

Fire Protection Handbook

Sixteenth Edition



National Fire Protection Association

Editor-in Chief: Arthur E. Cote
Managing Editor: Jim L. Linville
Associate Editor: John S. Petraglia
Consulting Editor: Gordon P. McKinnon
Editorial Staff: Gene A. Moulton
Marion Cole
Copyeditors: Catherine G. Cronin
Stanley T. Dingman
Parrish Dobson
Artwork: Kathy Linnehan
George Nichols
Frank Lucas
Text Processing: Elizabeth K. Carmichael
Debra A. Rose
Louise Grant
Interior Design: K. Sulier Associates
Cover Design: George Nichols
Production Coordinator: Donald C. McGonagle
Composition: William Byrd Press
Printed By: R.R. Donnelley & Sons

First Impression, March 1986
Fifty thousand Copies

Previous Editions

First	1896
Second	1901
Third	1904
Fourth	1909
Fifth	1914
Sixth	1921
Seventh	1924
Eighth	1935
Ninth	1941
Tenth	1948
Eleventh	1954
Twelfth	1962
Thirteenth	1969
Fourteenth	1976
Fifteenth	1981

The following are other registered trademarks of the National Fire Protection Association, Inc.

Fire Command
Fire Journal
Learn Not To Burn
Life Safety Code and 101
National Electrical Code and NEC
National Fire Codes
NFPA and Design (Logo)

Library of Congress Catalog Card Number 62-12655
NFPA Number: FPH1686
ISBN: 0-87765-315-1

The National Fire Protection Association
Batterymarch Park, Quincy, MA 02269
Copyright © 1986 by the National Fire Protection Association. All rights reserved
Printed in the United States of America

Dedication

To the professional men and women of the fire protection community whose untiring devotion to the task of protecting life and property from the ravages of fire has made this world a better place.

INTRODUCTION

Since its first edition exactly 90 years ago the *Fire Protection Handbook* has endeavored to fulfill the needs of the fire protection community for a single-source handbook on the state of the art in fire protection and fire prevention practices.

It was originally known as the *Crosby-Fiske Handbook of the Underwriter's Bureau of New England*, and first published in 1896, the same year that the National Fire Protection Association was founded. The original authors were Everett U. Crosby and Henry A. Fiske, who were joined by H. Walter Forster in 1918. In 1935 Crosby, Fiske, and Forster donated all rights to their handbook to the NFPA, and NFPA has published all successive editions since that 8th edition.

The *Fire Protection Handbook* has changed significantly in the last nine decades. While the body of knowledge in the field of fire protection has proliferated, the HANDBOOK has kept pace, expanding from less than 200 pages in the first edition to almost 1800 pages in this 16th edition. As the most pressing concerns of fire protection have evolved, from city-wide conflagrations in the last 1800s through building fires and more recently to room fires, the number of subjects covered by the *Handbook* has greatly increased. This is evidenced by the expansion of the text from the short, running commentary that comprised the first edition to material organized into 173 chapters in this volume. Today, there are nearly as many chapters as there were pages in 1896!

Production of the *Fire Protection Handbook* through 16 editions has involved literally thousands of fire protection experts from within and outside NFPA. However, in addition to its founders, over the last half-century four individuals were especially responsible for establishing the HANDBOOK as the "bible" for fire protection practitioners.

Robert S. Moulton, late NFPA Technical Secretary who, during his 40 years of service, edited the 9th, 10th, and 11th editions;

George H. (Hitch) Tryon, late NFPA Assistant Vice President who edited the 12th and 13th editions;

Richard E. Stevens, retired NFPA Vice President and Chief Engineer who, during his 35 years with the Association, contributed to five editions of the HANDBOOK and served as chief technical consultant for the 14th and 15th editions; and

Gordon P. (Mac) McKinnon, retired NFPA Editor-in-Chief, who has been directly involved in the preparation of five editions of the HANDBOOK over a quarter century. He served as Editorial Coordinator of the 12th edition, Managing Editor of the 13th edition, Editor of the 14th and 15th editions, and Consulting Editor for this edition.

In offering this Edition of the *Fire Protection Handbook*, the editors solicit suggestions for improvements in the interest of continuing to make future editions increasingly useful to all concerned. Every effort has been made to assure that the text is consistent with the best available information on current fire protection practices. However, the National Fire Protection Association, as a body, is not responsible for the contents, as there has been no opportunity for the membership to review the *Handbook* prior to its publication. If readers discover errors or omissions, the editors would appreciate those shortcomings being called to their attention.

Arthur E. Cote, P.E.

PREFACE

Without a doubt, supervising the editing of the 16th edition of the *Fire Protection Handbook* has been the most challenging and complicated task I've had the pleasure of attempting during my 20 (plus) years in technical book publishing. When you finally have the time to stop and think about it, the facts are mind boggling: 173 chapters by almost 200 authors; hundreds of reviewers to keep track of; more than 2,000 illustrations to be rendered, captioned, cropped, and checked; tens of thousands of metric conversions to make; close to a million words to edit; a readership that ranges from fire fighters and fire protection engineers to university professors and research scientists; a breakneck schedule with a small but dauntless staff augmented by part-time help, and freelancers; an end-product with more pages than most major magazines publish in an entire year; but, most of all, the haunting knowledge that this book is different because it's *The FIRE PROTECTION HANDBOOK*, and a misplaced comma or a poorly worded sentence could result in an innocent person's injury or death. There are times when you simply have to strive for excellence and the *HANDBOOK* is one of those times.

This 16th edition of the *Fire Protection Handbook* is a major revision. It has a new Editor-in-Chief, a new editorial staff, a new design, and many new authors. Not only has it been thoroughly updated to reflect current fire protection and fire prevention practices, it also reflects the personalities and priorities of its staff. The changes made in this edition are too numerous to list individually, but in general:

1. There are 22 sections of which three are new: "Education for Fire Protection," "Hazardous Wastes and Materials," and "Fire Modeling and Analysis."
2. Every chapter has been thoroughly updated, and there are more than 50 new or totally revised chapters.
3. The "Life Safety" section has been revised and reorganized to parallel the *Life Safety Code*®; it includes 16 new chapters.
4. More than 60 authors have contributed to the *HANDBOOK* for the first time.
5. The chapter Bibliographies have been expanded and updated.
6. Metric equivalents for all values have been added to the text, illustrations, and tables.
7. The book has been completely redesigned and reorganized to reflect its status as the foremost professional reference book on fire protection.

