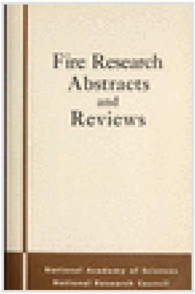

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FIRE RESEARCH ABSTRACTS AND REVIEWS will abstract papers published in scientific journals, progress reports of sponsored research, patents, and research reports from technical laboratories. At intervals, reviews on subjects of particular importance will be published. The coverage will be limited to articles of significance in fire research, centered on the quantitative understanding of fire and its spread.

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1974

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FOREWORD

The state of fire research is chaotic, although the situation is probably neither more nor less confusing than that of the rest of the world. At the present reading (November 1975) FRAR is significantly behind schedule. To remedy this situation we are publishing Volume 16 as a single issue, and we plan to use the same approach for Volume 17. With the completion of these two volumes, we expect to be able to reestablish our currentness with improved coverage. This may cause some minor anachronisms in these two volumes, which we hope the reader will forgive.

The new Administration for the Prevention and Control of Fires is now established as a branch of the federal government under the Department of Commerce. Its charter was passed by the 93rd Congress and signed by the President. The Administration has broad powers under an Administrator and Deputy Administrator, who report directly to the Secretary of Commerce. The President nominated, and the Congress confirmed, Mr. Howard Tipton as Administrator and Mr. David Lucht as Deputy Administrator. The reader will recall that Mr. Tipton was the Executive Secretary of the Presidential Commission on Fire Prevention and Control, which published the influential report, "America Burning." Mr. Lucht was Ohio's State Fire Marshal from April 1974 to January 1975 and initiated a number of important fire prevention and control projects in Ohio. Your editor and the Committee on Fire Research join the fire community in wishing Administrators Tipton and Lucht well in their new endeavors. The Administration will have an enormous influence on the course of fire research in the coming years. Therefore, we have reprinted the enabling legislation (see p. 1) so that the reader can judge for himself the scope of this new presence in the field.

In November 1974, under a Federal Trade Commission consent order, an agreement was made to establish an independent nonprofit research trust to be called the "Products Research Committee." The objective of the committee is to further the understanding of the flammability hazards of cellular polymers. The trust is to be administered by a committee of nine drawn from the government, industrial, and university communities. They will administer a $5 million budget over a five-year period; funds will be provided by the 25 plastic manufacturers through The Society of the Plastics Industry. The nine trustees are:

Walter E. Becker, Jr.	Mobay Chemical Company
Howard W. Emmons	Harvard University
Robert M. Fristrom	APL/The Johns Hopkins University
Irvin Glassman	Princeton University
Donald L. Graham	Dow Chemical Company
Ralph Long	National Science Foundation
John Lyons (Chairman)	National Bureau of Standards
D. W. McDonald	Monsanto Company
Herbert G. Nadeau	Upjohn Company

The Committee chose Lowell R. Perkins of the National Bureau of Standards as the Executive Director. They plan to support a broad program in the area of fire and flammability hazards of cellular plastics through grants and contracts to university, nonprofit, government, and industrial laboratories. Information on the program can be obtained by addressing the chairman:

Dr. John Lyons, Chairman
Products Research Committee
National Bureau of Standards
Building 225, Room B142
Washington, D.C. 20234

This issue begins a new feature edited by Mr. Boris Kuvshinoff of the Applied Physics Laboratory, The Johns Hopkins University. In the Current Literature Section he has collected the titles for the year 1974 of major fire research journals. These titles have been indexed according to subject and author and are collected here at the end of the section. This approach offers a method of broadening the coverage of FRAR. We are normally limited by space and monetary constraints so that many valuable articles are lost to FRAR. Many of these articles will be abstracted, but more than half would not have been covered. The new feature will alert the reader to articles that could not otherwise be abstracted. We hope this new feature will prove useful to the readers of FRAR and, if so, we will try to continue this coverage.

The issue contains two reviews. A paper by Dr. V. Sjolin discusses fire defense education in Sweden. This is an area where Sweden has done some excellent work that we may find useful in this country. A review by Dr. R. Fristrom of the Applied Physics Laboratory, The Johns Hopkins University, covers the problems of flame sampling.

The "Directory of Fire Research in the United States," 7th Edition, 1971-1973, published by the Committee on Fire Research, National Research Council (abstracted on p. 247), lists the many programs and establishments active in the fire field. The relations between the new Fire Prevention and Control Administration and the federal fire research agencies are being established. The Fire Center at the National Bureau of Standards and the Fire Program of NSF/RANN are beginning to show the fruits of continuing programs. An impressive summary of the NSF/RANN work is abstracted on page 243. This bibliography of the NSF/RANN work to date is available as indicated in the abstract. In future issues we hope to carry descriptions of a number of the major fire programs and herewith solicit concise current surveys from large multidisciplinary programs.

ROBERT M. FRISTROM
Editor

CONTENTS

Volume 16

Page

Federal Fire Prevention and Control Act of 1974 1

FIRELITER—Review of 1974 Fire Related Journal Literature—B. W. Kuvshinoff and J. B. Jernigan 18

Fire Technology Education in Sweden—Vilhelm Sjolin 99

Probe Measurements in Laminar Combustion Systems—R. M. Fristrom 109

ABSTRACTS AND REVIEWS

A. Prevention of Fires, Safety Measures, and Retardants

Variations in Hydrocarbon Gas Concentration During Supertanker Cleaning Operations—J. Barstad, J. B. Boler, O. Hjorteland, and E. Solum 145

A Field Study of Non Fire-Resistive Multiple Dwelling Fires—F. L. Brannigan 145

Experimental Appraisal of an American Sprinkler System for the Protection of Goods in High Racked Storages—N. W. Bridge and R. A. Young 146

A Comparison between Potential Hazard Reduction from Fabric Flammability Standards, Ignition Source Improvement and Public Education—B. Buchbinder and A. Vickers 146

Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill—D. Burgess, J. N. Murphy, M. G. Zabetakis, and H. E. Perlee 146

Minimizing Serious Fires and Explosions in the Distilling Process—W. H. Doyle 147

Safety Aspects of Electrical Engineering Practice in the Petroleum Industry—H. Edmonds-Brown 147

Evaluation of the Effectiveness of Anti-Mist Fuel Additives in the Prevention of Vapor Phase Fire and Explosions—G. W. Gandee and R. G. Clodfelter 148

Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of

Organic Interior Building Materials. Part II. Checks on Factors Concerning the Surface Flame Spread Rate and Smoke Evolution of Organic Building Materials by Small Inclined Type Test Furnace—T. Handa, H. Suzuki, A. Takahashi, Y. Ikeda, and M. Saito 148
Design Approach to Fire Safety in Buildings—T. Z. Harmathy 149
Designers Option: Fire Resistance or Ventilation—T. Z. Harmathy 149
Flame Deflectors—T. Z. Harmathy 150
The High Rise Fire Problem—G. A. Harrison 150
Interruption of Explosions by Flame Arresters: First Report on the Quenching Ability of Sintered Metals—T. Hayashi and H. Tarumi ... 151
Flammability of Selected Wood Products under Motor Vehicle Safety Standards—C. A. Holmes 151
Uses and Evaluation of Non-Flammable Elastomeric Materials—W. Krucke 152
Fire Endurance of Concrete-Protected Steel Columns—T. T. Lie and T. Z. Harmathy 152
Electrostatic Hazards in Tank Filling Operations—A. R. Lyle and H. Strawson 153
Respirator Requirements and Practices—J. R. Lynch 153
Fireproofing of Cellular Polyurethane Materials—M. Mallet 153
Vulnerability Assessment of JP-4 and JP-8 under Vertical Gunfire Impact Conditions—J. R. Manheim 154
Aerospace Vehicle Hazard Protection Test Program: Detectors; Materials; Fuel Vulnerability—J. H. O'Neill, D. E. Sommers, and E. B. Nicholas 154
Calculating the Admission of Nitrogen to Prevent Explosions when Underground Fires Are Being Sealed Off—S. N. Osipov, V. Yu. Gorb, and A. Ya. Bovsunovskaya 155
The Use of Nitrogen for Extinguishing an Underground Fire—S. N. Osipov and N. V. Orlov 155
Bibliography on Aircraft Fire Hazards and Safety—J. J. Pelouch, Jr. and P. T. Hacker 156
Investigation of Safe Operation of a Radiant Portable LPG Heater—A. I. Pitt 156
Deficiencies in Safety Schemes which Rely on Stochastically Failing Protective Equipment—J. H. Powell 156
Some Observations on Building Corridor Fires—J. Quintiere 157
Catalytic Reactor for Inerting of Aircraft Fuel Tanks—J. Rousseau and G. H. McDonald 157
High Voltage Equipment for Use in Flammable Atmospheres—Safety in Mines Research Establishment 158
Gas Detection with Semiconductor Metal Oxides—Safety in Mines Research Establishment 158
Synthetic Hydrocarbon Fluid is Fire Resistant, Safer than 5606 Oil—H. Schwenker and J. J. Sullivan 158

Efficient Extraction of Smoke from a Thin Layer under a Ceiling—D. Spratt and A. J. M. Heselden 158
Fail-safe Earth Fault Detection Device for Battery Supplies—L. E. Virr and F. K. Pearson 159
Effect of Fire Retardants on Combustible Materials Underground—Y. Watanabe, *et al.* 159
Evaluation of the Nuclear Fire Threat to Urban Areas—S. J. Wiersma and S. B. Martin 160
The Use of Water Cooling for Protection against Thermal Radiation from a Nuclear Weapon Detonation—D. M. Wilson, B. S. Katz, and D. Demske 161
The Fire Problems of Pedestrian Precincts, Part 5. A Review of Fires in Enclosed Shopping Complexes—H. G. H. Wraight 161

B. Ignition of Fires

The Influence of Flow Parameters on Minimum Ignition Energy and Quenching Distance—D. R. Ballal and A. H. Lefebvre 162
Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill—D. Burgess, J. N. Murphy, M. G. Zabetakis, and H. E. Perlee 162
Some Aspects of Ignition by Localized Sources, and of Cylindrical and Spherical Flames—G. Dixon-Lewis and I. G. Shepherd 162
Effective Heating of Fuel Ahead of Spreading Fire—W. H. Frandesen .. 163
Critical Conditions of Self-Ignition of a Poly-Dispersed Gas Suspension of Solid-Fuel Particles—M. A. Gurevich, G. E. Ozerova, and A. M. Stysanov 163
Examination of the Conditions for the Self-Ignition of Wood: Part II. Critical Conditions and Anisotropy Effect for the Self-Ignition of Wood Spheres Compared with Computer Simulation—T. Handa, H. Suzuki, A. Takahashi, and M. Morita 164
An Evaluation of the Relative Fire Hazards of Jet A and Jet B for Commercial Flight—R. R. Hibbard and P. T. Hacker 165
Flame Spread over a Porous Surface under an External Radiation Field—T. Kashiwagi 165
A Radiative Ignition Model of a Solid Fuel—T. Kashiwagi 165
Criteria of Incipient Combustion in Coal Mines—J. M. Kuchta, M. Hertzberg, R. Cato, C. D. Litton, D. Burgess, and R. W. Van Dolah 166
Initiation of Weak Coal-Dust Explosions in Long Galleries and the Importance of the Time Dependence of the Explosion Pressure—D. Rae 167
Flammability and Combustion Properties of Polyolefinic Materials—J. R. Richard, C. Vovelle, and R. Delbourgo 167
Thermal Degradation and Spontaneous Ignition of Paper Sheets in Air by Irradiation—U. K. Shivadev and H. W. Emmons 168

The Ignition of Corrugated Fibreboard (Cardboard) by Thermal Radiation—H. Wraight 168

C. Detection of Fires

Fire Detection: The State of the Art—R. L. P. Custer and R. G. Bright 169
Sniffing the Fire and Snuffing It—Electrical Review 169
The Infrared Radiance and the Optical Detection of Fires and Explosions—M. Hertzberg, C. D. Litton, W. F. Donaldson, and D. Burgess 170
The Relationship between the Testing, Utilization and Assessment of Fire Detectors—H. Luck 170
Aerospace Vehicle Hazard Protection Test Program: Detectors; Materials; Fuel Vulnerability—J. H. O'Neill, D. E. Sommers, and E. B. Nicholas 170
Approvals Criteria for Automatic Fire Detectors and Alarm Systems—R. W. Pickard 170
Response Characteristics of Smoke Detectors in the Early Stage of Fire—A. Watanabe and A. Takemoto 171
Automatic Fire Detection Equipment—R. B. Whitehouse 171

