

Contents

Contributors List	V
Preface to the Third Edition	IX
How to use this book	XI
Structure	XI
References	XI
Illustrations and tables	XII
I Fundamentals	1
1 Introduction	3
1.1 Historical Review	3
1.2 The Present Situation	4
2 The Market Situation	8
2.1 Plastics	8
2.2 Flame Retardants	13
2.2.1 Flame Retardants Market in the United States of America	14
2.2.2 Flame Retardants Market in Western Europe	17
2.2.3 Flame Retardants Market in Japan	21
2.3 Overview of the Flame Retardants Industry	24
2.3.1 Flame Retardants Industry in the United States of America	24
2.3.2 Flame Retardants Industry in Western Europe	27
2.3.3 Flame Retardants Industry in Japan	29
3 The Burning Process and Enclosure Fires	33
3.1 Introduction	33
3.2 General Description of the Process of Combustion	34
3.2.1 A Burning Candle	34
3.2.2 Other Solid Fuels	35
3.3 General Description of Fire Growth in an Enclosure	36
3.4 Factors Influencing the Fire Development in an Enclosure	38
3.5 Engineering Models for Enclosure Fires	41
3.5.1 Energy Evolved and Species Generated	44
3.5.2 Fire-Induced Environment	44
3.5.3 Heat Transfer	45
3.6 Summary	45
4 The Burning of Plastics	47
4.1 The Combustion Process	47
4.1.1 Heating	47
4.1.2 Decomposition	48

4.1.3	Ignition and Smoldering	52
4.1.4	Flame Spread	54
4.1.5	Heat Release Rate	56
4.2	Thermal Properties and Burning Behavior of the Most Important Plastics ..	58
4.2.1	Thermal Properties of Thermoplastics	58
4.2.1.1	Scope	59
4.2.1.2	Techniques to Study the Thermal Degradation of Thermoplastics	60
4.2.1.3	Thermal Degradation Pathways	61
4.2.1.4	Concluding Comments	73
4.2.2	Thermal Properties of Foam Plastics	76
4.2.2.1	PS Foam	77
4.2.2.2	PVC Foams	78
4.2.2.3	Polyurethane Foams	78
4.2.2.4	Phenolic Foams	82
4.2.2.5	Urea Foams	83
4.2.3	Thermal Degradation of Thermosetting Polymers	83
4.2.3.1	Phenolic Resins	83
4.2.3.2	Unsaturated Polyesters	86
4.2.3.3	Epoxy Resins	87
4.2.3.4	Amino Resins	90
4.2.3.5	Curable Polyimides	92
4.2.4	High Temperature Resistant Plastics	99
4.2.4.1	Organic Polymers	99
4.2.4.2	Inorganic Polymers	105
4.2.5	Geopolymers	107
4.2.6	Thermal Properties of Elastomers	111
4.2.6.1	Introduction	111
4.2.6.2	Vulcanizable Elastomers	111
4.2.6.3	Thermoplastic Elastomers (TPEs)	126
4.2.6.4	Outlook	130
5	Flame Retardant Plastics	133
5.1	Flame Retardants	133
5.1.1	Mode of Action	133
5.1.1.1	Physical Action	133
5.1.1.2	Chemical Action	134
5.1.2	The Most Important Flame Retardants and Their Mode of Action ..	134
5.1.2.1	Flame Retardants Acting Through Gas Phase Mechanism	134
5.1.2.2	Flame Retardant Polymer Interaction in the Condensed Phase	136
5.1.2.3	Intumescence Flame Retardants and Char Formation ...	139
5.1.2.4	Flame Retardants Acting Through Physical Effects ...	145
5.1.2.5	Phosphorus-Containing Flame Retardants	148
5.1.2.6	Flame Retardants Acting Through Combined Mechanism	148
5.1.3	Outlook	152
5.2	The Most Important Flame Retardant Plastics	158
5.2.1	Plastics with All-Carbon Backbones	162
5.2.1.1	Polyolefins	162
5.2.1.2	Poly(vinyl chloride)	163