The result is a book with more than 600 pages of "new" material and a grand total of approximately 1,750 pages.

Acknowledgments

Each edition of any book as massive and as important as the *Fire Protection Handbook* is an enormous undertaking requiring the cooperation of hundreds of people, and this 16th edition is no exception. In one way or another virtually every NFPA staff member has been involved; many made generous personal sacrifices; all deserve accolades. One member of our team, however, deserves special mention. Louise Grant not only keyboarded every word, (sometimes three or four times) but did so with enthusiasm and skill. If this book is good it owes much to Louise. Likewise, over the five year period between this and the previous edition, many conscientious readers have called errors and inconsistencies to our attention. We wish we had time and/or space to mention them all. Nothing is perfect, and so we continue to solicit your comments. We do try, we do care, and we do promise to respond to each and every letter.

Obviously, no one person can know everything about a subject as enormous and complex as fire protection. Every word in this edition was reviewed by the Editor-in-Chief and other appropriate NFPA staff members. Selected chapters were reviewed by qualified outside experts from all over the world. Therefore, the editors wish to acknowledge and thank all of those experts who contributed their time and energy to improving the HANDBOOK. Special thanks are due Dr. Jack Snell, Director, U.S. National Bureau of Standards, Center for Fire Research; Mr. Paul M. Fitzgerald, Chief Operating Officer, Factory Mutual Research Corporation; Mr. James A. Lambert, Vice-President Engineering, Industrial Risk Insurers; and Mr. Jack A. Bono, President, Underwriters Laboratories Inc. Their willingness to allow their respective staffs to devote time to participate as both reviewers and authors of many of the chapters in this HANDBOOK is gratefully acknowledged. Without their help the book would have suffered. Special thanks is also due Harold E. (Bud) Nelson, of the U.S. National Bureau of Standards, Center for Fire Research and Past-President of the Society of Fire Protection Engineers, whose eagerness to share his personal knowledge of the subject and that of his colleagues in the SFPE led us to many of the new authors in this edition, and many of its technical reviewers.

The following experts from outside the NFPA staff gave generously of their time and experience by reviewing chapters from the 15th edition and offering suggestions for revisions as a prelude to preparing the new edition:

Louis G. Almgren, Norman Alvarez, Mario Antonette, Wayne E. Ault, Carl Baldasserra, Irwin Benjamin, Vytenis Babrauskas, Boris Bresseler, Edward Budnick, Jim Byers, John Campbell, Kenneth Charter, Al Clark, Leonard Cooper, Iving Deutsch, John E. Echternacht, Richard Gann, Richard Gewain, Thomas E. Goonan, Matrin Hertzburg, Clayton Huggett, David C. Jeanes, John D. Jensen, Rolf H. Jensen, Peter Johnson, John Krasney, Jane Lataille, Barry M. Lee, Bernard Levin, T.T. Lie, Richard E. Master, Harold E. Nelson, John O'Neill, William Parker, Patrick E. Phillips, Robert G. Planer, James Quintiere, John Rockett, Robert Rosenberg, Gerald J. Rosicky, John Ed Ryan, Merwin Schulkin, Jack Snell, Thomas E. Seymoure, James G. Spence, Richard Stevens, Roger K. Sweet, Richard Thornberry, R. Brady Williamson, Rexford Wilson, James Winger, and Reginald Wright.

And finally, thanks to Catherine Cronin, whose diligent work gave the *Handbook* any degree of consistency it may have; Stanley Dingman, who was fast and accurate; John Petraglia, who deserves special mention for hard work and dedication to accuracy; John Titus, of Worcester Polytechnic Institute, who prepared the expanded Bibliographies; Peter Johnson, of the Central Investigation and Research Laboratory, Melbourne, Australia, who served as metrication consultant, general technical reviewer, and chief critic; Joan Croce, who gave up Thanksgiving and Christmas to prepare the Index; and last (but not least), Gordon P. (Mac) McKinnon who stuck it out for one more year to hold my hand through this his final (and my first) edition of the *Fire Protection Handbook*. Your comments and suggestions for improving the 17th Edition will be appreciated.

Jim L. Linville
Managing Editor

CONTENTS

Foreword	xiii	Chapter 4	Theory of Fire and Explosion Control <i>Walter Haessler</i>	4-42
Preface	xv			
Section 1/ THE FIRE PROBLEM	1-1	Section 5/ FIRE HAZARDS OF MATERIALS		5-1
Chapter 1	Assessing the Magnitude of the Fire Problem <i>Arthur E. Cote</i>	Chapter 1	Fire Hazards of Materials: An Overview <i>Frederic B. Clarke</i>	5-2
	1-2	Chapter 2	Wood and Wood-Based Products <i>Harold O. Beals</i>	5-8
Chapter 2	Human Behavior and Fire <i>John L. Bryan</i>	Chapter 3	Fibers and Textiles <i>John F. Krasny and Stephen B. Sello</i>	5-17
	1-17	Chapter 4	Flammable and Combustible Liquids <i>Martin F. Henry</i>	5-28
Section 2/ FIRE LOSS INFORMATION	2-1	Chapter 5	Gases <i>Wilbur L. Walls</i>	5-39
Chapter 1	Fire Loss Investigation <i>Richard L. P. Custer</i>	Chapter 6	Chemicals <i>William J. Bradford</i>	5-59
	2-2	Chapter 7	Explosives and Blasting Agents <i>Samuel J. Porter</i>	5-68
Chapter 2	Collecting Fire Data <i>Carl E. Peterson</i>	Chapter 8	Plastics and Rubber <i>Bert M. Cohn</i>	5-77
	2-8	Chapter 9	Dusts <i>Richard F. Schwab</i>	5-97
Chapter 3	Use of Fire Loss Information <i>John R. Hall, Jr.</i>	Chapter 10	Metals <i>Robert O'Laughlin</i>	5-107
	2-15	Chapter 11	Tables and Charts <i>Vytenis Babrauskas</i>	5-117
Section 3/ EDUCATION FOR FIRE PREVENTION	3-1			
Chapter 1	Firesafety Education <i>Diane C. Roche</i>	Section 6/ HAZARDOUS WASTES AND MATERIALS		6-1
	3-2	Chapter 1	The Role of the Fire Protection Community in Hazardous Waste Control <i>Philip Blye and James Yess</i>	6-2
Chapter 2	Fire Prevention Practices in Commerce and Industry <i>Philip Blye and James Yess</i>	Chapter 2	Identification of the Hazards of Materials <i>Martin F. Henry</i>	6-9
	3-10			
Chapter 3	Traffic and Exit Drills <i>John L. Bryan</i>			
	3-14			
Section 4/ THE CHARACTERISTICS AND BEHAVIOR OF FIRE	4-1			
Chapter 1	Chemistry and Physics of Fire <i>John deRis</i>			
	4-2			
Chapter 2	Explosions <i>William J. Cruice</i>			
	4-17			
Chapter 3	Combustion Products and Their Effects on Life Safety <i>Gordon E. Hartzell</i>			
	4-33			

