*

*ANSI Z136.6-2015, American National Standard for Safe Use of Lasers Outdoors*

*ANSI Z136.7-2008, American National Standard for Testing and Labeling of Laser Protective Equipment*

*ANSI Z136.8-2012, American National Standard for Safe Use of Lasers in Research, Development, or Testing*

*ANSI Z136.9-2013, American National Standard for Safe Use of Lasers in Manufacturing Environments*

This American National Standard provides guidance for the safe use of lasers and laser systems in an outdoor environment, including laser products that have been granted a variance or exemption from the provisions of the Federal Laser Product Performance Standard (21 CFR 1040). Products and applications covered include laser light shows, lasers used for outdoor scientific research, and military lasers. In addition to injurious levels of optical radiation, which are covered in other ANSI Z136 standards, this standard also covers possible indirect hazards such as visual interference that can be caused by exposure to visible laser radiation, particularly at night.

Development of this standard has been a collaborative effort of members of the SAE G-10 Committee, laser light show industry, DoD, FDA/CDRH, FAA, NASA, laser and laser light show manufacturers, and laser users including scientists and astronomers. This document serves as a companion to the SAE Aerospace Standard AS4970, 21 CFR 040, FAA Order 7400.2 and related FAA documents, Military Standard 1425A, and Military Handbook 828B, for determining the hazards from outdoor laser operations.

This standard provides acceptable levels of irradiation in particular defined zones of navigable airspace in order to minimize visual interference to aircrews. These zones were created to reduce illumination levels of aircrews during critical phases of flight, primarily during takeoff and

landing, in response to numerous incidents of aircraft illuminations that have occurred during the past several years. These defined levels of irradiation may also apply to operators of vehicles other than aircraft. As more powerful commercial off the shelf lasers have become available, the threat to aircraft and other vehicles from illumination by a laser has increased. For visible laser exposure, indirect hazards due to hampered vision have been demonstrated at levels below the levels that would cause permanent eye injury.

This standard has been published as part of the American National Standard Z136 series. The basic document is *American National Standard for Safe Use of Lasers*, ANSI Z136.1. In general, this standard may be used independently of ANSI Z136.1. Instances where additional guidance contained in ANSI Z136.1 is required are noted in this document.

It is expected that this standard will be periodically revised as new information and experience in the use of lasers are gained. Future revisions may have modified content and the use of the most current document is highly recommended.

While there is considerable compatibility among existing laser safety standards, some requirements differ among state, federal, and international standards. These differences may have an effect on the particulars of the applicable control measures.

Occasionally questions may arise regarding the meaning or intent of portions of this standard as it relates to specific applications. When the need for an interpretation is brought to the attention of the secretariat, the secretariat will initiate action to prepare an appropriate response. Since ANSI Z136 standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, the secretariat is not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. Requests for interpretations and suggestions for improvements of the standard are welcome. They should be sent to ASC Z136 Secretariat, Laser Institute of America, 13501 Ingenuity Drive, Suite 128, Orlando, FL 32826.

This standard was developed by Standards Subcommittee 6 (SSC-6) “Safe Use of Lasers Outdoors” and approved by ANSI Accredited Standards Committee (ASC) Z136 for Safe Use of Lasers. Committee approval of the standard does not necessarily imply that all members voted for its approval.

Robert Thomas, Committee Chair  
Sheldon Zimmerman, Committee Vice-Chair  
Ben Edwards, Committee Secretary

**Notice**

(This notice is not a normative part of ANSI Z136.6-2015, *American National Standard for Safe Use of Lasers Outdoors.*)

Z136 standards and recommended practices are developed through a consensus standards development process approved by the American National Standards Institute. The process brings together volunteers representing varied viewpoints and interests to achieve consensus on laser safety related issues. As secretariat to ASC Z136, the Laser Institute of America (LIA) administers the process and provides financial and clerical support to the committee.