	5.2.1.3	Polystyrene and Styrene Copolymers	164
	5.2.2	Plastics with a Heterogeneous Backbone	165
	5.2.2.1	Polyurethane Foam	165
	5.2.2.2	Thermosetting Resins	167
	5.2.2.3	Engineering Plastics	168
	5.2.2.4	Inherently Flame Retardant Polymers	170
6		Textiles	173
	6.1	Burning Behavior of Textiles	174
	6.1.1	Burning Behavior of Fibers	174
	6.1.2	Effect of Fabric and Yarn Structures	175
	6.1.3	Particularly Hazardous Textiles	177
	6.2	Flammability Testing of Textiles	178
	6.3	Flame Retardant Textiles	182
	6.3.1	Cellulosics	183
	6.3.1.1	Flame Retardant Cottons	184
	6.3.1.2	Flame Retardant Viscose	184
	6.3.1.3	Flame Retardant Wool and Blends	185
	6.3.1.4	Flame Retardant Synthetic Fibers	185
	6.4	High Heat and Flame Resistant Synthetic Fibers and Textiles	186
	6.5	Intumescent Application to Textiles	186
7		Smoke Development and Suppression	189
	7.1	Constitution of Smoke	190
	7.1.1	Definition of Smoke	190
	7.1.2	Origin of Smoke from Polymers in Fire	190
	7.1.3	Smoke Production	192
	7.2	Smoke Production from the Most Important Polymers	195
	7.3	Smoke Suppressants	197
	7.4	Smoke Suppressants in Plastics	198
	7.4.1	Smoke Suppressants in PVC	198
	7.4.2	Smoke Suppressants in Styrene Polymers	200
	7.4.3	Smoke Suppressants in Unsaturated Polyester Resins	201
	7.4.4	Smoke Suppressants in Polyurethane Foams	201
	7.4.5	Miscellaneous	202
II		National and International Fire Protection Regulations and Test Procedures	207
8		Methodology of Fire Testing	209
	8.1	Fire Safety Objectives	209
	8.2	Fire Scenarios	210
	8.3	Historical Development of Fire Testing	213
	8.4	Terminology	214
	8.5	Test Methods	215
	8.5.1	Design Requirements	215
	8.5.2	Laboratory-Scale Tests	217
	8.5.3	Large-/Full-/Real-Scale Tests	218
	8.5.4	Correlation of Test Methods	219
9		Regulations and Testing	222
	9.1	Sets of Regulations	222
	9.2	Overview of the Subject	224
	9.3	Test Methods	225

10 Building	227
10.1 Introduction	227
10.1.1 Statutory Regulations	228
10.1.2 Classification and Testing of the Fire Performance of Building Materials and Components	228
10.1.3 Official Approval	230
10.1.4 Present Situation and Future Developments	230
10.2 United States of America	231
10.2.1 Statutory Regulations	231
10.2.2 New Developments in Statutory Regulations	232
10.2.2.1 International Building Code (IBC)	232
10.2.2.2 International Residential Code (IRC)	232
10.2.3 Classification and Fire Testing of Building Materials and Components	233
10.2.3.1 Test Methods Referenced in US Building Codes	233
10.2.3.2 Additional Fire Test Standards	235
10.2.3.3 ASTM D 1929-96 Determining Ignition Temperature of Plastics	236
10.2.3.4 NFPA 268 (1996) Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source	237
10.2.3.5 NFPA 259 (1998) Potential Heat of Building Materials	238
10.2.3.6 ASTM D 2843-99 Density of Smoke from the Burning or Decomposition of Plastics	238
10.2.3.7 ASTM E 84-00a Surface Burning Characteristics of Building Materials	239
10.2.3.8 ASTM E 970-98 Critical Radiant Flux of Exposed Attic Floor Insulation Using a Radiant Heat Energy Source	241
10.2.3.9 ASTM E 119-00 Fire Tests of Building Construction and Materials	242
10.2.3.10 FM-4880 (1994) Building Corner Fire Test Procedure ..	243
10.2.3.11 NFPA 285 (1998) Flammability Characteristics of Exterior Wall Using the Intermediate-Scale, Multistory Test Apparatus	245
10.2.3.12 ASTM E 108-00 Fire Tests of Roof Coverings	246
10.2.3.13 FM 4450 (1989) Approval Standard for Class I Insulated Steel Roof Decks	247
10.2.3.14 UL 1256 (2000) Fire Test of Roof Deck Constructions	248
10.2.3.15 ANSI/DASMA 107-1997 Room Fire Test Standard for Garage Doors Using Foam Plastic Insulation	249
10.2.3.16 NFPA 252 (1999) Fire Tests of Door Assemblies	250
10.2.3.17 ASTM D 2859-96 [Carpet and Rug, 16 CFR, Part 1630.4, 1631.4] Ignition Characteristics of Finished Textile Floor Covering Materials	251
10.2.3.18 ASTM E 648-99 Critical Radiant Flux of Floor Covering Systems Using a Radiant Heat Energy Source	251
10.2.3.19 NFPA 265 (1995) Fire Tests for Evaluation of Room Fire Growth Contribution of Textile Wall Coverings ...	252