D. Propagation of Fires

Fire Spread over Paper—A. S. Campbell 172
Laminar Flame Spread over PMMA Surfaces—A. Fernandez-Pello and F. A. Williams 172
Fire Spread through Porous Fuels from the Conservation of Energy—W. H. Frandsen 172
Effective Heating of Fuel Ahead of a Spreading Fire—W. H. Frandsen 173
Analysis of the Surface Flame Spread of Organic Building Materials, Part I. Surface Flame on Plywood Materials in an Inclined Tunnel Furnace as a Model of the Initial Cause of Fire—T. Handa and A. Takahashi 173
An Evaluation of the Relative Fire Hazards of Jet A and Jet B for Commercial Flight—R. R. Hibbard and P. T. Hacker 173
Effects of Radiation and Convection on Gas Velocity and Temperature Profiles of Flames Spreading over Paper—T. Hirano and K. Sato 174
Experimental Observation of Flame Spread Characteristics over Selected Carpets—T. Kashiwagi 174
Flame Spread over a Porous Surface under an External Radiation Field—T. Kashiwagi 174
A Study of Flame Spread over a Porous Material under External Radiation Fluxes—T. Kashiwagi 175
Mechanism of the Inhibition of Combustion of Hydrocarbon-Air Mixtures by Finely Dispersed Particles—G. I. Ksandopulo, B. Ya. Kolesnikov, V. A. Zavadskii, D. S. Odnorog, and T. P. Elovskaya 175

The Burning of Vertical Wooden Slabs—H. Kung 175
Upward Turbulent Fire Spread and Burning of Fuel Surface—L. Orloff, J. de Ris, and G. H. Markstein 176
Fire Spread over Liquid Fuels: Liquid Phase Parameters—K. E. Torrance and R. L. Mahajan 177
Experimental Structural Fires—T. E. Waterman 177

E. Suppression of Fires

The Destruction of High Expansion Fire-Fighting Foam by the Components of Fuel Pyrolysis and Combustion. III. Tests of Full Scale Foam Generators Equipped with Scrubbers—R. S. Alger and N. J. Alvares 178
Development and Evaluation of Practical Self-Help Fire Retardants—A. J. Amaro and A. E. Lipska 178
Flame Structure Studies of CF_3Br - Inhibited Methane Flames. II. Kinetics and Mechanisms—J. C. Biordi, C. P. Lazzara, and J. F. Papp 179
Firefighting Effectiveness of Aqueous - Film - Forming - Foam (AFFF) Agents—G. B. Geyer 180
Recent Research Concerning Extinguishment of Coal Dust Explosions—J. Grumer 180
Interruption of Explosions by Flame Arresters: First Report on the Quenching Ability of Sintered Metals—T. Hayashi and H. Turumi 181
Cooling Explosive Products from Methane-Air Mixtures in a Slot between Steel and Plastic Flanges—A. A. Kaimakov and A. N. Bauer 181
Extinction of Laminar Diffusion Flames for Liquid Fuels—J. H. Kent and F. A. Williams 181
Mechanism of the Inhibition of Combustion of Hydrocarbon-Air Mixtures by Finely Dispersed Particles—G. I. Ksandopulo, B. Ya. Kolesnikov, V. A. Zavadskii, D. S. Odnorog, and T. P. Elovskaya 182
Suppression of Evaporation of Hydrocarbon Liquids and Fuels by Films Containing Aqueous Film Forming Foam (AFFF) Concentrate FC-196—J. T. Leonard and J. C. Burnett 182
A Summary of Experimental Data on the Maximum Experimental Safe Gap—G. A. Lunn and H. Phillips 183
Extinguishment of Radiation Augmented Plastic Fires by Water Sprays—R. S. Magee and R. D. Reitz 183
Theory of Suppression of Explosions by Narrow Gaps—H. Phillips 184
Extinction Phenomena in Liquids—A. F. Roberts 184
The Mechanism of Flame Inhibition by Sodium Salts—K. Sridhar Iya, S. Wollowitz, and W. E. Kaskan 185
Mine Explosion Suppression Method and Apparatus—U.S. Patent 3,684,021, August 15, 1972 186

F. Fires, Damage, and Salvage

Smoke Extraction by Intrainment into a Ducted Water Spray—H. P. Morgan and M. L. Bullen 186
Effects of Decomposition Products of PVC in Fire on Structural Concrete—W. A. Morris and J. S. Hopkinson 186
Smoke Generation from Building Materials—F. Saito 187

G. Combustion Engineering and Tests

A Chromatographic and Interferometric Study of the Diffusion Flame around a Simulated Fuel Drop—S. I. Abdel-Khalik, T. Tamaru, and M. M. El-Wakil 187
Further Studies of the Fire Resistance of Reinforced Concrete Columns—D. E. Allen and T. T. Lie 188
Gas Explosions in Buildings, Part 2. The Measurement of Gas Explosion Pressures—S. A. Ames 188
A Laboratory Fire Test for Foam Liquids—S. P. Benson, P. R. Bevan, and J. G. Corrie 189
Further Experiments on Turbulent Jet Diffusion Flames—R.W. Bilger and R. E. Beck 189
How Fourteen Coating Systems Affected Smoke Yield from Douglas Fir Plywood—J. J. Brenden 190
Standardization of Halogen Fire Extinguisher Agents—R. Bröll 190
Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill—D. Burgess, J. N. Murphy, M. G. Zabetakis, and H. E. Perlee 190
Gas Explosions in Buildings, Part III. A Rapid Multichannel Automatic Chromatographic Gas Analysis System—R. N. Butlin, S. A. Ames, and C. F. J. Berlemont 190
The Role of Buoyancy Direction and Radiation in Turbulent Diffusion Flames on Surfaces—J. de Ris and L. Orloff 191
Overall Reaction Rates of NO and N_2 Formation from Fuel Nitrogen—G. G. De Soete 191
Fire Resistance of Solid-Core Wood Flush Doors—H. W. Eickner 192
Measurements of the Behavior of Incidental Fires in a Compartment—J. B. Fang 192
Contribution of Interior Finish Materials to Fire Growth in a Room—J. B. Fang and D. Gross 193
Fire Spread through Porous Fuels from the Conservation of Energy—W. H. Frandsen 193
The Effect of Pressure on the Flame Structure in the Wake of a Burning Hydrocarbon Droplet—S. R. Gollahalli and T. A. Brzustowski 193
Critical Conditions of Self-Ignition of a Poly-Dispersed Gas Suspension of Solid-Fuel Particles—M. A. Gurevich, G. E. Ozerova, and A. M. Stysanov 194