Chapter 3	Handling Hazardous Materials Transportation Emergencies <i>James V. McKiernan and Callie McDowell</i>	6-21	Chapter 14	Special Structures <i>John G. Degenkolb</i>	7-164
Chapter 4	Obtaining Technical Assistance in Hazardous Materials Emergencies <i>Philip Blye and James Yess</i>	6-29	Chapter 15	Building Codes and Standards <i>Arthur E. Cote</i>	7-173
Chapter 5	Hazardous Waste Control <i>Sami Atallah</i>	6-47	Chapter 16	Fire Hazards of Construction, Alterations, and Demolition of Buildings <i>John A. Sharry</i>	7-178
			Chapter 17	Evaluating Structural Damage <i>Herman H. Spaeth</i>	7-183
Section 7/	FIRESAFETY IN BUILDING DESIGN AND CONSTRUCTION	7-1	Section 8/	FIRE HAZARDS OF BUILDING SERVICES	8-1
Chapter 1	Fundamentals of Firesafe Building Design <i>Robert W. Fitzgerald</i>	7-2	Chapter 1	Hazards of Building Services <i>Robert W. Ryan</i>	8-2
Chapter 2	Systems Concepts for Building Firesafety <i>Clifford S. Harvey</i>	7-10	Chapter 2	Electrical Systems and Appliances <i>Peter J. Schram</i>	8-7
Chapter 3	Concepts of Egress Design <i>John L. Bryan</i>	7-20	Chapter 3	Heating Systems and Appliances <i>J. Herbert Witte and Richard L. Stone</i>	8-40
Chapter 4	Building and Site Planning for Firesafety <i>Clifford S. Harvey</i>	7-41	Chapter 4	Air Conditioning and Ventilating Systems <i>William A. Schmidt</i>	8-74
Chapter 5	Classification of Building Construction <i>Richard G. Gewain and David C. Jeanes</i>	7-49	Chapter 5	Building Transportation Systems <i>Edward A. Donoghue</i>	8-82
Chapter 6	Building Construction <i>Richard G. Gewain and David C. Jeanes</i>	7-56	Chapter 6	Miscellaneous Building Services <i>Robert W. Ryan</i>	8-91
Chapter 7	Interior Finish <i>Norman DeHaan</i>	7-72	Section 9/	HAZARDS TO LIFE IN STRUCTURES	9-1
Chapter 8	Structural Integrity During Fire <i>Robert W. Fitzgerald</i>	7-82	Chapter 1	Assessing Life Safety in Buildings <i>John M. Watts, Jr.</i>	9-2
Chapter 9	Confinement of Fire in Buildings <i>John A. Campbell</i>	7-109	Chapter 2	Assembly Occupancies <i>John A. Sharry</i>	9-8
Chapter 10	Smoke Movement in Buildings <i>Harold E. Nelson</i>	7-125	Chapter 3	Educational Occupancies <i>John A. Sharry</i>	9-13
Chapter 11	Venting Practices <i>Gunnar Heskestad</i>	7-137	Chapter 4	Health Care Facilities <i>Donald W. Belles</i>	9-16
Chapter 12	Structural Firesafety: One and Two Family Dwellings <i>Bertram M. Vogel</i>	7-151	Chapter 5	Board and Care Facilities <i>Alfred J. Longhitano</i>	9-26
Chapter 13	Energy Conservation in Buildings <i>T. T. Lie</i>	7-156	Chapter 6	Detention and Correctional Facilities <i>Wayne G. Carson</i>	9-30