The LIA and its directors, officers, employees, members, affiliates, and sponsors, expressly disclaim liability for any personal injury, property, or other damages of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this document or these standards. The LIA's service as secretariat does not constitute, and LIA does not make any endorsement, warranty, or referral of any particular standards, practices, goods, or services that may be referenced in this document. The LIA also makes no guarantee or warranty as to the accuracy or completeness of any information published herein. The LIA has no power, nor does it undertake to police or enforce compliance with the contents of this document.

In issuing and making this document available, the LIA is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is the LIA undertaking to perform any duty owed by any person or entity to someone else. Anyone using this document should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

**Participants** At the time it approved this standard, ASC Z136 had the following members:

<i>Organization Represented</i>	<i>Name of Representative</i>
Academy of Laser Dentistry	Scott Benjamin
Altos Photonics, Inc.	Lucian Hand
American Academy of Dermatology	Ray Jalian
American College of Obstetricians & Gynecologists	Ira Horowitz
American Dental Association	Harvey Wigdor
American Glaucoma Society	Michael Berlin
American Industrial Hygiene Association	R. Timothy Hitchcock
American Society for Laser Medicine & Surgery	David Sliney
American Society of Safety Engineers	Patti Owens (Alt)
	Thomas V. Fleming
	Walter Nickens (Alt)
American Veterinary Medical Association	Kenneth Sullins
American Welding Society	Mark McLear
Association of periOperative Registered Nurses (AORN)	Evangeline Dennis
Association of Surgical Technologists	Kevin Frey
Buffalo Filter	Daniel Palmerton
Camden County College	Fred Seeber
Daniel Laser Safety	Paul Daniel, Jr.
Federal Aviation Administration (FAA)	Ricky Chitwood
Fort Hays State University	C.D. Clark III
Health Physics Society	Ken Barat
	Thomas Johnson (Alt)
High-Rez Diagnostics	Richard Hughes
Institute of Electrical and Electronics Engineers (SCC-39)	Ron Petersen
International Imaging Industry Association (I3A)	Joseph Greco
International Laser Display Association (ILDA)	Patrick Murphy
Kentek Corporation	William Arthur
KLA-Tencor	Karl Umstadter
L*A*I International	Thomas Lieb
Laser Institute of America	Gus Anibarro
Lawrence Berkeley National Laboratory	Greta Toncheva
Lawrence Livermore National Laboratory	Robert Ehrlich
Lightwave International	Roberta McHatton
Los Alamos National Laboratory	Connon Odom
National Aeronautics and Space Administration	Guy Camomilli
	Randall Scott (Alt)

<i>Organization Represented</i>	<i>Name of Representative</i>
National Institute of Standards and Technology (NIST)	Joshua Hadler
North American Association for Laser Therapy (NAALT)	Raymond Lanzafame
Power Technology, Inc.	William Burgess
Rockwell Laser Industries	William Ertle
SLAC National Accelerator Laboratory	Michael Woods
Solta Medical Inc.	George Frangineas
TASC, Inc.	Edward Early
Underwriters Laboratories, Inc.	Peter Boden
University of Chicago, School of Dentistry	Michael D. Colvard
University of Texas, Southwestern Medical Center	John Hoopman
U.S. Department of Health and Human Services, Center for Devices and Radiological Health	Richard Felten Robert James (Alt)
U.S. Department of Labor, Occupational Safety & Health Administration	Jeffrey Lodwick
U.S. Department of the Air Force, Air Force Research Laboratory	Benjamin Rockwell Robert Thomas (Alt)
U.S. Department of the Air Force, Surgeon General's Office	Edward Kelly Bret Rogers (Alt)
U.S. Department of the Army, Army Public Health Center (APHC)	Jeffrey Pfoutz Penelope Galoff (Alt)
U.S. Department of the Army, Army Institute of Surgical Research	Bruce Stuck
U.S. Department of the Navy, Naval Air Systems Command	James Sheehy
U.S. Department of the Navy, Naval Sea Systems Command	Sheldon Zimmerman Mary Zimmerman (Alt)

*Individual Members*

Robert Aldrich  
Richard Crowson  
Jerome Dennis  
David Dewey  
Ben Edwards  
Mark Festenstein  
Donald Haes  
Robert Handren, Jr.  
Ami Kestenbaum  
David J. Lund  
Martin Mainster  
Wesley Marshall  
J. Stuart Nelson