	10.2.3.20	NFPA 701 (1999) Fire Tests for Flame Resistant Textiles and Films	253
	10.2.3.21	ASTM D 635-98 Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position ...	254
	10.2.3.22	UL 1975 (1996) Fire Tests for Foamed Plastics Used for Decorative Purposes	255
	10.2.4	Official Approval	256
	10.2.5	Future Developments	256
	10.2.5.1	NFPA 5000 Building Code	256
	10.2.5.2	Performance-Based Building Codes	257
10.3	Canada	.....	258
	10.3.1	Statutory Regulations	258
	10.3.2	Classification and Testing of the Fire Performance of Building Materials and Components	258
	10.3.2.1	CAN4-S114. Determination of the Noncombustibility of Building Materials	259
	10.3.2.2	CAN/ULC-S102. Test for Surface Burning Characteristics of Building Materials	260
	10.3.2.3	CAN/ULC-S102.2. Test for Surface Burning Characteristics of Floor Coverings and Miscellaneous Materials	260
	10.3.2.4	ULC-S102.3. Fire Test for Light Diffusers and Lenses ..	261
	10.3.2.5	ULC-S127. Corner Wall Test for Flammability Characteristics of Nonmelting Building Materials	261
	10.3.2.6	NBC Requirements for Interior Finish Materials	262
	10.3.2.7	ULC- S109. Flame Tests of Flame Resistant Fabrics and Films	263
	10.3.3	Official Approval	265
	10.3.4	Future Developments	265
10.4	European Union	.....	266
	10.4.1	The Construction Products Directive	266
	10.4.2	The Role of Regulators, Notified Bodies, and Standardization Bodies	267
	10.4.3	The Euroclasses	267
	10.4.4	Definitions	270
	10.4.5	Classification and Fire Testing of Building Products	271
	10.4.5.1	EN 13501 Fire Classification and EN 13238 Standard Substrates	271
	10.4.5.2	EN ISO 1716 Calorific Potential	271
	10.4.5.3	EN ISO 1182 Noncombustibility Test	271
	10.4.5.4	ISO 9705 Room/Corner Test	272
	10.4.5.5	EN 13823 Single Burning Item (SBI) Test	274
	10.4.5.6	EN ISO 11925-2 Small-Flame Test	276
	10.4.5.7	EN ISO 9239-1 Floor Covering Test	276
	10.4.6	Future Developments	277
10.5	Austria	.....	278
	10.5.1	Statutory Regulations	278
	10.5.2	Classification and Testing of the Fire Performance of Building Materials and Components	279
	10.5.2.1	Noncombustibility Test to ÖNORM B 3800 Part 1	280
	10.5.2.2	Combustibility Class B1: Low Combustibility According to the Schlyter Test	281