CONTENTS

Chapter 7	Hotels <i>Gerald Kirby</i>	9-37	Chapter 9	Welding and Cutting <i>T. E. Willoughby</i>	10-63
Chapter 8	Apartment Buildings <i>Kenneth Bush</i>	9-40	Chapter 10	Chemical Processing Equipment <i>William J. Bradford</i>	10-71
Chapter 9	Lodging or Rooming Houses <i>Gregory Haley</i>	9-46	Chapter 11	Grinding Processes <i>Delwyn D. Bluhm</i>	10-82
Chapter 10	One and Two Family Dwellings <i>Harry L. Bradley</i>	9-49	Chapter 12	Extrusion and Forming Processes <i>Jerome P. Carroll</i>	10-93
Chapter 11	Mobile Homes and Recreational Vehicles <i>Michael Slifka</i>	9-51	Chapter 13	Molten Salt Baths <i>Q. D. Mehrkam</i>	10-100
Chapter 12	Mercantile Occupancies <i>William Hiotaky</i>	9-55	Chapter 14	Solvent Extraction <i>C. Louis Kingsbaker</i>	10-106
Chapter 13	Business Occupancies <i>Clifford S. Harvey</i>	9-62	Chapter 15	Refrigeration Systems <i>Emil E. Roy</i>	10-111
Chapter 14	Industrial Occupancies <i>Michael Slifka</i>	9-66	Chapter 16	Food Processing <i>Jane I. Lataille</i>	10-115
Chapter 15	Storage Occupancies <i>Bruce W. Hisley</i>	9-69	Chapter 17	Nuclear Facilities <i>George Weldon</i>	10-121
Chapter 16	Occupancies in Unusual Structures <i>Roger T. Boyce, Sr.</i>	9-76	Chapter 18	Metalworking Processes <i>William Atkinson</i>	10-127
Section 10/	PROCESS FIRE HAZARDS	10-1	Chapter 19	Woodworking Processes <i>Edwin P. Bounous</i>	10-131
Chapter 1	Boiler Furnaces <i>O. W. Durrant</i>	10-2	Chapter 20	Automated Processing Equipment <i>John F. Bloodgood</i>	10-134
Chapter 2	Stationary Combustion Engines <i>Frank J. Mapp and Vincent J. Hession</i>	10-12	Chapter 21	Aerosol Charging Operations <i>Henry C. Scuoteguazza</i>	10-138
Chapter 3	Heat Transfer Systems (Nonwater Media) <i>J. G. Coutu</i>	10-15	Chapter 22	Semiconductor Manufacturing <i>Richard P. Bielen and Kathleen Robinson</i>	10-143
Chapter 4	Fluid Power Systems <i>Paul K. Schacht</i>	10-19	Chapter 23	Mining Methods and Equipment <i>William H. Pomroy</i>	10-148
Chapter 5	Industrial and Commercial Heat Utilization Equipment <i>James M. Simmons</i>	10-22	Section 11/	STORAGE PRACTICES AND HAZARDS	11-1
Chapter 6	Oil Quenching <i>Raymond Ostrowski</i>	10-42	Chapter 1	General Indoor Storage <i>Martin M. Brown</i>	11-2
Chapter 7	Spray Finishing and Powder Coating <i>Don R. Scarbrough</i>	10-47	Chapter 2	Cold Storage Warehouses <i>Robert Hodnett</i>	11-22
Chapter 8	Dipping and Coating Processes <i>Nicholas L. Talbot and Paul H. Dobson</i>	10-56	Chapter 3	Outdoor Storage Practices <i>Martin M. Brown</i>	11-25
			Chapter 4	Storage of Flammable and Combustible Liquids <i>Martin F. Henry</i>	11-30

Chapter 5	Storage of Gases Wilbur L. Walls	11-44	Chapter 12	Lightning Protection Systems Norman H. Davis, III	12-92
Chapter 6	Storage and Handling of Chemicals William J. Bradford	11-49	Chapter 13	Air Moving Equipment John K. Bouchard	12-104
Chapter 7	Storage and Handling of Grain Mill Products Max R. Spencer	11-55	Chapter 14	Waste Handling Systems and Equipment Lawrence G. Doucet	12-112
Chapter 8	Storage and Handling of Solid Fuels Jack J. Ellis and Mel Gould	11-63	Chapter 15	Upholstered Furniture and Mattresses Vytenis Babrauskas and John F. Krasny	12-120
Chapter 9	Storage and Handling of Records Thomas E. Goonan	11-71	Section 13/	TRANSPORTATION FIRE HAZARDS	13-1
Chapter 10	Library and Museum Collections Stephen E. Bush	11-80	Chapter 1	Aviation James J. Brenneman	13-2
Section 12/	SPECIAL FIRE PROTECTION AND PREVENTION PROBLEMS	12-1	Chapter 2	Motor Vehicles Hugh McGinley	13-20
Chapter 1	Protection of Computers and Electronic Equipment John H. Uliana	12-2	Chapter 3	Rail Transportation Systems Roger K. Fitch	13-31
Chapter 2	Protection for Laboratories Henry P. Beltramini	12-6	Chapter 4	Fixed Guideway Transit Systems Eugene Nunes and John J. Troy	13-43
Chapter 3	Oxygen-Enriched Atmospheres George J. Frankel	12-12	Chapter 5	Marine Charles L. Keller, Donald J. Kerlin, and Robert Loeser	13-50
Chapter 4	Medical Gases Burton Klein	12-22	Section 14/	ORGANIZATION FOR PRIVATE PROTECTION	14-1
Chapter 5	Pesticides Robert Benedetti	12-31	Chapter 1	Fire Loss Prevention and Control Management Peter K. Schontag	14-2
Chapter 6	Fire Retardant and Flame Resistant Treatments of Cellulosic Materials James R. Shaw	12-35	Chapter 2	Responsibilities of the Fire Loss Prevention and Control Manager Peter K. Schontag	14-5
Chapter 7	Materials Handling Equipment Richard E. Munson	12-44	Chapter 3	Private Emergency Organizations Peter K. Schontag	14-13
Chapter 8	Housekeeping Practices Kathleen M. Robinson	12-54	Section 15/	PUBLIC FIRE PROTECTION	15-1
Chapter 9	Forest, Brush, and Grass Fires C. Bentley Lyon	12-61	Chapter 1	Fire Department Organization Carl E. Peterson	15-2
Chapter 10	Control of Electrostatic Ignition Sources Martin F. Henry	12-66	Chapter 2	Fire Department Administration and Management Gary Tokle	15-11
Chapter 11	Special Systems for Explosion Damage Control Parker Peterson	12-77			

