

Contents

Part I: Introductory Material

1	Introduction — 3
1.1	Accidents in the research laboratory — 3
1.1.1	Vladimir Likhonos: eating explosives — 3
1.1.2	Karen Wetterhahn: a deadly droplet — 4
1.1.3	Michele Dufault: hair is a hazard — 4
1.1.4	Louis Slotin: A slipped screwdriver — 6
1.1.5	Preston Brown: Ignoring safety protocols — 7
1.1.6	Sheri Sangji: a spontaneous fire — 9
1.2	Factors contributing to laboratory accidents — 9
1.2.1	Reason's Swiss cheese model — 9
1.2.2	Accident "causes" — 11
1.2.3	Unsafe conditions versus unsafe behavior — 11
1.3	Hazards in the laboratory — 13
1.3.1	Types of hazards — 13
1.3.2	Main risks in laboratories — 14
2	Ethical responsibilities — 15
2.1	Who requires protection? — 15
2.2	Ethical responsibility to others in the lab — 16
2.3	Penalties for ethical violations — 18
3	Assessing and controlling risk — 20
3.1	Distinguishing hazard from risk — 20
3.2	Simple methods for estimating risk — 20
3.3	A semiquantitative method for risk estimation in the laboratory — 22
3.4	Risk assessment exercises — 25
4	Hazard and risk controls — 26
4.1	The hazard control process — 26
4.1.1	Hazard identification — 26
4.1.2	Risk screening — 27
4.1.3	Hazard analysis — 28
4.1.4	Hazard control — 28
4.2	Classifying hazard controls — 29
4.2.1	Functional classification of hazard controls — 29
4.2.2	Traditional hierarchy of controls — 30

- 4.2.3 Creativity in hazard control — **31**
- 4.3 Exercises: Hazard control — **31**

Part II: Hazard classes and control methods

- 5 Hazard identification methods — **35**
 - 5.1 Brainstorming, mind-mapping, and other creative methods — **35**
 - 5.2 Checklists — **36**
 - 5.3 Reference books — **36**
 - 5.4 Regulations and standards — **37**
 - 5.5 Real-life hazard identification — **38**
 - 5.6 Exercises: Hazard identification — **39**
- 6 Physical hazards — **40**
 - 6.1 Mechanical hazards — **40**
 - 6.1.1 Pinch points — **40**
 - 6.1.2 Guards and interlocks for mechanical hazards — **40**
 - 6.1.3 Shear points — **42**
 - 6.1.4 Run-in points — **43**
 - 6.1.5 Wrap points — **45**
 - 6.1.6 Clobbering — **47**
 - 6.2 Sharps — **48**
 - 6.2.1 What is a sharp? — **49**
 - 6.2.2 Sharps handling — **49**
 - 6.2.3 Sharps disposal — **50**
 - 6.3 Heat — **52**
 - 6.3.1 Common laboratory sources of heat — **52**
 - 6.3.2 Heat-protective apparel — **53**
 - 6.3.3 Using torches, burners, and other open flames in the lab — **54**
 - 6.4 Cold (including cryogen safety) — **55**
 - 6.4.1 Common laboratory sources of low temperatures — **56**
 - 6.4.2 Safe procedures for maintenance of refrigerators and freezers — **56**
 - 6.4.3 Cryogenic temperatures — **57**
 - 6.5 Pressure and vacuum — **63**
 - 6.5.1 Compressed gases — **63**
 - 6.6 Electricity and magnetism — **73**
 - 6.6.1 Electricity — **74**
 - 6.6.2 Magnetism — **78**
 - 6.7 General environmental hazards — **80**
 - 6.7.1 Trips, slips, and-falls — **80**

6.7.2	Lighting — 81
6.7.3	Noise — 81
6.7.4	Security hazards — 81
6.8	Case study: Chemistry experiment — 82
6.9	Exercises: Physical hazards — 84
7	Chemical hazards — 86
7.1	Routes of exposure to chemical hazards — 86
7.2	Chemical properties contributing to hazard — 86
7.2.1	Reactivity — 86
7.2.2	Volatility — 87
7.3	The chemical fume hood — 87
7.4	General hazard classifications and precautions — 90
7.4.1	Experimental protocols for chemical handling — 90
7.4.2	Flammables and oxidizers — 91
7.4.3	Corrosives — 100
7.4.4	Toxics — 104
7.4.5	Physical hazards from chemicals — 110
7.4.6	Reactive chemicals — 110
7.5	Communicating chemical hazards — 113
7.5.1	NFPA 704 “fire diamond” — 113
7.5.2	Transportation labeling — 114
7.5.3	The Globally Harmonized System — 115
7.5.4	The Safety Data Sheet — 116
7.6	Case studies — 118
7.6.1	Chemistry experiment — 118
7.6.2	Biology experiment — 121
7.7	Exercises: Chemical hazards — 124
8	Biological hazards — 125
8.1	Lab-acquired infections — 125
8.2	Assessment of biological infection risk — 126
8.2.1	Agent hazards — 126
8.2.2	Laboratory procedure hazards — 128
8.3	Biosafety levels — 129
8.3.1	Biosafety level 1 (BSL–1) — 129
8.3.2	Biosafety level 2 (BSL–2) — 130
8.3.3	Biosafety level 3 (BSL–3) — 130
8.3.4	Biosafety level 4 (BSL–4) — 132
8.4	Biological laboratory work practices — 134
8.4.1	General laboratory practices — 134
8.4.2	Personal protection — 135