*Individual Members cont'd*

Jay Parkinson  
Randolph Paura  
William P. Roach  
Penny J. Smalley  
Nikolay Stoev  
Paul Testagrossa  
Thomas Tierney  
Antonio Triventi  
Anthony Zmorenski

*Emeritus Members*

Prem Batra  
Darrell Seeley  
James Smith  
Robert Weiner  
Myron Wolbarsht

The various subcommittees that participated in developing this standard had the following members:

*Safe Use of Lasers Outdoors, SSC-6*

Robert Aldrich, Chair	Darvis Cospers	Connon Odom
Penelope Galoff, Vice-Chair	Jerome Dennis	Jay Parkinson
Paul Sorensen, Secretary	Howard Donovan	Ron Petersen
	William Ertle	Jeffrey Pfoutz
	Mark Festenstein	Bret Rogers
	Donald Haes	Denny Rossbach
	Richard Hughes	Randall Scott
	Wesley Marshall	David Sliney
	Roberta McHatton	Paul Szajowski
	Leon McLin	Robert Thomas
	Wallace Mitchell	Mary Zimmerman
	Patrick Murphy	Sheldon Zimmerman
	John O'Hagan	Anthony Zmorenski

*Laser Bioeffects, TSC-1*

Bruce Stuck, Chair	Robert Aldrich	Wesley Marshall
David Sliney, Vice-Chair	Kenneth Bartels	Leon McLin
Jeffrey Pfoutz, Secretary	C.D. Clark III	John O'Hagan
	Patrick Clark	Jeffrey Oliver
	Michael D. Colvard	Jay Parkinson
	Francois Delori	Ron Petersen
	Jerome Dennis	Leslie Pollard
	William Ertle	William P. Roach
	Penelope Galoff	Benjamin Rockwell
	Jennifer Hunter	Noam Sapiens
	Saleh Jany	Karl Schulmeister
	Thomas Johnson	James Sheehy
	Robert Kang	Robert Thomas
	Edward Kelly	Stephen Till
	Paul Kennedy	Stephen Trokel
	Do-Hyun Kim	Myron Wolbarsht
	Yafu Lin	Hao F. Zhang
	Brian J. Lund	Mary Zimmerman
	David J. Lund	Sheldon Zimmerman
	Damien Luviano	Joseph Zuclich
	Martin Mainster	

*Hazard Evaluation & Classification, TSC-2*

Penelope Galoff, Chair	Robert Aldrich	Benjamin Rockwell
Karl Umstadter, Vice-Chair	Ahsan Chowdary	David Sliney
Jeffrey Pfoutz, Secretary	Jerome Dennis	Paul Szajowski
	Edward Early	Paul Testagrossa
	Robert Fairchild	Robert Thomas
	Wesley Marshall	Xiaowei Yan
	Randolph Paura	Sheldon Zimmerman
	Ron Petersen	

*Control Measures & Training, TSC-4*

William Ertle, Chair	Robert Aldrich	Connon Odom
Benjamin Rockwell, Vice-Chair	Gus Anibarro	Patti Owens
Michael Woods, Secretary	Ken Barat	Daniel Palmerton
	Prem Batra	Jay Parkinson
	David Bothner	Randolph Paura
	Richard Crowson	Ron Petersen
	Paul Daniel, Jr.	William P. Roach
	Jerome Dennis	Darrell Seeley
	Howard Donovan	James Sheehy
	Robert Fairchild	David Sliney
	Mark Festenstein	Penny J. Smalley
	Thomas V. Fleming	Casey Stack
	Penelope Galoff	Nikolay Stoev
	R. Timothy Hitchcock	Bruce Stuck
	John Hoopman	Paul Testagrossa
	Richard Hughes	Robert Thomas
	Stu Hutchinson	Stephen Trokel
	Bill Janssen	Karl Umstadter
	Kimberly Kantner	Robert Weiner
	Edward Kelly	Urban Widén
	Thomas Lieb	Wendy Woehr
	Wesley Marshall	Scott Wohlstein
	Roberta McHatton	Xiaowei Yan
	Mark McLear	Shefiu S. Zakariyah
	Robert Moore	Sheldon Zimmerman
	C. Eugene Moss	Anthony Zmorenski
	John O'Hagan	