	10.5.2.3	Combustibility Class B2: Moderately Combustible According to the Small Burner Test	281
	10.5.2.4	Combustibility Class B3: Highly Combustible	282
	10.5.2.5	ÖNORM B 3810. Fire Behavior of Floor Coverings ...	284
	10.5.3	Official Approval	285
	10.5.4	Future Developments	286
10.6	Belgium	.....	286
	10.6.1	Statutory Regulations	286
	10.6.1.1	Overview of Authorities	286
	10.6.1.2	The Federal Level	287
	10.6.1.3	Regions and Communities	288
	10.6.1.4	Provinces and Communes	289
	10.6.1.5	Belgian Standards	289
	10.6.2	Classification and Testing of the Fire Performance of Building Materials and Components	289
	10.6.3	Official Approval	290
	10.6.4	Future Developments	291
10.7	Czech Republic	.....	292
	10.7.1	Statutory Regulations	292
	10.7.2	Classification and Testing of the Fire Performance of Building Materials and Components	292
	10.7.2.1	CSN 73 0861. Noncombustibility Test for Building Materials	293
	10.7.2.2	CSN 73 0862. Determination of Flammability of Building Materials	293
	10.7.3	Official Approval	295
	10.7.4	Future Developments	296
10.8	France	.....	297
	10.8.1	Statutory Regulations	297
	10.8.2	Classification and Testing of the Fire Performance of Building Materials and Components	297
	10.8.2.1	NF P 92-501. Epiradiateur Test	298
	10.8.2.2	NF P 92-503. Electrical Burner Test	299
	10.8.2.3	NF P 92-504. Rate of Spread of Flame Test	300
	10.8.2.4	NF P 92-505. Dripping Test	301
	10.8.2.5	NF P 92-506. Radiant Panel Test for Floor Coverings ..	302
	10.8.2.6	NF P 92-510. Determination of Calorific Potential	303
	10.8.3	Classification of Building Materials	304
	10.8.4	The Use of Synthetic Materials	306
	10.8.5	Official Approval	306
	10.8.6	Future Developments	308
10.9	Germany	.....	309
	10.9.1	Statutory Regulations	309
	10.9.2	Classification and Testing of the Fire Performance of Building Materials and Components	310
	10.9.2.1	DIN 4102-1 Building Materials	311
	10.9.3	Official Approval	318
	10.9.4	Future Developments	323
10.10	Hungary	.....	324
	10.10.1	Statutory Regulations	324
	10.10.2	Classification and Testing of the Fire Performance of Building Materials and Components	325

	10.10.2.1	MSZ 14800-2:1994 Noncombustibility Test	325
	10.10.2.2	MSZ 14800-3:1982 and MSZ 14800-4:1984. Testing Building Materials for “Low Combustibility” and “Moderate Combustibility”	325
	10.10.2.3	MSZ 14800-6:1980. Fire Propagation Test for Facades	326
	10.10.2.4	MSZ 14800-8:1994. Test for Burning Dripping of Plastic Building Materials	328
	10.10.3	Official Approval	328
	10.10.4	Future Developments	329
10.11		Italy	330
	10.11.1	Statutory Regulations	330
	10.11.2	Classification and Testing of the Fire Performance of Building Materials and Components	330
	10.11.2.1	UNI ISO 1182 Noncombustibility Test	331
	10.11.2.2	UNI 8456 Small Burner Test (Edge Application of Flame)	331
	10.11.2.3	UNI 8457 Small Burner Test (Surface Application of Flame)	332
	10.11.2.4	UNI 9174 Spread of Flame Test	333
	10.11.3	Classification of Building Materials	335
	10.11.3.1	UNI 9175 Fire Reaction of Upholstered Furniture Under Small-Flame Action	336
	10.11.3.2	Specimen Preparation Before Testing	337
	10.11.4	Official Approval	338
	10.11.5	Future Developments	339
10.12		The Netherlands	339
	10.12.1	Statutory Regulations	339
	10.12.2	Classification and Testing of the Fire Performance of Building Products and Components	340
	10.12.2.1	Test Methods for Reaction to Fire	340
	10.12.2.2	Other Important Fire-Related Test Methods	342
	10.12.2.3	Classification	342
	10.12.2.4	Requirements	343
	10.12.3	Official Approval	344
	10.12.4	Future Developments	344
10.13		Nordic Countries	345
	10.13.1	Statutory Regulations	345
	10.13.2	Nordtest Methods	345
	10.13.2.1	NT Fire 001 Noncombustibility Test	346
	10.13.2.2	NT Fire 002 Ignitability Test	346
	10.13.2.3	NT Fire 004 Heat Release and Smoke Generation Test	347
	10.13.2.4	NT Fire 006 Test for Roofings: Fire Spread	349
	10.13.2.5	NT fire 007 Test for Floorings: Fire Spread and Smoke Generation	350
	10.13.2.6	NT Fire 025/ISO 9705:1993 Fire tests – Full Scale Room Tests for Surface Products	351
	10.13.2.7	NT Fire 033/ISO 5657:1997 Fire Tests – Reaction to Fire – Ignitability of Building Products	351
	10.13.2.8	NT Fire 036 Pipe Insulation: Fire Spread and Smoke Production – Full-Scale Test	351

