# Laser Safety
## IN THE LAB

# Laser Safety
## IN THE LAB

Ken Barat

SPIE PRESS
Bellingham, Washington USA

Library of Congress Cataloging-in-Publication Data

Barat, Kenneth.
Laser safety in the lab / Ken Barat.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-8194-8819-0 (alk. paper)
1. Lasers–Safety measures. 2. Laboratories–Safety measures. I. Title.
TA1677.B359 2013
621.36'60289–dc23

2011042692

Published by

SPIE
P.O. Box 10
Bellingham, Washington 98227-0010 USA
Phone: +1 360.676.3290
Fax: +1 360.647.1445
Email: Books@spie.org
Web: http://spie.org



Printed in the United States of America.

Second Printing

SPIE

*People read dedications by authors to their families—know what? It is all true. Grateful thanks to Pat, Emily, and Leah Barat.*

# Contents


**Preface** .......... **xiii**

**Chapter 1 Hazard Classification** .......... **1**

1.1 Introduction .......... 1
1.2 Hazard Classes .......... 2

**Chapter 2 Regulatory Landscape** .......... **5**

2.1 Introduction .......... 5
2.2 Manufacturer Rules .......... 6
2.2.1 FDA/Center for Devices and Radiological Health .......... 6
2.2.2 International Electrotechnical Commission .......... 7
2.3 User Regulations and Guidance .......... 7
2.3.1 Occupational and Safety Health Administration .......... 7
2.3.2 Federal Aviation Administration .......... 8
2.4 State Regulations .......... 9
2.4.1 List of U.S. states that have laser regulatory programs .......... 10
2.5 User Standards .......... 11
2.6 Export Controls .......... 13

**Chapter 3 The Laser Safety Officer** .......... **15**

3.1 Laser Safety Officer/Laser Safety Advisor .......... 15
3.2 LSO Duties .......... 15
3.2.1 Delegation of LSO responsibilities .......... 17

3.3 Laser Safety Committee ........ 17
3.4 Management Responsibility for Laser Safety ........ 18
3.5 Laser Safety Program ........ 18

**Chapter 4 Biological Effects ........ 21**
*Contributed by Robert J. Thomas.*

4.1 Introduction ........ 21
4.2 Exposure Type ........ 21
4.3 Exposures to the Eye ........ 22
4.3.1 Anatomy and optics of the human eye ........ 23
4.3.2 Aversion response ........ 25
4.3.3 Dazzle/startle effects ........ 26
4.3.4 Wavelength-dependent biological effects 26
4.4 Damage Mechanisms ........ 30
4.4.1 Photomechanical/Acoustic damage ........ 30
4.4.2 Photoablation ........ 30
4.4.3 Thermal damage ........ 31
4.4.4 Photochemical damage ........ 31
4.4.5 Effect of low-power visible beams ........ 31
4.4.6 Extended and point sources ........ 32
4.5 Laser-Radiation Effects on Skin ........ 33
4.5.1 Epidermis ........ 34
4.5.2 Dermis ........ 34
4.5.3 Subcutaneous tissue ........ 34
4.6 Skin Injury ........ 34
4.7 Nominal Hazard Zone ........ 35
4.8 Specular Reflection Nominal Ocular Hazard Distance ........ 35
4.9 The Effect of Optical Viewing Instruments ........ 36
4.9.1 Normal light ........ 36
4.9.2 Laser light ........ 36
Further Reading ........ 36

**Chapter 5 Hazard Evaluation by LSO or User Self-Assessment ........ 39**

5.1 Hazard Evaluation ........ 39
5.2 Designing a Laser Lab/Experimental Setup ........ 42

**Chapter 6 Laser Program Elements and Laser Controls .......... 43**

6.1 Laser Program Elements .......... 43
6.2 Engineering Controls .......... 43
6.3 Administrative Controls .......... 46
6.4 On-the-Job Training (OJT) .......... 49
6.5 Standard Operating Procedures (SOP) .......... 51
6.6 Beam Alignment Procedures .......... 52
6.7 Class 3B and Class 4 Indoor Laser-Controlled Area .......... 56
6.8 Guidance for Laser-Lab Visitors .......... 58
6.9 Laser Lessons-Learned Program .......... 59
6.10 Event Description .......... 60
6.10.1 Corrective actions .......... 60
6.11 Laser Disposal .......... 61
6.11.1 Laser-related waste .......... 61

**Chapter 7 Protective Eyewear .......... 63**

7.1 Introduction .......... 63
7.2 Eyewear Requirements .......... 64
7.3 Considerations in Choosing Laser-Protective Eyewear .......... 64
7.4 Comfort and Fit .......... 65
7.5 Optical Density .......... 65
7.6 Optical Density Time-Basis Criteria .......... 66
7.7 Visible Luminous Transmission (VLT) .......... 67
7.8 Identification of Eyewear .......... 69
7.9 Cleaning and Inspection .......... 69
7.10 Ultrafast Lasers .......... 70
7.11 Alignment Eyewear .......... 70
7.11.1 Factors in selecting alignment eyewear .......... 71
7.12 Eyewear Use with High-Power Lasers (High-Power, Multikilowatt Laser Beams) .......... 71
7.13 Other Factors .......... 72

**Chapter 8 Special Lasers and Applications** ........ **75**

8.1 Fiber Optic Safety ........ 75
8.1.1 Diodes ........ 78
8.2 Laser-Scanning Confocal Microscope ........ 80
8.3 Outdoor Laser Safety ........ 81
8.3.1 Outdoor control measures ........ 81
8.4 Laser Pointers and Handheld Lasers ........ 82
8.4.1 User beware: examples ........ 83
8.4.2 Traditional types of laser pointers ........ 84
8.4.3 New generation of handheld laser ........ 85
References ........ 86