Polymer Surface Reflectance Absorptance Characteristics—J. R. Hallman, J. R. Welker, and C. M. Sliepcevich 194
Characterization of the Mode of Combustion and Smoke Evolution of Organic Materials in Fires. Part II. Analysis of the Change in Particle Size of Polystyrene Smoke Particles Due to Secondary Oxidation—T. Handa, H. Suzuki, and A. Takahashi 195
Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part II. Checks on Factors Concerning the Surface Flame Spread Rate and Smoke Evolution of Organic Building Materials by Small Inclined Type Test Furnace—T. Handa, H. Suzuki, A. Takahashi, Y. Ikeda, and M. Saito 195
Commensurability Problems in Fire Endurance Testing—T. Z. Harmathy 196
Development of a Radiant Panel Test for Flooring Material—L. G. Hartzell 196
The Behavior of Nitrogen Species in Fuel Rich Hydrocarbon Flames—B. S. Haynes, N. Y. Kirov, and D. Iverach 196
Gas Velocity and Temperature Profiles of a Diffusion Flame Stabilized in the Stream over Liquid Fuel—T. Hirano and M. Konoshita 197
Effects of Radiation and Convection on Gas Velocity and Temperature Profiles of Flames Spreading over Paper—T. Hirano and K. Sato 198
Correlations of ASTM Exposure Tests for Evaluating Durability of Fire-Retardant Treatments of Wood—C. A. Holmes 198
Flammability of Selected Wood Products under Motor Vehicle Safety Standards—C. A. Holmes 198
Diffusion Controlled Combustion of Polymers—D. J. Holve and R. F. Sawyer 198
Predictions of Laminar Flame Speeds in Boron-Oxygen-Nitrogen Dust Clouds—M. K. King 199
Mechanism of the Inhibition of Combustion of Hydrocarbon-Air Mixtures by Finely Dispersed Particles—G. I. Ksandopulo, B. Ya. Kolesnikov, V. A. Zavadskii, D. S. Odnorog, and T. P. Elovskaya 199
Fire Endurance of Concrete-Protected Steel Columns—T. T. Lie and T. Z. Harmathy 200
A Summary of Experimental Data on the Maximum Experimental Safe Gap—G. A. Lunn and H. Phillips 200
Radiative Energy Transfer from Gaseous Diffusion Flames—G. H. Markstein 200
Breakdown of Cyanogen in Fuel Rich H_2-N_2-O_2 Flames—J. N. Mulvihill and L. F. Phillips 200
Aerospace Vehicle Hazard Protection Test Program: Detectors; Materials; Fuel Vulnerability—J. H. O'Neill, D. E. Sommers, and E. B. Nicholas 201
Studies on the Structure of a Spray Combustion Flame—Y. Onuma and M. Ogasawara 202

Counterflow Diffusion Flame of Ethyl Alcohol—T. P. Pandya and N. K. Srivastava 202
Fire Build Up in Reduced Size Enclosures—W. J. Parker and B. T. Lee .. 202
Production of Chemi-Ions and Formation of CH and CH_2 Radicals in Methane-Oxygen and Ethylene-Oxygen Flames—J. Peeters and C. Vinckier 203
NO_x Emissions from Fluidized - Bed Coal Combustors—F. J. Pereira, J. M. Beer, B. Gibbs, and A. B. Hedley 204
Theory of Heterogeneous Combustion Instabilities of Spherical Particles—N. Peters 204
The Use of a Thermal Model of Ignition to Explain Aspects of Flame-proof Enclosure—H. Phillips 204
An Evaluation of Flame Spread Test Methods for Floor Covering Materials—J. Quintiere and C. Huggett 205
Some Observations on Building Corridor Fires—J. Quintiere 205
Flammability and Combustion Properties of Polyolefinic Materials—J. R. Richard, C. Vovelle, and R. Delbourgo 205
Some Aspects of Fire Behavior in Tunnels—A. F. Roberts 206
Relationship between the Burning Rate of a Mixture and the Chemical Structure of the Fuel—L. D. Romodanova, V. I. Pepekin, A. Ya. Apin, and P. F. Pokhil 206
Smoke Generation from Building Materials—F. Saito 206
Gas Explosions in Buildings, Part V. Strain Measurements on the Gas Explosion Chamber—M. Senior 206
Estimates of the Effect of Flame Size on Radiation from Fires—M. Sibulkin 207
Smoke and Toxic Gases from Burning Building Materials. 1. A Test Rig for Large Scale Fires—G. W. V. Stark and P. Field 207
The Tranas Fire Tests. Field Studies of Heat Radiation from Fires in a Timber Structure—I. Strōmdahl 208
Characterization of Factors in Estimating Fire Hazard by Furnace Test
Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part I. Checks on the Factors in Estimating Fire Hazard of Several Organic Building Materials—H. Suzuki, T. Handa, Y. Ikeda, and M. Saito 211
The Effect of Crib Porosity in Recent CIB Experiments—P. H. Thomas . 212
Smoke Producing Characteristics of Materials—Y. Tsuchiya and K. Sumi 212
Effect of Fire Retardants on Combustible Materials Underground—Y. Watanabe, *et al.* 212
Experimental Structural Fires—T. E. Waterman 212
Concentration and Mass Distribution of Charged Species in Sooting Flames—B. L. Wersborg, A. C. Yeung, and J. B. Howard 212
The Smoke Emission Properties of Materials Used in Mines—S. Yamao 213

H. Chemical Aspects of Fires

The Destruction of High Expansion Fire-Fighting Foam by the Components of Fuel Pyrolysis and Combustion. III. Tests of Full Scale Foam Generators Equipped with Scrubbers—R. S. Alger and N. J. Alvares ... 214
Development and Evaluation of Practical Self-Help Fire Retardants—A. J. Amaro and A. E. Lipska ... 214
Flame Structure Studies of CF_3Br-Inhibited Methane Flames. II. Kinetics and Mechanisms—J. C. Biordi, C. P. Lazzara, and J. F. Papp ... 214
Mechanism of Ion and Emitter Formation Due to Cyanogen in Hydrogen-Oxygen-Nitrogen Flames—M. A. Bredo, P. J. Guillaume, and P. J. Van Tiggelen ... 214
The Kinetics of Formation of Chloride Ions in Atmospheric-Pressure Flames by $HCl + e^- \rightarrow Cl^- + H$—N. A. Burdett and A. N. Hayhurst ... 215
Gas Explosions in Buildings, Part III. A Rapid Multichannel Automatic Chromatographic Gas Analysis System—R. N. Butlin, S. A. Ames, and C. F. J. Berlemont ... 216
NO and NO_2 Formation in a Turbulent Hydrocarbon-Air Diffusion Flame—N. P. Cernansky and R. W. Sawyer ... 216
Overall Reaction Rates of NO and N_2 Formation from Fuel Nitrogen—G. G. De Soete ... 216
Reactions in the Recombination Region of Hydrogen and Lean Hydrocarbon Flames—G. Dixon-Lewis, J. B. Greenberg, and F. A. Goldsworthy ... 216
The Behavior of Nitrogen Species in Fuel Rich Hydrocarbon Flames—B. S. Haynes and N. Y. Kirov ... 218
Calorimetric Bead Techniques for the Measurement of Kinetic Data for Solid Heterogeneous Reactions—A. Jones, J. G. Firth, and T. A. Jones ... 218
Structure in Methane-Oxygen Diffusion Flames—A. Melvin and J. B. Moss ... 218
Nitrogen Oxide Formation in Flames: The Roles of NO_2 and Fuel Nitrogen—E. L. Merryman and A. Levy ... 219
Breakdown of Cyanogen in Fuel Rich H_2-N_2-O_2 Flames—J. N. Mulvihill and L. F. Phillips ... 219
Emission of Small Quantities of Gas and Odours in the Spontaneous Combustion of Coal—N. Oda and I. Naruse ... 220
Production of Chemi-Ions and Formation of CH and CH_2 Radicals in Methane-Oxygen and Ethylene-Oxygen Flames—J. Peeters and C. Vinckier ... 220
The Effect of Two Flame Retardants on Particulate and Residue Production—C. W. Philpot, C. W. George, A. D. Blakely, G. M. Johnson, and W. H. Wallace ... 220
The Pyrolysis Products and Thermal Characteristics of Cottonwood and Its Components—C. W. Philpot ... 221