10.13.3	Equivalents of the Nordtest Methods in the Individual Nordic Countries	352
10.13.4	Classification of Building Products	352
10.13.4.1	Linings	353
10.13.4.2	Roof Coverings	355
10.13.4.3	Floor Coverings	355
10.13.4.4	Pipe Insulation	356
10.13.4.5	Fabrics Used for Tents	356
10.13.4.6	Tests in Conjunction with Production Control	357
10.13.4.7	Modeling Fire Growth	357
10.13.5	Official Approval	357
10.13.5.1	Denmark	358
10.13.5.2	Finland	359
10.13.5.3	Iceland	359
10.13.5.4	Norway	359
10.13.5.5	Sweden	359
10.13.6	Future Developments	360
10.14	Poland	360
10.14.1	Statutory Regulations	360
10.14.2	Classification and Testing of the Fire Performance of Building Materials and Components	363
10.14.2.1	Noncombustibility of Building Products to PN-B-02862	363
10.14.2.2	Gross Calorific Value by Oxygen Bomb Calorimeter to ISO 1716	363
10.14.2.3	Fire Performance of Building Materials to PN-B-02874	363
10.14.2.4	Flame Propagation of Floorings to PN-B-02854	364
10.14.2.5	Testing of Fire Spread Rate of Building Elements	365
10.14.2.6	Evaluation of Toxicity to PN-88/B-02855	366
10.14.2.7	Smoke Density Testing to PN-89/B-02856	366
10.14.3	Official Approval	367
10.14.4	Future Developments	367
10.15	Spain	368
10.15.1	Statutory Regulations	368
10.15.2	Classification and Testing of the Fire Performance of Building Materials and Components	368
10.15.3	Official Approval	372
10.15.4	Future Developments	373
10.15.4.1	Regulations	373
10.15.4.2	Standardization	373
10.15.4.3	Certification	373
10.16	Slovak Republic	374
10.16.1	Statutory Regulations	374
10.16.2	Classification and Testing of the Fire Performance of Building Materials and Components	374
10.16.3	Official Approval	375
10.16.4	Future Developments	375
10.17	Switzerland	376
10.17.1	Statutory Regulations	376
10.17.2	Classification and Testing of the Fire performance of Building Materials and Components	377
10.17.2.1	Fire behavior	377
10.17.2.2	Smoke Developing Behavior	378