8.4.3	Pipetting, syringing, and other sample-transfer methods —	135
8.4.4	Equipment use —	136
8.4.5	Storage, inventory, and labeling —	136
8.5	The biological safety cabinet —	137
8.5.1	A BSC is not a chemical fume hood —	139
8.5.2	The “laminar flow hood” or “clean air hood” is not a BSC —	139
8.5.3	Using a BSC —	141
8.6	Case studies —	143
8.6.1	Biology experiment —	143
8.6.2	Civil/environmental engineering experiment —	145
8.7	Exercises: biological hazards —	146
9	Radiation hazards —	148
9.1	Ionizing radiation —	148
9.1.1	Types of ionizing radiation —	148
9.1.2	Sources of hazard from ionizing radiation —	148
9.1.3	Control of ionizing radiation —	151
9.2	Non-ionizing radiation —	153
9.2.1	Ultraviolet radiation —	153
9.2.2	Infrared radiation —	154
9.2.3	Radiofrequency (RF) radiation —	155
9.2.4	Laser light sources —	156
9.3	Case studies —	162
9.3.1	Chemical engineering experiment —	162
9.3.2	Medical experiment —	164
9.3.3	Exercises: radiation hazards —	166

Part III: Hazard analysis techniques

10	The Checklist technique —	171
10.1	Strengths, weaknesses, and suitability —	171
10.2	Sources of checklists —	171
10.3	Example checklist: Quick laboratory inspection —	172
10.4	Evaluating recommendations from hazard analyses —	175
10.5	Exercises: laboratory inspection —	175
11	The Job Hazard Analysis technique (JHA) —	176
11.1	Strengths, weaknesses, and suitability —	176
11.2	Technique —	176
11.3	Example JHA —	178
11.4	Exercises: Job Hazard Analysis —	178

12	The What-If? technique — 180
12.1	Strengths and weaknesses — 180
12.2	Suitability — 180
12.3	What-If? Technique — 181
12.3.1	Scoping — 181
12.3.2	Team assembly — 183
12.3.3	What-If? — 183
12.3.4	Causes — 185
12.3.5	Consequences — 185
12.3.6	Controls — 186
12.3.7	Current risk — 186
12.3.8	Recommendations — 187
12.3.9	Revised risk — 188
12.4	Example What-If? Study: Multi-axis press — 188
12.4.1	Nodes — 191
12.4.2	Team assembly — 191
12.4.3	What-if #1: What if a hydraulic actuator fails? — 191
12.4.4	What-if #2: What if a hydraulic line fails? — 192
12.4.5	What-if #3: What if the hydraulic pump develops a leak? — 193
12.5	Exercise: What-if? technique — 195

Part IV: Practical applications of hazard control

13	Controlling hazards in a laboratory procedure using JHA — 199
13.1	Reproducing a procedure from the literature — 199
13.2	Exercises: Using procedures taken from a research paper — 201
14	Evaluating risks in an experimental apparatus using What-If? technique — 202
14.1	Case study: What-If? technique — 202
14.2	What-If? technique study on an experimental apparatus — 206
15	Designing an experiment from scratch — 207
15.1	Hazard controls are <i>ex post facto</i> solutions — 207
15.2	The only set factor in an experiment is the objective — 207
15.3	Inherently safer design principles — 208
15.3.1	The history of ISD — 208
15.3.2	ISD design principles — 209
15.4	Case studies in laboratory ISD — 210
15.4.1	Lab ISD case study: Impact testing of steel — 210

- 15.4.2 Lab ISD case study: The “Rainbow Experiment” — **211**
- 15.5 Exercise: Inherently safer design of a hazardous experiment — **212**

Part V: Appendices

- 16 Laboratory safety checklists (abbreviated) — **215**
- 17 Checklist reviews for common laboratory operations — **223**
 - 17.1 Delivering gas from a compressed gas cylinder — **223**
 - 17.2 Flame-sealing a glass tube with an oxyacetylene torch — **226**
 - 17.3 Using a biological safety cabinet — **228**
- 18 Writing experimental protocols and Standard Operating Procedures — **230**
 - 18.1 Types of “SOP” — **230**
 - 18.2 General advice on writing protocols — **230**
 - 18.3 Writing protocols for hazardous materials handling — **232**
 - 18.4 Writing protocols for experimental procedures — **239**
 - 18.5 Writing protocols for use of hazardous equipment — **242**
- 19 Annotated bibliography of laboratory safety references — **247**

References — 250

Index — 257