Relationship between the Burning Rate of a Mixture and the Chemical Structure of the Fuel—L. D. Romodanova, V. I. Pepekin, A. Ya. Apin, and P. F. Pokhil 221
Catalytic Reactor for Inerting of Aircraft Fuel Tanks—J. Rousseau and G. H. McDonald 221
Gas Explosions in Buildings, Part V. Strain Measurements on the Gas Explosion Chamber—M. Senior 222
The Role of Soot in Transport of Hydrogen Chloride from Fires—J. P. Stone, F. W. Williams, and H. W. Carhart 222
A Study on Nitric Oxide Formation in Turbulent Diffusion Flames—T. Takagi, M. Ogasawara, M. Daizo, and K. Fujii 222
Rate Constant of the Elementary Reaction of Carbon Monoxide with Hydroxyl Radical—J. Vandooren, J. Peeters, and P. J. Van Tiggelen 223
Chemical Kinetics of Reactions of Chlorine, Chlorine Oxides and Hydrogen Chloride in Gas Phase: A Bibliography—F. Westley 223

I. Physical Aspects of Fires

Measuring Methods for Determining Droplet Size—A. Bürkholz 224
Laminar Flame Spread over PMMA Surfaces—A. Fernandez-Pello and F. A. Williams 224
Influence of Mine Fires on the Ventilation of Underground Mines—R. E. Greuer 224
Polymer Surface Reflectance Absorptance Characteristics—J. R. Hallman, J. R. Welker, and C. M. Sliepcevich 225
Aerosol Measurement by Laser Doppler Spectroscopy. I. Theory and Experimental Results for Aerosols Homogeneous—W. Hinds and P. C. Reist 225
Aerosol Measurement by Laser Doppler Spectroscopy. II. Operational Limits, Effects of Polydispersity, and Applications—W. Hinds and P. C. Reist 225
Visibility through Fire Smoke—T. Jin 226
Experimental Study of the Electrification Produced by Dispersion of Dust into the Air—A. K. Kamra 226
Gross Vortex Activities in a Simple Simulated Urban Fire—S. L. Lee and F. W. Otto 227
Characterization of Dispersed Systems, Particle Size Analysis—K. Leschonski 227
Radiative Energy Transfer from Gaseous Diffusion Flames—G. H. Markstein 227
Nonluminous Radiation from Hydrocarbon-Air Diffusion Flames—A. T. Modak 228
Experiments in Gasdynamics of Explosions—A. K. Oppenheim and R. I. Soloukin 228

A Physical Description of Coal Mine Explosions—J. K. Richmond and I. Liebman 229
Thermal Degradation and Spontaneous Ignition of Paper Sheets in Air by Irradiation—U. K. Shivadev and H. W. Emmons 229
Estimates of the Effect of Flame Size on Radiation from Fires—M. Sibulkin 229
Experimental Structural Fires—T. E. Waterman 229

J. Meteorological Aspects of Fires

Gross Vortex Activities in a Simple Simulated Urban Fire—S. L. Lee and F. W. Otto 229

K. Physiological and Psychological Problems from Fires

Toxicologic Aspects of Flammability and Combustion of Polymeric Materials—J. Autian 230
Physiological and Toxicological Effects of the Products of Thermal Decomposition from Polymeric Materials—M. M. Birky 230
A Comparison between Potential Hazard Reduction from Fabric Flammability Standards, Ignition Source Improvement, and Public Education—B. Buchbinder and A. Vickers 231
Respirator Requirements and Practices—J. R. Lynch 231
Epidemiology of Burns, the Burn-Prone Patient—J. D. MacArthur and F. D. Moore 231
Breathing Resistance of Respiratory Apparatus—Safety in Mines Research Establishment 231
The Role of Soot in Transport of Hydrogen Chloride from Fires—J. P. Stone, F. W. Williams, and H. W. Carhart 232
Combined Lethal Effect of Temperature, CO, CO_2 and O_2 of Simulated Fire Gases—Y. Tsuchiya and K. Sumi 232
Carbon Monoxide Toxicity in Human Fire Victims—H. A. Zarem, C. C. Rattenborg, and M. H. Harmel 232

L. Operations Research, Mathematical Methods, and Statistics

COMPF: A Program for Calculation Post Flashover Fire Temperatures—V. Babrauskas 233
A Field Study of Non-Fire Resistive Multiple Dwelling Fires—F. L. Brannigan 233
Preliminary Analysis of Fire Reports from Fire Brigades in the United Kingdom, 1973—S. E. Chandler 233
Predicting the Losses in Sawtimber Volume and Quality from Fires in Oak-Hickory Forests—R. M. Loomis 233
Fire in Wildland Management Predicting Changes in Chaparral Flammability—R. C. Rothermel and C. W. Philpot 234

Matches and Lighters in Flammable Fabric Incidents: The Magnitude of the Problem—J. A. Slater, B. Buchbinder, and H. Tovey 234
Fire Incidents Involving Sleepwear Worn by Children Ages 6-12—J. A. Slater 235
Drapery and Curtain Fires - Data Element Summary of Case Histories—A. K. Vickers 235
Study on the Fire Spread Formula for Forest Fires—K. Yasuno 236

M. Model Studies and Scaling Laws

Laminar Flame Spread over PMMA Surfaces—A. Fernandez-Pello and F. A. Williams 236
The Burning of Vertical Wood Slabs—H. Kung 236
Gross Vortex Activities in a Simple Simulated Urban Fire—S. L. Lee and F. W. Otto 236
Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part II. Checks on Factors Concerning the Surface Flame Spread Rate and Smoke Evolution of Organic Building Materials by Small Inclined Type Test Furnace—T. Handa, H. Suzuki, A. Takahashi, Y. Ikeda, and M. Saito 237
A Sandbox Model Used to Examine the Stress Distribution around a Simulated Longwall Coal-Face—G. W. Harris 237
Modeling of Pool Fires with a Variety of Polymers—A. Murty Kanury 237
Fire Build Up in Reduced Size Enclosures—W. J. Parker and B. T. Lee 238
A Mathematical Model for Predicting Fire Spread in Wildland Fuels—R. C. Rothermel 238
Fire in Wildland Management Predicting Changes in Chaparral Flammability—R. C. Rothermel and C. W. Philpot 238
Simulation of Southern California Forest Fires—A. E. Stevenson, D. A. Schermerhorn, and S. C. Miller 238