Chapter 3	Fire Department Operations <i>J. Gordon Routley</i>	15-23	Chapter 5	Water Storage Facilities and Suction Supplies <i>Robert M. Hodnett</i>	17-60
Chapter 4	Fire Prevention and Code Enforcement <i>James R. Bell</i>	15-37	Chapter 6	Fire Pumps <i>Robert M. Hodnett</i>	17-74
Chapter 5	Fire and Arson Investigation <i>Robert E. Carter</i>	15-48	Chapter 7	Fire Streams <i>Robert G. Purington</i>	17-90
Chapter 6	Fire Department Apparatus, Equipment, and Facilities <i>A. K. Rosenhan</i>	15-59	Chapter 8	Test of Water Supplies <i>John R. Anderson</i>	17-102
Chapter 7	Evaluation and Planning of Public Fire Protection <i>John Granito</i>	15-90	Section 18/	WATER-BASED EXTINGUISHING SYSTEMS	18-1
Chapter 8	Analysis of Fire Department Data and Decision Making <i>Carl Peterson</i>	15-102	Chapter 1	Automatic Sprinkler Systems <i>Robert M. Hodnett</i>	18-2
Chapter 9	Emergency Medical Services <i>James O. Page</i>	15-112	Chapter 2	Water Supplies for Sprinkler Systems <i>Robert M. Hodnett</i>	18-27
Section 16/	FIRE ALARM SYSTEMS, DETECTION DEVICES, AND GUARD SERVICES	16-1	Chapter 3	Automatic Sprinklers <i>Robert M. Hodnett</i>	18-36
Chapter 1	Fire Department Emergency Communication Systems <i>Max R. Schulman</i>	16-2	Chapter 4	Residential "Quick- Response" Sprinklers <i>Arthur E. Cote</i>	18-50
Chapter 2	Protective Signaling Systems <i>Charles E. Zimmerman</i>	16-13	Chapter 5	Waterflow Alarms and Sprinkler System Supervision <i>Vincenzo Cirigliano</i>	18-60
Chapter 3	Household Warning Systems <i>Charles E. Zimmerman</i>	16-22	Chapter 6	Standpipe and Hose Systems <i>Robert M. Hodnett</i>	18-69
Chapter 4	Automatic Fire Detectors <i>Charles E. Zimmerman</i>	16-29	Chapter 7	Water Spray Protection <i>Robert M. Hodnett</i>	18-77
Chapter 5	Gas and Vapor Testing <i>Richard L. Swift</i>	16-40	Chapter 8	Care and Maintenance of Water-Based Extinguishing Systems <i>Robert M. Hodnett</i>	18-83
Chapter 6	Fire Guard Services and Fire Protection Surveillance <i>Dean K. Wilson</i>	16-46	Section 19/	SPECIAL FIRE SUPPRESSION AGENTS AND SYSTEMS	19-1
Section 17/	WATER AND WATER SUPPLIES FOR FIRE PROTECTION	17-1	Chapter 1	Carbon Dioxide and Application Systems <i>H. V. Williamson</i>	19-2
Chapter 1	Water and Water Additives for Fire Fighting <i>Robert M. Hodnett</i>	17-2	Chapter 2	Halogenated Agents and Systems <i>Daniel W. Moore</i>	19-11
Chapter 2	Hydraulics <i>Robert M. Hodnett</i>	17-12	Chapter 3	Dry Chemical Agents and Application Systems <i>Walter Haessler</i>	19-24
Chapter 3	Water Supply Requirements for Fire Protection <i>John R. Anderson</i>	17-33	Chapter 4	Foam Extinguishing Agents and Systems <i>Norman R. Lockwood</i>	19-32
Chapter 4	Water Distribution Systems <i>John R. Anderson</i>	17-39			

Chapter 5	Combustible Metal Agents and Application Techniques <i>Andrew S. Prokopovitch</i>	19-49	Chapter 3	Hand Calculations for Enclosure Fires <i>Edward K. Budnick and David D. Evans</i>	21-19
Chapter 6	Special Systems and Extinguishing Techniques <i>Peter F. Johnson</i>	19-55	Chapter 4	Computer Fire Models <i>Edward K. Budnick and William D. Walton</i>	21-25
Section 20/	PORTABLE FIRE EXTINGUISHERS	20-1	Chapter 5	Room Fire Temperature Computations <i>Vytenis Babrauskas</i>	21-31
Chapter 1	The Role of Extinguishers in Fire Protection <i>Marshall E. Petersen</i>	20-2	Chapter 6	Pool Fires: Burning Rates and Heat Fluxes <i>Vytenis Babrauskas</i>	21-36
Chapter 2	Selection, Operation, and Distribution of Fire Extinguishers <i>Marshall E. Petersen</i>	20-9	Section 22/	MISCELLANEOUS DATA	22-1
Chapter 3	Inspection and Maintenance of Fire Extinguishers <i>Marshall E. Petersen</i>	20-27	Chapter 1	Inspection, Surveying, and Mapping <i>Carl E. Peterson</i>	22-2
Chapter 4	Auxiliary Portable Fire Extinguishing Devices <i>Marshall E. Petersen</i>	20-33	Chapter 2	SI Units and Conversion Tables <i>Peter F. Johnson</i>	22-8
Section 21/	FIRE MODELING AND ANALYSIS	21-1	Chapter 3	Microcomputer Applications in Fire Protection <i>John M. Watts, Jr.</i>	22-13
Chapter 1	Fire Hazard Assessment <i>Frederic B. Clarke</i>	21-2	APPENDICES		
Chapter 2	Fire Risk Analysis <i>John R. Hall, Jr.</i>	21-10	Appendix A	Strength and Size of Materials	A-1
			Appendix B	Complete Listing of All Current NFPA Codes, Standards, Manuals, and Recommended Practices	B-1
			INDEX		I-1

SECTION 1
THE FIRE PROBLEM

1. Assessing the Magnitude of the Problem	1-2	The Recreational Environment	1-10
U.S. Civilian Fire Deaths	1-2	Our Forests and Wildlands	1-11
U.S. Civilian Fire Injuries	1-3	Agricultural (Rural) America	1-12
Number of Fires and Property Loss	1-3	Our American Heritage	1-13
Multiple-Death Fires	1-5	Topical Fire Problem Areas	1-13
Dividing the Fire Problem into Manageable Terms	1-5	2. Human Behavior and Fire	1-17
The Home Environment	1-5	Introduction	1-17
The Mobile Environment	1-7	Decision Processes of the Individual	1-19
The American Community	1-8	Behavior Actions of Occupants	1-21
The Industrial Environment	1-9	Handicapped or Impaired Occupants	1-30
		Summary	1-30

ASSESSING THE MAGNITUDE OF THE FIRE PROBLEM

Arthur E. Cote, P.E.

In *America Burning*, the Report of the National Commission on Fire Prevention and Control NCFPC (1973), the problem of fire in the United States was defined and put into proper perspective: "Indifferent to fire as a national problem, Americans are similarly careless about fire as a personal threat. It takes the careless or unwise action of a human being, in most cases, to begin a destructive fire. In their home environments, Americans live their daily lives amid flammable materials, close to potential sources of ignition. Though Americans are aroused to issues of safety in consumer products, firesafety is not one of their prime concerns. And often when fire strikes, ignorance of what to do leads to panic behavior and aggravation of the hazards, rather than to successful escape."

The fire problem must be addressed as a personal threat; personal behavior before and during fire emergencies must be changed so that individuals will know how to prevent fires, to protect themselves in the event a fire does occur, and to persuade others to prevent and protect themselves from fire.