	10.17.2.3 Classification	378
	10.17.2.4 Application of Combustible Building Materials in Buildings	378
	10.17.3 Official Approval	382
	10.17.4 Future Developments	383
10.18	United Kingdom	384
	10.18.1 Statutory Regulations	384
	10.18.2 Classification and Testing of the Fire Performance of Building Materials and Components	384
	10.18.2.1 BS 476 Part 4 Noncombustibility test	385
	10.18.2.2 BS 476 Part 6 Fire Propagation Test	385
	10.18.2.3 BS 476 Part 7 Surface Spread of Flame Test	387
	10.18.2.4 BS 476 Part 11 Heat Emission Test	388
	10.18.3 Test Methods for Thermoplastics	389
	10.18.3.1 BS 2782 Method 508A, Rate of Burning	390
	10.18.3.2 BS 5438 Flammability of Textile Fabrics	391
	10.18.4 Official Approval	393
	10.18.5 Future Developments	394
10.19	Australia	395
	10.19.1 Statutory Regulations	395
	10.19.2 Classification and Testing of the Fire Performance of Building Materials and Components	395
	10.19.2.1 AS 1530.1 Combustibility Test for Materials	396
	10.19.2.2 AS 1530.2 Test for Flammability of Materials	396
	10.19.2.3 AS/NZS 1530.3 Simultaneous determination of ignitability, flame propagation, heat release, and smoke release (known as the Early Fire Hazard Test)	398
	10.19.3 Official Approval	401
	10.19.4 Future Developments	402
10.20	New Zealand	403
	10.20.1 Statutory Regulations	403
	10.20.2 Classification and Testing of the Fire Performance of Building Materials and Components	404
	10.20.3 Official Approval	404
	10.20.4 Future Developments	405
10.21	People's Republic of China	405
	10.21.1 Statutory Regulations	405
	10.21.2 Classification and Testing of the Fire Performance of Building Materials and Components	405
	10.21.3 Generally Used Tests and Classifications for Building Materials	407
	10.21.3.1 GB/T 5464-1999 Noncombustibility of Building Materials	407
	10.21.3.2 GB/T 8625-88 Low flammability of Building Materials	407
	10.21.3.3 GB/T 8626-88 Moderate Flammability of Building Materials	407
	10.21.3.4 GB/T 8627-88 Smoke Density of Building Materials	408
	10.21.4 Specific Tests Used for Plastics, Textiles, and Floor Coverings and Further Tests to Determine Noncombustibility and Smoke Toxicity of Building Materials	408

10.21.4.1	GB/T 2406-88 Flammability of Pipe Insulation	409
10.21.4.2	GB/T 2408-1996 Flammability of Plastic Conduit Pipes	409
10.21.4.3	GB/T 5454-1997 Flammability of Textiles by the Oxygen Index Test	410
10.21.4.4	GB/T 5455-1997 Flammability of Textiles by Using a Vertical Bunsen Burner Test	410
10.21.4.5	GB/T 8332-87 Flammability of Cellular Plastics – Horizontal Burning	411
10.21.4.6	GB/T 8333-87 Flammability of Cellular Plastics – Vertical Burning	411
10.21.4.7	GB/T 11785-89 Critical Radiant Flux of Floor Coverings	411
10.21.4.8	GB/T 14402-93 Calorific Potential of Building Materials	412
10.21.4.9	GB/T 14403-93 Heat Emission of Building Materials	412
10.21.4.10GA	132-1996 Smoke Toxicity of Fire Effluents	412
10.21.4.11	Special Requirements for Composite Materials and Surface Coatings	413
10.21.5	Official Approval	413
10.21.6	Future Developments	413
10.22	Japan	414
10.22.1	Statutory Regulations	414
10.22.2	Classification and Testing of the Fire Performance of Building Materials and Components	414
10.22.3	Official Approval	417
10.22.3.1	Approval for the Reaction-to-Fire of Building Materials	417
10.22.3.2	Approval for Fire Resistance	417
10.22.4	Future Developments	417
10.23	International Organization for Standardization (ISO)	418
10.23.1	Introduction	418
10.23.2	ISO/TC 92 Fire Related Activities	419
10.23.2.1	TC 92/ SC1 Fire Initiation and Growth	421
10.23.2.2	The Present Package of Standards and Technical Reports from ISO TC 92/SC1	421
10.23.3	Future Developments	432

11	Transportation	433
11.1	Motor Vehicles	433
11.1.1	Statutory Regulations	433
11.1.2	Technical Fire Protection Requirements and Tests	434
11.1.2.1	Materials and Components for Use in Car Interiors	435
11.1.2.2	Buses and Coaches	436
11.1.2.3	Bodywork	437
11.1.2.4	Fuel Tanks	438
11.1.2.5	Plastic Windows	440
11.1.3	Future Developments	441
11.2	Rail Vehicles	442
11.2.1	Statutory Regulations	443
11.2.2	Fire Protection Requirements, Classification and Tests on Railway Vehicles in Selected Countries	443