N. Instrumentation and Fire Equipment

A Mobile Field Laboratory for Fires of Opportunity—R. S. Alger and J. R. Nichols 239
A Calorimeter for Measuring the Heat Flux from Experimental Fires—S. P. Benson and J. G. Corrie 239
Development of a Long Duration Flow Facility for Studies of Blast Fire Interaction—J. H. Boyes, M. P. Kennedy, and C. Wilton 239
An Apparatus Developed to Measure Rate of Heat Release from Building Materials—J. J. Brenden 240
Laser Anemometer Measurements in Flames with Swirl—N. A. Chigier and K. Dvorak 240

Advances in High Speed Photography—J. S. Courtney-Pratt 241
A Report on the Tenth International Congress on High Speed Photography, Nice, 25-30 September, 1972—C. H. Elmer and L. L. Endelman 241
Calibration of a Hot-Wire Anemometer for Velocity Perturbation Measurements—R. Kinns 241
The Response of a Hot-Wire Anemometer in Flows of Gas Mixtures—J. McQuaid and W. Wright 242
Development of a Heat Release Rate Calorimeter at NBS—W. J. Parker and M. E. Long 242
Gas Explosions in Buildings, Part I. Experimental Explosion Chamber—P. S. Tonkin and C. F. J. Berlemont 243

O. Miscellaneous

Bibliography of RANN-Supported Fire Research Literature—B. W. Kuvshinoff and J. Jernigan 243
The Effect of Structural Characteristics on Dwelling Fire Statistics—W. J. Christian 245
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Attacking the Fire Problem; A Plan for Action—K. Giles and P. Powell 252
Consequences of LNG Spills on Land—Battelle Columbus Laboratories . 253
Fire Protection Abroad; USSR; Respiration Training of Firemen—F. Obukhov 254
Bibliography on Aircraft Fire Hazards and Safety—J. J. Pelouch, Jr. and P. T. Hacker 257
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Fire Fighting Hydraulics—R. Purington 261
Heat Transfer in Fires: Thermophysics, Social Aspects, Economic Impact—P. L. Blackshear, Ed. 262

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Problems in Combustion and Extinguishment, Collection of Articles—I. V. Ryabov, A. N. Baratov, and I. I. Petrov, Eds. 265

PERIODICALS

Flammability News Bulletin 3—E. E. Stahly, U.S. Editor, S. B. Sello, Co-editor, J. DiPietro, International Editor 266

MEETINGS

Symposium on Fire Detection for Life Safety, March 31-April 1, 1975, Committee on Fire Research, National Research Council, National Academy of Sciences, Washington, D.C.; Chairman: W. J. Christian 266
Symposium on Flammability and Burning Characteristics of Materials and Fuels, Central and Western States Sections, The Combustion Institute, April 21-22, 1975, San Antonio, Texas; Meeting Chairman: W. McLain 267
Symposium on Physiological and Toxicological Aspects of Combustion Products, Committee on Fire Research, National Research Council, National Academy of Sciences and the Flammability Research Center, University of Utah, Salt Lake City, Utah, March 18-20, 1974; Chairman: I. N. Einhorn 270
Symposium on Products of Combustion of (Plastics) Building Materials, March 25-26, 1973, Research and Development Center, Armstrong Cork Company, Lancaster, Pennsylvania; Chairman: H. J. Roux 273
Second Seminar and Workshop in the Teaching of Fire Sciences, April 27-28, 1974, Northern Virginia Community College, Annandale, Virginia; Proceedings Editor R. L. Tuve 274
National Science Foundation, Research Applied to National Needs Conference on Fire Research, May 28-29, 1974, Georgia Institute of Technology, Atlanta, Georgia 275
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FEDERAL FIRE PREVENTION AND CONTROL ACT OF 1974

Public Law 93-498
93rd Congress, S. 1769
October 29, 1974

An Act

To reduce losses of life and property, through better fire prevention and control, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Federal Fire Prevention and Control Act of 1974."

FINDINGS

SEC. 2. The Congress finds that—

(1) The National Commission on Fire Prevention and Control, established pursuant to Public Law 90-259, has made an exhaustive and comprehensive examination of the Nation's fire problem, has made detailed findings as to the extent of this problem in terms of human suffering and loss of life and property, and has made ninety thoughtful recommendations.

(2) The United States today has the highest per capita rate of death and property loss from fire of all the major industrialized nations in the world.

(3) Fire is an undue burden affecting all Americans, and fire also constitutes a public health and safety problem of great dimensions. Fire kills 12,000 and scars and injures 300,000 Americans each year, including 50,000 individuals who require extended hospitalization. Almost $3 billion worth of property is destroyed annually by fire, and the total economic cost of destructive fire in the United States is estimated conservatively to be $11,000,000,000 per year. Firefighting is the Nation's most hazardous profession.

(4) Such losses of life and property from fire are unacceptable to the Congress.

(5) While fire prevention and control is and should remain a State and local responsibility, the Federal Government must help if a significant reduction in fire losses is to be achieved.

(6) The fire service and the civil defense program in each locality would both benefit from closer cooperation.

(7) The Nation's fire problem is exacerbated by

(A) the indifference with which some Americans confront the subject;

(B) the Nation's failure to undertake enough research and development into fire and fire-related problems;

(C) the scarcity of reliable data and information;

(D) the fact that designers and purchasers of buildings and products generally give insufficient attention to fire safety;

(E) the fact that many communities lack adequate building and fire prevention codes; and

(F) the fact that local fire departments spend about 95 cents of every dollar appropriated to the fire services on efforts to extinguish fires and only about 5 cents on fire prevention.

(8) There is a need for improved professional training and education oriented toward improving the effectiveness of the fire services, including an increased emphasis on preventing fires and on reducing injuries to firefighters.

(9) A national system for the collection, analysis, and dissemination of fire data is needed to help local fire services establish research and action priorities.

(10) The number of specialized medical centers which are properly equipped and staffed for the treatment of burns and the rehabilitation of victims of fires is inadequate.

(11) The unacceptably high rates of death, injury, and property loss from fire can be reduced if the Federal Government establishes a coordinated program to support and reinforce the fire prevention and control activities of State and local governments.