An important milestone of the late 1970s was introduction into the nation's schoolrooms of firesafety education based upon sound behavioral principles and good learning techniques. NFPA's Learn Not to Burn campaign, which includes both a curriculum and a public information program, is a good example of thoughtfully prepared educational campaigns with specific far-reaching goals. The *Learn Not to Burn Curriculum*[®], in particular, offers the real prospect of reaching all elementary and middle school children by teaching and reinforcing 25 key firesafety behaviors that can be retained for a lifetime. Most dramatically, fire prevention education is moving away from the sporadic and negative, or threatening, methods of promoting firesafety—with mixed results at best—to a more positive and long-lasting approach. While the positive effects on the population as a whole may take years to realize, through 1985 more than 200 cases of lives being saved as a direct result of NFPA's Learn Not to Burn campaign have been recorded.

Mr. Cote is the Assistant Vice President/Standards of the National Fire Protection Association, and is Secretary to the NFPA Standards Council.

Since its beginning, NFPA has sought quantitative measures of the fire problem. Table 1-1A presents a summary of historical statistics published by NFPA during the fifty year period up to 1984. Some of the sharp changes in fire loss estimates evident in Table 1A have resulted from changes in statistical methods rather than from changes in the fire problem.

During 1977 and 1978, NFPA further modified its survey techniques to utilize modern statistical design principles, in the process greatly improving its estimates of the size of the national fire problem.

U.S. CIVILIAN FIRE DEATHS

By most measures the number of civilian (non fire service) fire deaths and the rate of such deaths per million population have declined by about a third since the publication of *America Burning* (NCFPC 1973), which set a goal of cutting the fire problem in half in a generation. America appears to be on schedule to achieve that goal. Fire deaths seem to have declined fairly steadily and significantly since 1977, as shown in Table 1-1B.

Despite sustained declines in U.S. fire deaths, however, the U.S. and Canada still have the highest fire death rates of all developed countries in the free world.

In the late 1970s, a series of reports by the Georgia Institute of Technology showed that fire fatality rates per million population in the U.S. and Canada are at least twice the rates in Japan and western Europe (the only other areas examined). No single cause has been identified to explain this pattern, but analyses have shown that, while the U.S. does well in holding down the average severity of fires, it fares very badly in holding down the fire incident rate.

From 1977 through 1984, an average of 6,633 civilians died each year from fire in the United States. Of this total, an average of 5,634 died in structure fires (85 percent of all fire deaths). Most of the structure fire deaths—96 percent, or an annual average of 5,384 fatalities—occurred in fires in residential structures.

TABLE 1-1A. Fifty-Year Record of U.S. Fire Losses

Years	No. of Fires	No. of Building Fires	Deaths ¹	Deaths per 100,000 Population ¹⁵	Dollar Loss	Loss in 1984 Dollars ¹⁵	
						Total	per Capita
1926	350,000 ²	N/A	10,000 ³	8.5	\$ 560,548,642 ⁴	3.3 Billion	28
1936	643,000 ⁵	N/A	10,000 ⁶	7.8	303,700,000 ⁵	2.3 Billion	14
1946	608,000 ⁷	528,000 ⁸	10,000 ⁹	7.1	580,000,000 ⁷	3.1 Billion	22
1956	1,940,150 ¹⁰	824,400 ¹⁰	12,000 ¹¹	7.1	1,231,576,000 ¹⁰	4.7 Billion	28
1966	2,396,550 ¹²	970,800 ¹²	12,100 ¹³	6.2	1,860,500,000 ¹²	5.9 Billion	30
1977 ¹⁴	3,264,500	1,098,000	7,395	3.4	4,709,000,000	8.1 Billion	37
1984 ¹⁴	2,343,000	848,000	5,240	2.5	6,707,000,000	6.7 Billion	28

Notes:

- ¹ Death estimates prior to 1966 are not specific to a year, but are typical values published by NFPA during the respective periods.
- ² *Fire Protection Handbook*, 8th Edition, 1935, p. 1. Figure is typical of the period, but not specific to a year, and only includes reported fires.
- ³ *Fire Protection Handbook*, 8th Edition, 1935, p. 8.
- ⁴ *NFPA Quarterly*, Vol 21, No. 1, p. 14, July 1927. National Board of Fire Underwriters' estimate.
- ⁵ "Fires and Losses by Occupancy and Cause," Dr. Wayne E. Nolting, *NFPA Quarterly*, Vol. 31, No. 2, October 1937, p. 151.
- ⁶ *Fire Protection Handbook*, 9th Edition, 1941, p. 6.
- ⁷ "Fires and Fire Losses Classified, 1946," *NFPA Quarterly*, Vol. 41, No. 2, p. 135, October 1947.
- ⁸ "Fires and Fire Losses Classified, 1947," *NFPA Quarterly*, Vol. 42, No. 2, p. 103, October 1948.
- ⁹ *Fire Protection Handbook*, 10th Edition, 1948, p. 1.
- ¹⁰ "Fires and Fire Losses Classified, 1956," *NFPA Quarterly*, Vol. 51, No. 2, p. 143, October 1957.
- ¹¹ *Fire Protection Handbook*, 12th Edition, 1962, p. 1-2.
- ¹² "Fires and Fire Losses Classified, 1966," *Fire Journal*, Vol. 61, No. 5, p. 84, September 1967.
- ¹³ "Fire Protection Developments in 1966," Percy Bugbee, *Fire Journal*, Vol. 61, No. 2, p. 43, March 1967.
- ¹⁴ The estimates are based on data reported to the NFPA by fire departments that responded to the 1977 and 1984 NFPA National Fire Experience Survey. Dollar loss figures represent direct property loss only.
- ¹⁵ Population and consumer price index figures taken from Statistical Abstract of the United States and Historical Statistics of the United States, Colonial Times to 1970 (published 1976). Both published by the U.S. Census Bureau.