	11.2.2.1	Germany	443
	11.2.2.2	Great Britain	448
	11.2.2.3	France	450
	11.2.2.4	Other European Countries	452
	11.2.2.5	United States of America	452
	11.2.3	UIC Regulations	453
	11.2.4	Future Developments	454
11.3		Aircraft	457
	11.3.1	Statutory Regulations	458
	11.3.2	Technical Fire Protection Requirements and Tests	458
	11.3.2.1	Bunsen Burner-Type Tests	459
	11.3.2.2	Fire Behavior and Smoke Tests	463
	11.3.2.3	Technical Fire Requirements in the Conditions of Delivery of the Aviation Industry – Additional Requirements Relating to Smoke Density and Toxicity of Combustion Products	468
	11.3.3	Future developments	470
11.4		Ships	471
	11.4.1	Statistics of Fire on Board Passenger Ships	471
	11.4.2	SOLAS Chapter II-2: International Regulations for Fire Safety of Ships	472
	11.4.2.1	Existing SOLAS Fire Safety Regulations and Revision Activities	472
	11.4.2.2	Structure of New Chapter II-2 of SOLAS	473
	11.4.3	Fire Test Procedures Code (FTP code)	476
	11.4.4	Other Test Methods for High-Speed Craft	485
12		Electrical Engineering	487
12.1		International Fire Regulations and Standards (IEC)	488
	12.1.1	Objectives and organization	488
	12.1.2	Fire Hazard Testing, IEC/TC 89	489
	12.1.2.1	Fire Hazard Assessment	490
	12.1.2.2	Fire Statistics	494
	12.1.2.3	Fire Hazard Assessment Tests for Electrotechnical Products	497
	12.1.2.4	Combustion Characteristic Tests for Preselection of Materials, IEC 60695-1-30 (Under Revision)	510
	12.1.2.5	Side Effects of a Fire	519
	12.1.2.6	Fire Safety Engineering	530
	12.1.3	International Certification	531
12.2		Fire Regulations in North America (UL, CSA)	531
	12.2.1	Test and Approval Procedures of the Underwriters Laboratories	531
	12.2.1.1	UL 94. Flammability tests	532
	12.2.1.2	Fire Regulations in other UL Standards	538
	12.2.2	CSA Test and Approval Procedures	544
12.3		Fire Regulations and Standards in Europe	545
	12.3.1	European Committee for Electrotechnical Standardization (CENELEC)	545
	12.3.2	Electrotechnical Products and EU Directives	546
	12.3.3	Approval Procedures in Europe	548
12.4		Fire Regulations and Standards in Asia	549
12.5		Fire Hazard Assessment on Cables	551

12.5.1	Small-Scale Testing	551
12.5.2	Large-Scale Testing	555
12.5.3	Side Effects of Cable Fires	563
12.5.4	Fire Resisting Characteristics of Cables	564
12.5.5	Fire Hazard Assessment on Railway Rolling Stock Cables	567
12.5.6	Future Developments in Cable Testing	567
12.6	Other Fire Safety Test Methods	569
12.6.1	Fire Hazard Testing of Cable Management Systems	569
12.6.2	Fire Hazard Testing of Office and Consumer Equipment	569
	12.6.2.1 Office equipment	569
	12.6.2.2 Consumer Equipment	572
	12.6.2.3 Household Appliances	572
12.7	Future Developments	573
13	Furniture and Furnishings	580
13.1	Introduction	580
13.2	Fire Behavior of Upholstered Furniture	584
13.3	Regulations and Test Methods	585
13.3.1	EC Draft Directive and European Tests	585
13.3.2	Tests and Test Development	586
13.3.3	UK Regulations and Tests for Furniture Suitable for Domestic Use	587
	13.3.3.1 Fillings	588
	13.3.3.2 Covers and Interliners	589
	13.3.3.3 Composites	589
13.3.4	UK Regulations and Tests for Furniture Used in Public Areas	589
13.3.5	ISO Ignition Tests	590
13.3.6	US Regulations and Tests	590
	13.3.6.1 Regulatory Test Methods for Mattresses	591
	13.3.6.2 Voluntary UFAC Standard Test for Seating	591
	13.3.6.3 California Tests	593
13.4	Fire Growth Rate, Heat Release Rate, Smoke Production Rate and Toxicity Tests	598
	13.4.1 The Furniture Calorimeter	599
	13.4.2 Furniture Fire Models	600
13.5	Future Developments	602
III	Fire Effluents	609
14	Preliminary Remarks	611
15	Smoke Development of Fire Effluents	612
15.1	Introduction	612
15.2	Fundamental Principles of Smoke Measurement	612
15.2.1	Optical Methods	613
	15.2.1.1 Static Methods	616
	15.2.1.2 Dynamic Methods	617
15.2.2	Mechanical Methods	617
15.2.3	Electrical Methods	617
15.3	Test Apparatus and Test Procedures in Practical Applications	618
15.3.1	Validity and Differences of Individual Methods	618