PURPOSES

SEC. 3. It is declared to be the purpose of Congress in this Act to—

(1) reduce the Nation's losses caused by fire through better fire prevention and control;

(2) supplement existing programs of research, training, and education, and to encourage new and improved programs and activities by State and local governments;

(3) establish the National Fire Prevention and Control Administration and the Fire Research Center within the Department of Commerce; and

(4) establish an intensified program of research into the treatment of burn and smoke injuries and the rehabilitation of victims of fires within the National Institutes of Health.

DEFINITIONS

SEC. 4. As used in this Act, the term—

(1) "Academy" means the National Academy for Fire Prevention and Control;

(2) "Administration" means the National Fire Prevention and Control Administration established pursuant to section 5 of this Act;

(3) "Administrator" means the Administrator of the National Fire Prevention and Control Administration;

(4) "fire service" means any organization in any State consisting of personnel, apparatus, and equipment which has as its purpose protecting property

and maintaining the safety and welfare of the public from the dangers of fire, including a private fire-fighting brigade. The personnel of any such organization may be paid employees or unpaid volunteers or any combination thereof. The location of any such organization and its responsibility for extinguishment and suppression of fires may include, but need not be limited to, a Federal installation, a State, city, town, borough, parish, county, fire district, fire protection district, rural fire district, or other special district. The terms "fire prevention", "firefighting", and "firecontrol" relate to activities conducted by a fire service;

(5) "local" means of or pertaining to any city, town, county, special purpose district, unincorporated territory, or other political subdivision of a State;

(6) "Secretary" means the Secretary of Commerce; and

(7) "State" means any State, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, the Canal Zone, Guam, American Samoa, the Trust Territory of the Pacific Islands and any other territory or possession of the United States.

ESTABLISHMENT OF THE NATIONAL FIRE PREVENTION AND CONTROL ADMINISTRATION

SEC. 5. (a) *Establishment of Administration.*—There is hereby established in the Department of Commerce an agency which shall be known as the National Fire Prevention and Control Administration.

(b) *Administrator.*—There shall be at the head of the Administration the Administrator of the National Fire Prevention and Control Administration. The Administrator shall be appointed by the President, by and with the advice and consent of the Senate, and shall be compensated at the rate now or hereafter provided for level IV of the Executive Schedule pay rates (5 U.S.C. 5315). The Administrator shall report and be responsible to the Secretary.

(c) *Deputy Administrator.*—There shall be in the Administration a Deputy Administrator of the National Fire Prevention and Control Administration who shall be appointed by the President, by and with the advice and consent of the Senate, and who shall be compensated at the rate now or hereafter provided for level V of the Executive Schedule pay rates (5 U.S.C. 5316). The Deputy Administrator shall perform such functions as the Administrator shall from time to time assign or delegate, and shall act as Administrator during the absence or disability of the Administrator or in the event of a vacancy in the office of Administrator.

PUBLIC EDUCATION

SEC. 6. The Administrator is authorized to take all steps necessary to educate the public and to overcome public indifference as to fire and fire prevention. Such steps may include, but are not limited to, publications, audio-visual presentations, and demonstrations. Such public education efforts shall include programs to provide specialized information for those groups of individuals who are particularly vulnerable to fire hazards, such as the young and the elderly. The Administrator shall sponsor and encourage research, testing, and experimentation to determine the most effective means of such public education.

NATIONAL ACADEMY FOR FIRE PREVENTION AND CONTROL

SEC. 7. (a) *Establishment.*—The Secretary shall establish, at the earliest practicable date, a National Academy for Fire Prevention and Control. The purpose of the Academy shall be to advance the professional development of fire service personnel and of other persons engaged in fire prevention and control activities.

(b) *Superintendent.*—The Academy shall be headed by a Superintendent, who shall be appointed by the Secretary. In exercising the powers and authority contained in this section the Superintendent shall be subject to the direction of the Administrator.

(c) *Powers of Superintendent.*—The Superintendent is authorized to—

(1) develop and revise curricula, standards for admission and performance, and criteria for the awarding of degrees and certifications;

(2) appoint such teaching staff and other personnel as he determines to be necessary or appropriate;

(3) conduct courses and programs of training and education, as defined in subsection (d) of this section;

(4) appoint faculty members and consultants without regard to the provisions of title 5, United States Code, governing appointments in the competitive service, and, with respect to temporary and intermittent services, to make appointments to the same extent as is authorized by section 3109 of title 5, United States Code;

(5) establish fees and other charges for attendance at, and subscription to, courses and programs offered by the Academy. Such fees may be modified or waived as determined by the Superintendent;

(6) conduct short courses, seminars, workshops, conferences, and similar education and training activities in all parts and localities of the United States;

(7) enter into such contracts and take such other actions as may be necessary in carrying out the purposes of the Academy; and

(8) consult with officials of the fire services and other interested persons in the exercise of the foregoing powers.

(d) *Program of the Academy.*—The Superintendent is authorized to—

(1) train fire service personnel in such skills and knowledge as may be useful to advance their ability to prevent and control fires, including, but not limited to—

(A) techniques of fire prevention, fire inspection, firefighting, and fire and arson investigation;

(B) tactics and command of firefighting for present and future fire chiefs and commanders;

(C) administration and management of fire services;

(D) tactical training in the specialized field of aircraft fire control and crash rescue;

(E) tactical training in the specialized field of fire control and rescue aboard waterborne vessels; and

(F) the training of present and future instructors in the aforementioned subjects;

(2) develop model curricula, training programs, and other educational materials suitable for use at other educational institutions, and to make such materials available without charge;

(3) develop and administer a program of correspondence courses to advance the knowledge and skills of fire service personnel;

(4) develop and distribute to appropriate officials model questions suitable for use in conducting entrance and promotional examinations for fire service personnel; and

(5) encourage the inclusion of fire prevention and detection technology and practices in the education and professional practice of architects, builders, city planners, and others engaged in design and planning affected by fire safety problems.

(e) *Technical Assistance.*—The Administrator is authorized, to the extent that he determines it necessary to meet the needs of the Nation, to encourage new programs and to strengthen existing programs of education and training by local fire services, units, and departments, State and local governments, and private institutions, by providing technical assistance and advice to—

(1) vocational training programs in techniques of fire prevention, fire inspection, firefighting, and fire and arson investigation;

(2) fire training courses and programs at junior colleges; and

(3) four-year degree programs in fire engineering at colleges and universities.

(f) *Assistance.*—The Administrator is authorized to provide assistance to State and local fire service training programs through grants, contracts, or otherwise. Such assistance shall not exceed 4 per centum of the amount authorized to be appropriated in each fiscal year pursuant to section 17 of this Act.