*Non-Beam Hazards, TSC-5*

Ben Edwards, Chair  
Donald Haes, Vice-Chair

Ken Barat  
Ritchie Buschow  
Joseph Greco  
Matthew Harrison  
R. Timothy Hitchcock  
Richard Hughes  
Albert Moore  
Daniel Palmerton

William Pate  
Ron Petersen  
Penny J. Smalley  
Robert Thomas  
Carine Vanpeteghem  
Michael Woods  
Sheldon Zimmerman

*Analysis and Applications, TSC-7*

Wesley Marshall, Chair  
Robert Thomas, Vice-Chair

Robert Aldrich  
Gary Bower  
Hong Chen  
Wallace Mitchell  
Connon Odom  
Jay Parkinson  
Randolph Paura  
Ron Petersen

William P. Roach  
Benjamin Rockwell  
David Sliney  
Bruce Stuck  
Paul Szajowski  
Scott Wohlstein  
Sheldon Zimmerman

*Editorial Working Group, EWG*

Ron Petersen, Chair  
Thomas Johnson, Secretary  
Wesley Marshall, TSC-7 Liaison

Kevin Frey  
Penelope Galoff  
Richard Hughes  
Bill Janssen

Thomas Johnson  
Connon Odom  
Wendy Woehr

# CONTENTS

SECTION	PAGE
1. General.....	1
1.1 Scope.....	1
1.2 Intended Use of this Standard.....	2
1.3 Coordination.....	2
1.4 Laser Safety Officer (LSO).....	3
1.5 Applications.....	4
2. Definitions.....	4
3. Hazard Classification and Hazard Evaluation.....	18
3.1 General.....	18
3.2 Laser Hazard Classification.....	19
3.3 Hazard Evaluation.....	21
4. Control Measures Requirements.....	25
4.1 General.....	25
4.2 Controls for Laser Applications.....	26
4.3 General Product Performance Requirements.....	28
4.4 Control of Beams from Class 4 and Higher-Power Class 3B Lasers near the Ground.....	30
4.5 Control of Laser Beams in Airspace.....	32
4.6 Visual Interference.....	33
5. Laser Safety Program Management and Training Requirements.....	34
5.1 General.....	34
5.2 Safety Organization.....	34
5.3 Training.....	36
6. Requirements for Military Specific Lasers.....	36
6.1 General.....	36
6.2 Designated Service Laser Hazard Agency (DSLHA).....	36
6.3 FLPPS/Military (DoD) Exemption Requirements and Considerations.....	37
6.4 Manufacturer's Laser Control Measures.....	38
6.5 Laser Safety Training.....	42
7. Non-Beam Hazards.....	42
7.1 General.....	42
7.2 Electromagnetic Interference (EMI) and Electromagnetic Compatibility (EMC).....	42
7.3 Ergonomics and Human Factors.....	43
7.4 Software/Robotic Control.....	43
7.5 Fire Hazards.....	43
8. Criteria for Exposures of Eye and Skin.....	43
8.1 General.....	43

SECTION	PAGE
8.2 MPE for Ocular Exposures .....	44
8.3 Visual Interference.....	44
8.4 Repetitive Pulse Lasers.....	45
8.5 MPE for Skin Exposure.....	45
8.6 Flight Geometry.....	45
9. Revision of Standards Referred to in this Document.....	46
9.1 ANSI Standards.....	46
9.2 Other Standards and Codes.....	47