TABLE 1-1B. U.S. Civilian Fire Deaths (1977-1983)*

	1977	1978	1979	1980	1981	1982	1983	1984
(Homes)‡	5,865	6,015	5,500	5,200	5,400	4,820	4,670	4,075
(Other Residential Structures)§	270	170	265	246	140	120	150	165
(Non-Residential Structures)	370†	165	205	229	220	260	270	285
(Structures Total)	6,505	6,350	5,970	5,675	5,760	5,200	5,090	4,525
(Vehicles)††#**	740	1,255	1,535	740	840	695	725	630
(All Other)††	150	105	70	90	100	125	105	85
	7,395	7,710	7,575	6,505	6,700	6,020	5,920	5,240

- * Estimates are based primarily on data reported to the NFPA by Fire Departments that respond to the NFPA's Annual Survey of Fire Departments for U.S. Fire Experience.
- † Includes the Beverly Hills Supper Club fire that took the lives of 165 people.
- ‡ Homes include one and two family dwellings, mobile homes and apartments.
- § Public residential properties including hotels and motels.
- || Includes public assembly, educational, institutional, store and office, industry, utility, storage and special structure properties.
- # Vehicle fire deaths prior to 1980 were unverified as to whether a reported vehicle death was caused by impact or fire, which may partially account for the high estimates of vehicle deaths for 1978 and 1979.
- ** Includes highway vehicles, trains, boats, ships, aircraft, farm vehicles and construction vehicles.
- †† Includes outside properties with value, as well as brush, rubbish, and other outside locations.

U.S. CIVILIAN FIRE INJURIES

Annual estimates of civilian injuries indicate little change from year to year over the last few years and show that on the average about 30,000 civilians are injured by fire annually in the U.S. Over the eight year period from 1977 to 1984, residential structure fires accounted for approximately 69 percent of all civilian injuries reported to fire departments. Table 1-1C shows civilian fire injuries in the U.S. from 1977 through 1984.

Many fire injuries are not reported to the fire service. These include minor injuries that did not require immediate medical attention, injuries that occurred at small fires the fire department did not attend, or injuries to persons who may not have been transported to medical

facilities by the fire service. For these reasons, the annual estimates for civilian injuries are probably on the low side.

NUMBER OF FIRES AND PROPERTY LOSS

Total fires attended by public fire departments during the 1977 through 1984 period averaged 2,752,100 annually. Over the same period, the number of structure fires averaged 994,000 annually, accounting for 36 percent of all fires. Also for the eight year period, vehicle fires accounted for an annual average of 473,600 fires or 17 percent of all fires, while outside fires and others accounted for an annual average of 1,284,500 fires or 47 percent of all fires. An average of 704,200 fires occurred annually in residential properties, accounting for 71 per-

TABLE 1-1C. U.S. Civilian Injuries (1977-1983)*

	1977	1978	1979	1980	1981	1982	1983	1984
Residential Structures†	22,600	21,260	20,450	21,100	20,375	21,100	21,450	19,275
Non-Residential Structures‡	3,710	3,725	4,400	3,625	5,325	4,475	4,700	3,750
Structures (Total)	26,310	24,985	24,850	24,725	25,700	25,575	26,150	23,025
Vehicles§	3,515	3,720	5,175	4,075	3,400	3,425	3,800	3,600
Other#	1,365	1,120	1,300	1,400	1,350	1,525	1,325	1,500
Total	31,190	29,825	31,325	30,200	30,450	30,525	31,275	28,125

* Estimates are based primarily on data reported to the NFPA by Fire Departments that respond to the NFPA's Annual Survey of Fire Departments for U.S. Fire Experience.

† Includes one and two family dwellings, apartments, hotels and motels and other residential properties.

‡ Includes public assembly, educational, institutional, stores and offices, industry, utility, storage, and special structure properties.

§ Includes highway vehicles, trains, boats, ships, aircraft, farm vehicles and construction vehicles.

Includes outside properties with value, as well as brush, rubbish, and other outside locations.

TABLE 1-1D. Fires Attended by Fire Departments in the U.S. (1977-1984)

	1977	1978	1979	1980	1981	1982	1983	1984
Residential Structures	750,000	730,500	721,500	757,500	733,000	676,500	641,500	623,000
Non-Residential Structures	348,000	331,500	315,000	307,500	294,500	270,000	227,000	225,000
Total Structure Fires	1,098,000	1,062,000	1,036,500	1,065,000	1,027,500	946,500	868,500	848,000
Outside Fires (with value)	130,000	110,000	80,500	86,500	81,000	54,000	49,500	45,000
Vehicles	508,000	503,000	495,500	471,500	466,500	443,000	447,000	454,500
Brush Grass, Wildland (no value)	734,000	582,500	614,500	718,500	711,000	522,500	467,500	487,500
Rubbish	406,000	296,000	342,000	397,000	341,000	309,500	288,000	303,000
All Other	388,500	264,000	276,500	249,500	266,500	262,500	206,000	205,000
TOTAL FIRES	3,264,500	2,817,500	2,845,500	2,988,000	2,893,500	2,538,000	2,326,500	2,343,000

cent of all structure fires over the eight-year period. Table 1-1D shows the number of fires attended by fire departments in the U.S. from 1977 through 1984. Over the 1980-1984 period, the number of structure fires followed a downward trend similar to that noted for all fires to which fire departments responded. The high occurred in 1980 with 1,065,000 fires, and the numbers have decreased each year since. The overall drop in structure fires over the five year period was 20 percent. Figure 1-1A shows the downward trend of all fires from 1980 through 1984.

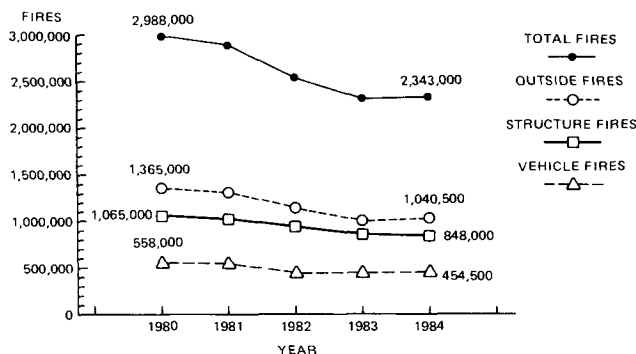
Direct property damage from fire increased over the 1977-1984 period. In 1977, total fires resulted in an estimated property damage of \$4,709,000,000 compared with \$6,707,000,000 in 1984, for an increase of 42 percent over the eight year period. For structure fires, an estimated \$4,125,000,000 in property damage occurred in 1977 com-

pared with \$5,891,000,000 in property damage in 1984—an increase of 43 percent over the eight year period. Structure fires accounted for an average of 88 percent of all fire property loss annually during the 1977-1984 period. Table 1-1E shows direct property loss in the U.S. from 1977 through 1984. Figure 1-1B shows the average property loss per structure in the U.S. from 1980 through 1984.