15.3.2	Tests Based on Static Methods	619
15.3.2.1	NBS Smoke Chamber Determination of Specific Optical Density	619
15.3.2.2	XP2 Smoke Density Chamber	621
15.3.2.3	Three Meter Cube Smoke Chamber	622
15.3.2.4	ISO Dual Chamber Box	623
15.3.3	Tests Based on Dynamic Methods	624
15.3.3.1	DIN 4102-15 Brandschacht	624
15.3.3.2	ISO 5660-2 Cone Calorimeter	624
15.3.3.3	DIN 5510-2 Using DB Brandschacht.	624
15.3.3.4	ASTM E 84 Steiner Tunnel	625
15.3.3.5	Smoke Generation According to ISO/TR 5659-3	625
15.3.3.6	Single Burning Item Test	626
15.4	Future Developments	626
16	Toxicity of Fire Effluents	628
16.1	Introduction	628
16.2	Toxic Principles of Toxic Agents from Smoke	630
16.2.1	Selection of Test Species for Bioassays	630
16.2.2	Dose-Response and Time-Response Relationships	632
16.2.3	Species Differences and Uncertainty Factors	635
16.3	Endpoints in Acute Toxic Potency Tests of Combustion Products	635
16.3.1	Selection of Endpoints	637
16.3.2	Assessment of Toxic Effects from Irritancy	637
16.3.3	Toxic Species in Blood	639
16.4	Life-Threatening Responses to Toxic Agents from Fires	640
16.4.1	Acute Responses to Toxic Agents	641
16.4.2	Chronic Toxicity and Environmental Exposure of Persistent Agents from Smoke	642
16.5	Principles of Acute Combustion Toxicity Tests	642
16.5.1	Exposure Systems	642
16.5.2	DIN 53436 Tube Furnace and Nose-Only Exposure of Animals	645
16.5.3	Acute Inhalation Toxicity	646
16.5.4	Calculation of the Median Lethal Concentration (LC ₅₀)	647
16.6	Prediction of the Actual Lethal Potency of Fire Effluents	648
16.7	Toxic Potency of Materials and Toxic Hazard from Fire Situations	653
16.8	Combustion Toxicology and Clinical Experience	655
16.9	Future Directions	656
17	Corrosivity of Fire Effluents	660
17.1	Introduction	660
17.2	Principles of Corrosion	661
17.3	Methods for Assessing Corrosivity	662
17.4	Clean-up Procedures	664
17.4.1	Methods to Stop Corrosion Attack After a Fire	665
17.4.2	Special Clean-up Procedures	665
17.4.2.1	Electrical and Electronic Equipment	665
17.4.2.2	Industry Machines	666
17.4.2.3	Buildings	666
17.5	Conclusions	669

IV Appendix	671
1 Suppliers of Flame Retardants and Smoke Suppressants	673
2 Abbreviations for Plastics and Additives	678
2.1 Abbreviations for Plastics	678
2.2 Abbreviations for Additives	679
3 Thermal Characteristics of Selected Thermoplastics	680
4 Terminology of Fire Protection	681
4.1 Definitions of terms connected with fire protection	682
4.2 English, German and French terms frequently used in connection with fire protection	684
5 International and National Standards Organizations	689
5.1 International Organizations	689
5.2 National Organizations	689
6 Electrotechnical Safety and Standard Organizations	696
7 Abbreviations	707
8 Journals and Books	717
8.1 Journals	717
8.2 Books	717
Author Index	719
Index of Standards	721
Key Word Index	729