Tables

Table 1. Photopic Luminous Efficiency Function $V(\lambda)$ .....	49
Table 2a. Selected Point Source Ocular MPEs .....	50
Table 2b. MPE Correction Factors .....	51
Table 2c. Correction Factor, $C_Q$ , ( $MPE_{pulsed} / MPE_{cw}$ ) as a Function of Pulse Repetition Frequency (PRF) for Pulsed Lasers .....	52
Table 2d. Skin MPEs.....	53
Table 3. Limiting and Measurement Apertures.....	54
Table 4. Visual Interference Levels .....	55
Table 5. Power Required to Produce a Hazardous Diffuse Reflection as a Function of Beam Diameter, $D_L$ , and Viewing Distance, $r_1$ , from a Visible CW Laser Beam.....	56
Table 6. Energy Required to Produce a Hazardous Diffuse Reflection as a Function of Beam Diameter, $D_L$ , and Viewing Distance, $r_1$ , from a Pulsed Laser Beam in the Retinal Hazard Region .....	57
Table 7. Magnifying Optical Sight Categories (Minimum optical density, $D(\lambda)$ , for magnifying and non-magnifying optical sights) .....	58
Table 8. Typical Buffer Angle (half-angle) for a Laser Using an Alignment Device (optics or sights) .....	59
Table 9a. Control Measures for Lasers that are not Military Exempted .....	60
Table 9b. Control Measures for Military Exempted Lasers .....	61

Figures

Figure 1. Specular Reflection Created from a Flat Glass Surface .....	62
Figure 2. Specular Reflections.....	63
Figure 3a. Controlled Area on a Laser Range .....	64
Figure 3b. Buffer Zone for Aircraft-based Laser.....	65
Figure 3c. Buffer Zone for Ground-based Laser .....	65
Figure 4. Laser-free Zone Next to a Single Runway .....	66
Figure 5. Interference Zones around Multiple Runways .....	67
Figure 6. Profile of Flight Zones .....	68
Figure 7a. IEC Warning Label, Hazard Symbol and Explanatory Label .....	69
Figure 7b. Caution Label Used in ANSI Z136.1-2007 (grandfathered in this standard) .....	69
Figure 7c. Danger Label Used in ANSI Z136.1-2007 (grandfathered in this standard) .....	70
Figure 8a. Example of Temporary Laser Range Warning Sign .....	70

SECTION	PAGE
Figure 8b. Example of ANSI Z535.2-compliant Caution Sign for Class 2, Class 2M and Class 3R Lasers .....	71
Figure 8c. Example of ANSI Z535.2-compliant Warning Sign for Class 3B and Class 4 Lasers.....	71
Figure 8d. Example of ANSI Z535.2-compliant Class 4 Danger Sign Format .....	72
Figure 8e. ANSI Z535.2 Signal Words .....	72
Figure 8f. Example of Permanent Laser Range Warning Sign.....	72
 Appendix A	
Administration/Coordination Considerations .....	73
A1. General.....	73
A2. Applying for a FDA/CDRH Variance .....	73
A3. Laser Light Shows .....	73
A4. Safety SOPs .....	74
A5. Laser Clearinghouse Coordination .....	74
A6. Sample SOP and Correspondence .....	74
 Appendix B	
Examples of Calculations, Hazard Evaluation, and Control Measures Implementation.....	85
B1. General .....	85
B2. Symbols.....	85
B3. Formulas and Examples Useful in Evaluation of Various Laser Applications.....	87
B4. Examples of Specific System Hazard Evaluations .....	99
B5. Specific Control Measures Examples .....	119
B6. Sub-nanosecond Pulses .....	120
B7. References .....	121
Table B1. Units conversion table .....	108
Table B2. Protection distances for Example 30.....	109
Table B3. Laser output power.....	112
Figure B1. Expansion of a Laser Beam.....	122
Figure B2. Laser Beam Expansion when Laser Beam has an External Beam Waist.....	123
Figure B3. Specular Reflection of a Laser Beam .....	123
Figure B4. Factors that Affect the Divergence of a Reflected Laser Beam .....	124
Figure B5. Drawing of Possible Beams from Laser Light Show Near Airport .....	125
Figure B6. Drawing of Laser Beacon Near Airport (side view) .....	126
Figure B7. Drawing of Laser Beacon Near Airport (top view).....	126
Figure B8. Diffuse Reflection of Laser Beam.....	127
Figure B9. Rough Drawing of Local Airport .....	127
 Appendix C	
Atmospheric Effects.....	128
C1. Introduction .....	128
C2. Atmospheric Scattering and Absorption .....	128
C3. Atmospheric Scintillation.....	128
C4. Hazard Distance Considerations .....	129