Over the 1980-1984 period, the average property loss for structures increased 36 percent, from \$5,121 in 1980 to \$6,947 in 1984. However, as Figure 1-1B shows, when the property loss is adjusted for inflation, there is hardly any change (just 8 percent) in the average loss per structure fire over the five year period.

It can be seen that the annual total number of fires has declined in recent years from a peak of more than three million in 1977. Total direct damage has increased, but this increase has been primarily due to inflation. Measured in dollars adjusted for inflation, average loss per fire has increased only slightly. With the decline in the number of fires, total damage in adjusted dollars has actually declined in recent years.

Rough estimates of the total cost of fire in the U.S. indicate that the cost of fire departments, the cost of built-in fire protection in new construction, and the net of fire insurance premiums over losses each involves costs on the same order of magnitude as the direct property damage due to fire.



SOURCE: NFPA'S ANNUAL SURVEY OF FIRE DEPARTMENTS FOR U.S. FIRE EXPERIENCE (1980-84)

FIG. 1-1A. Estimates of fires by type in the United States from 1980 to 1984.

Leading Classes of Fire Ignitions

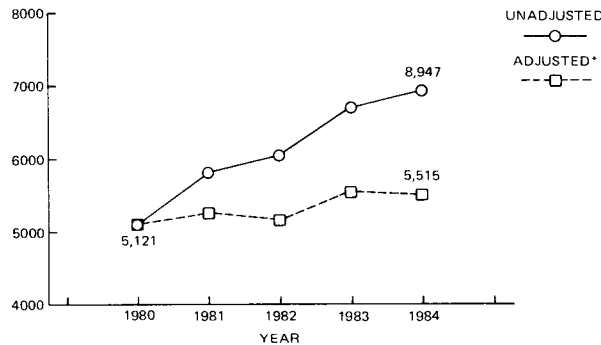
The four leading classes of fire ignitions are as follows:

A. Smoking material related ignitions, account for the largest share of civilian fire deaths, although the number

TABLE 1-1E. Direct Property Loss in the U.S. (1979-1984) × \$1,000,000

	1977	1978	1979	1980	1981	1982	1983	1984
Residential Structures	2,179	2,192	2,529	3,042	3,259	3,253	3,306	3,440
Non-Residential Structures	1,946	1,830	2,435	2,412	2,717	2,478	2,520	2,451
Total Structure Loss	4,125	4,022	4,964	5,454	5,976	5,731	5,826	5,891
Outside Fires (with value)	144	32	38	61	61	52	35	29
Vehicles	332	391	682	685	594	591	694	749
All Other	108	53	66	54	45	58	43	38
Total Property Loss	4,709	4,498	5,750	6,254	6,676	6,432	6,598	6,707

AVERAGE PROPERTY LOSS PER STRUCTURE FIRE



SOURCE: NFPA'S ANNUAL SURVEY OF FIRE DEPARTMENTS FOR U.S. FIRE EXPERIENCE (1980-1984)

*ADJUSTED FOR INFLATION BASED ON CONSUMER PRICE INDEX; 1980 USED AS BASE YEAR.

FIG. 1-1B. Average property loss per structure fire in the United States from 1980 to 1984.

and percentage of deaths due to these causes has been declining in recent years.

B. *Incendiary and suspicious ignitions*, account for the largest share of direct property damage, even in residential properties. The number of fires and dollars of loss in structures have been declining in recent years, however.

C. *Heating equipment related ignitions*, account for the largest share of residential fires. Auxiliary heating equipment related ignitions are the principal factor in the higher fire death rates in rural areas and in the South.

D. *Cooking equipment related ignitions*, account for the largest share of residential fire injuries to civilians and by far the largest share of fires that go unreported to fire departments.

MULTIPLE-DEATH FIRES

Most of the visibility of the fire problem comes from "multiple-death" incidents—fires that kill three or more persons. Deaths in such fires number approximately a thousand per year, considerably more than the combined U. S. totals for earthquakes, tornadoes, hurricanes, floods, and other natural disasters.

Table 1-1F shows the U.S. experience for both residential and non-residential multiple death fires (fires causing three or more deaths) from 1980 through 1984.

Table 1-1G presents the number of catastrophic multiple-death fires resulting in 10 or more deaths over the 1980-1984 period. A number of different types of residential properties experienced this kind of incident. Roughly

TABLE 1-1F. Multiple Death Fires 1980-1984

Year	Number of Multiple-Death Fires	Number of Deaths in Multiple-Death Fires*	Fires Causing 10 or More Deaths	Deaths in Fires Killing 10 or More
1984	244	1,007	5	84
1983	259	986	2	34
1982	266	1,111	7	116
1981	296	1,179	6	95
1980	326	1,356†	6	168†

* Includes both civilian and fire-fighter deaths.

† Includes 85 deaths in the MGM Grand Hotel Fire.

Note: The information presented in this Table for 1980 to 1984 may differ from previously published statistics because of additional information which has become available to the NFPA.

65 percent of both the incidents and deaths during this five year period occurred in residential occupancies.

DIVIDING THE FIRE PROBLEM INTO MANAGEABLE TERMS

There are numerous ways to look at the fire problem. One convenient method is that used in NFPA's Long Range Plan (NFPA 1979) which divides the American environment into eight major components and three topical fire problem areas:

Major Environmental Components

1. The Home Environment
2. The Mobile Environment
3. The American Community
4. The Industrial Environment
5. The Recreational Environment
6. Our Forest and Wildlands
7. Agricultural (Rural) America
8. Our American Heritage

Topical Fire Problem Areas

- A. Public Apathy
- B. Economic Impact of Protection
- C. Incendiarism, Arson, and Suspicious Fires

Each component represents a portion of the overall fire problem in the United States.

THE HOME ENVIRONMENT

The American fire problem is strikingly concentrated in the Home Environment, made up of one and two family dwellings (including mobile homes) and apartments. In