**Chapter 9 Nonbeam Hazards** ........ **87**

**Chapter 10 Life in the Laser Lab: Rules for Working in the Laser Lab** ........ **91**

10.1 Prior to Starting Work ........ 91
10.2 Work Like a Laser Guru ........ 92
10.3 Indirect Laser Beam Viewing Tools ........ 93
10.3.1 Laminated IR-viewing cards ........ 93
10.3.2 IR viewers ........ 95
10.3.3 CCD/webcam ........ 96
10.3.4 Beam blocks ........ 96
10.3.5 Unsecured beam blocks ........ 97
10.3.6 Plastic laser enclosures ........ 98
10.3.7 Solid plastic barriers ........ 99
10.3.8 Metal laser enclosures ........ 99
10.3.9 Laser curtains ........ 101
10.4 Optics on Your Table ........ 101
10.4.1 Check for movement ........ 102
10.4.2 Secure optics ........ 102
10.4.3 Keep optics clean ........ 102
10.4.4 Transporting the beam a “long distance”. 103
10.4.5 Dropping and picking up items from the floor ........ 103
10.4.6 Optical mounts ........ 103

10.5 Know Your Optics ..... 103
10.5.1 Cleaning optics ..... 105

**Chapter 11 Laser Accidents ..... 107**

11.1 Introduction ..... 107
11.2 Suspected Laser Injury ..... 108
11.3 A Few Case Histories ..... 109
11.4 The Perceived Incident ..... 110

**Chapter 12 Building a Laser Safety Culture ..... 111**

12.1 Introduction ..... 111
12.2 Management Tone ..... 111
12.3 Institutional Training ..... 112
12.3.1 Lessons-learned class ..... 113
12.3.2 On-the-job training (mentoring) ..... 113
12.3.3 Administrative controls ..... 114
12.3.4 Institutional assurance ..... 114
12.3.5 User actions (step back, housekeeping) ..... 115

**Chapter 13 Lay of the Lab: Hints for Designing Your Laser Lab ..... 117**

13.1 Checklist ..... 117
13.2 Further Examples ..... 119

**Appendix A Laser Basics Abridged ..... 129**

A.1 Laser Light Characteristics ..... 129
A.2 Common Laser Components ..... 130
A.3 Modes of Operation ..... 131

**Appendix B Laser Calculation Hints ..... 133**
*Contributed by Robert J. Thomas.*

B.1 Useful Approximations ..... 133
B.2 Important Conventions ..... 134
B.2.1 Repetitively pulsed lasers (RPLs) ..... 135

B.2.2 Extended-source viewing .............................. 136
B.2.3 Diffuse reflections .............................. 137
B.2.4 Nominal hazard zones .............................. 137
B.2.5 Protective eyewear .............................. 138
References (further reading) .............................. 138

**Appendix C Laser Safety Illustrations .............................. 141**

**Appendix D Glossary .............................. 155**

**Index .............................. 167**

# Preface

In 1960 T. Maiman demonstrated the first laser (ruby rod). I am uncertain if he knew what an impact it would have on society and the research community. A technology once commonly said to be looking for an application has now found a place in all sectors of modern society. In particular, the laser has made a dramatic impact on scientific research.

Within a few years of the development of that first laser, the first reported eye injury by laser occurred. Even before then, it was clear to many that this new technology presented unique hazards, and product and user guidance was needed.

In 1973 the first American National Standard Institute *Standard for the Safe Use of Lasers* was published (ANSI Z136.1). From that year forward, attempts to develop laser safety procedures and devices have been in progress.

In addition to laying a foundation for laser safety, the goal of this text is to give the laser user a useful reference source for laser safety solutions in the research and development environment.

Special thanks to Dr. Robert Thomas, who kindly contributed Chapter 4: Biological Effects and Appendix B: Laser Calculation Hints. Robert is a physicist with the U.S. Army Research Lab., a well-known instructor for the Health Physics Society Professional Enrichment Program courses, the webmaster for Z136.org, and a fine gentleman.

I would be remiss if I did not thank the people at SPIE who have given me this opportunity—John Cain, Jane Lindelof, and Tim Lamkins.

Sincere thanks to all I have encountered in my laser safety career—I feel each has enriched me.

There is no more-challenging setting for laser use than a research environment. In almost every other setting the laser controls count on engineering controls, and human exposure is kept to a minimum, whereas in research the user often manipulates the optical layout and thereby places him or herself in peril. But this does not mean that accidents and injury are unavoidable. On the contrary, laser accidents can be avoided by following a number of simple approaches.

A laser user may ask "Why do lasers receive such special attention?" The chief reason is the optical gain of the eye for wavelengths of 400–1400 nm. The average spot size of an image focused onto a retina is 250 μm, while the retinal spot size for a laser beam between 400–1400 nm focused by the lens onto the retina is 20 μm; therefore, 1 mW is equal to 100 $W/cm^2$ at the retina. A 1-W beam directed onto the retina is equal to 1,000,000 $W/cm^2$, which is why even a 2–4% reflection from an optical component could be over the threshold and cause eye injury. This threshold is called the maximum permissible exposure (MPE).

If you are not familiar with terms such as continuous wave and pulsed laser, or with the basic properties of a laser, refer to Appendix A before going on with this text. Another option is to read SPIE's *Field Guide to Lasers*, which gives an excellent explanation of laser properties.

*Ken Barat*
*Berkeley, California*
*October 2012*