SECTION	PAGE
C5. Scintillation .....	130
C6. Inclement Weather .....	130
C7. References .....	130
Table C1. Atmospherically Corrected Values of NOHD.....	131
Table C2. Reduction in NOHD as a Function of Atmospheric Attenuation Coefficient .....	132
Table C3. Total Atmospheric Transmission Depending on Visibility .....	133
Table C4. Attenuation Parameter According to Altitude.....	134

## Appendix D

Considerations for Outdoor Intentional Illumination with Visible Lasers .....	135
D1. Introduction.....	135
D2. Effects of Intense Light on Vision .....	135
D3. Summary of Laser Visual Effects .....	137
D4. Characterization of Power/Irradiance Levels Necessary to Achieve Desired Effects.....	141
D5. Conclusions.....	143
D6. Bibliography .....	143
Table D1. Laser Irradiance Levels for a Warning Effect at Night, Dawn/Dusk, and Day ...	142
Figure D1. Visual Function in Relation to the Normal Range of Light Intensities in the Human Eye .....	136
Figure D2. CIE Photopic Spectral Luminosity Curve for the Standard Observer.....	138
Figure D3. Simulated Nighttime and Daytime Aerial Scenes Used for Laser Warning Studies .....	139
Figure D4. Glare Angle of Obscuration from the Center of a Laser Source .....	139
Figure D5. Ratings of the Severity of Laser Glare on the Questionnaire for Different Irradiance Levels .....	140
Figure D6. Photographs on the Axis of the Laboratory Laser Beam at 160 m .....	141
Figure D7. Ocular Irradiance as a Function of Distance from the Laser Aperture for a 33 mW Laser with a 4 mrad Divergence.....	142
Figure D8. Ocular Irradiance as a Function of Distance from the Laser Aperture for a 100 mW Laser with a 4 mrad Divergence.....	143

## Appendix E

Outdoor Laser Safety Analysis Methodology.....	145
E1. Operational Volume and Protection Distances .....	145
E2. Local Airports and Flight Hazard Zones .....	145
E3. Air Traffic Patterns and Densities .....	145
E4. Relative Risk of Airspace.....	146
E5. Aircraft Considerations .....	146
E6. Defining Laser Operations .....	146
E7. Relative Risk of the Laser Operations.....	147
E8. Relative Risk of Laser Operations versus Air Space .....	147
E9. Preventive Methods .....	148
Figure E1. Relative Risk Based on Air Traffic Densities and Flight Hazard Zones.....	146
Figure E2. Relative Risk Based on Operations and Hazard Distances .....	147
Figure E3. Relative Risk Based on a Combination of Operations and Air Traffic .....	148
Figure E4. Reasonable Control Techniques .....	148

SECTION	PAGE
Appendix F	
Aircraft Detection Systems .....	149
F1. General.....	149
F2. Safety Observer .....	149
F3. Radar.....	150
F4. Solid-State Infrared Cameras.....	152
F5. References .....	152
Appendix G	
Training Requirements.....	154
G1. General.....	154
G2. Laser Safety Specialists .....	154
G3. LSMO LSO.....	155
G4. Site LSO.....	155
G5. Authorized Laser Operators.....	155
G6. Personnel in the Target Area of a Laser.....	155
G7. Safety Observers .....	156
Appendix H	
Visible and Invisible Laser Radiation — Problems in Laser Safety Terminology.....	158
H1. Introduction.....	158
H2. Background .....	158
H3. Class 2 ‘Visible’ Lasers .....	159
H4. The ‘Invisible’ Laser.....	160
H5. Recommended Practice.....	160
H6. Product Labeling .....	162
H7. Conclusions.....	162
H8. References.....	163
Figure H1. Photopic Luminous Sensitivity .....	159
Index .....	165