(g) *Site Selection.*—The Academy shall be located on such site as the Secretary selects, subject to the following provisions:

(1) The Secretary is authorized to appoint a Site Selection Board consisting of the Academy Superintendent and two other members to survey the most suitable sites for the location of the Academy and to make recommendations to the Secretary.

(2) The Site Selection Board in making its recommendations and the Secretary in making his final selection, shall give consideration to the training and facility needs of the Academy, environmental effects, the possibility of using a surplus Government facility, and such other factors as are deemed important and relevant. The Secretary shall make a final site selection not later than 2 years after the date of enactment of this Act.

(h) *Construction Costs.*—Of the sums authorized to be appropriated for the purpose of implementing the programs of the Administration, not more than $9,000,000 shall be available for the construction of facilities of the Academy on the site selected under subsection (g) of this section. Such sums for such construction shall remain available until expended.

(i) *Educational and Professional Assistance.*—The Administrator is authorized to—

(1) provide stipends to students attending Academy courses and pro-

grams, in amounts up to 75 per centum of the expense of attendance, as established by the Superintendent;

(2) provide stipends to students attending courses and non-degree training programs approved by the Superintendent at universities, colleges, and junior colleges, in amounts up to 50 per centum of the cost of tuition;

(3) make or enter into contracts to make payments to institutions of higher education for loans, not to exceed $2,500 per academic year for any individual who is enrolled on a full-time basis in an undergraduate or graduate program of fire research or engineering which is certified by the Superintendent. Loans under this paragraph shall be made on such terms and subject to such conditions as the Superintendent and each institution involved may jointly determine; and

(4) establish and maintain a placement and promotion opportunities center in cooperation with the fire services, for firefighters who wish to learn and take advantage of different or better career opportunities. Such center shall not limit such assistance to students and graduates of the Academy, but shall undertake to assist all fire service personnel.

(j) *Board of Visitors.*—Upon establishment of the Academy, the Secretary shall establish a procedure for the selection of professionals in the field of fire safety, fire prevention, fire control, research and development in fire protection, treatment and rehabilitation of fire victims, or local government services management to serve as members of a Board of Visitors for the Academy. Pursuant to such procedure, the Secretary shall select eight such persons to serve as members of such Board of Visitors to serve such terms as the Secretary may prescribe. The function of such Board shall be to review annually the program of the Academy and to make comments and recommendations to the Secretary regarding the operation of the Academy and any improvements therein which such Board deems appropriate. Each member of such Board shall be reimbursed for any expenses actually incurred by him in the performance of his duties as a member of such Board.

(k) *Accreditation.*—The Superintendent is authorized to establish a Committee on Fire Training and Education which shall inquire into and make recommendations regarding the desirability of establishing a mechanism for accreditation of fire training and education programs and courses, and the role which the Academy should play if such a mechanism is recommended. The Committee shall consist of the Superintendent as Chairman and eighteen other members appointed by the Administrator from among individuals and organizations possessing special knowledge and experience in the field of fire training and education or related fields. The Committee shall submit to the Administrator within two years after its appointment a full and complete report of its findings and recommendations. Upon the submission of such report, the Committee shall cease to exist. Each appointed member of the Committee shall be reimbursed for expenses actually incurred in the performance of his duties as a member.

(l) *Admission.*—The Superintendent is authorized to admit to the courses and programs of the Academy individuals who are members of the firefighting, rescue, and civil defense forces of the Nation and such other individuals, including candidates for membership in these forces, as he determines can benefit from attendance. Students shall be admitted from any State, with due regard to adequate representation in the student body of all geographic regions of the Nation. In selecting students, the Superintendent may seek nominations and advice from the fire services and other organizations which wish to send students to the Academy.

FIRE TECHNOLOGY

SEC. 8. (a) *Technology Development Program.*—The Administrator shall conduct a continuing program of development, testing, and evaluation of equipment for use by the Nation's fire, rescue, and civil defense services, with the aim of making available improved suppression, protective, auxiliary, and warning devices incorporating the latest technology. Attention shall be given to the standardization, compatibility, and interchangeability of such equipment. Such development, testing, and evaluation activities shall include, but need not be limited to—

(1) safer, less cumbersome articles of protective clothing, including helmets, boots, and coats;

(2) breathing apparatus with the necessary duration of service, reliability, low weight, and ease of operation for practical use;

(3) safe and reliable auxiliary equipment for use in fire prevention, detection, and control, such as fire location detectors, visual and audio communications equipment, and mobile equipment;

(4) special clothing and equipment needed for forest fires, brush fires, oil and gasoline fires, aircraft fires and crash rescue, fires occurring aboard waterborne vessels, and in other special firefighting situations;

(5) fire detectors and related equipment for residential use with high sensitivity and reliability, and which are sufficiently inexpensive to purchase, install, and maintain to insure wide acceptance and use;

(6) in-place fire prevention systems of low cost and of increased reliability and effectiveness;

(7) methods of testing fire alarms and fire protection devices and systems on a non-interference basis;

(8) the development of purchase specifications, standards, and acceptance and validation test procedures for all such equipment and devices; and

(9) operation tests, demonstration projects, and fire investigations in support of the activities set forth in this section.

(b) *Limitation.*—The Administration shall not engage in the manufacture or sale of any equipment or device developed pursuant to this section, except to the extent that it deems it necessary to adequately develop, test, or evaluate such equipment or device.

(c) *Management Studies.*—(1) The Administrator is authorized to conduct, directly or through contracts or grants, studies of the operations and management aspects of fire services, utilizing quantitative techniques, such as operations research, management economics, cost effectiveness studies, and such other techniques and methods as may be applicable and useful. Such studies shall include, but need not be limited to, the allocation of resources, the optimum location of fire stations, the optimum geographical area for an integrated fire service, the manner of responding to alarms, the operation of citywide and regional fire dispatch centers, firefighting under conditions of civil disturbance, and the effectiveness, frequency, and methods of building inspections.

(2) The Administrator is authorized to conduct, directly or through contracts or grants, research concerning the productivity and efficiency of fire service personnel, the job categories and skills required by fire services under varying conditions, the reduction of injuries to fire service personnel, the most effective fire prevention programs and activities, and techniques for accurately measuring and analyzing the foregoing.

(3) The Administrator is authorized to conduct, directly or through contracts, grants, or other forms of assistance, development, testing, and demonstration projects to the extent deemed necessary to introduce and to encourage the acceptance of new technology, standards, operating methods, command techniques, and management systems for utilization by the fire services.

(4) The Administrator is authorized to assist the Nation's fire services, directly or through contracts, grants, or other forms of assistance, to measure and evaluate, on a cost-benefit basis, the effectiveness of the programs and activities of each fire service and the predictable consequences on the applicable local fire services of coordination or combination, in whole or in part, in a regional, metropolitan, or statewide fire service.

(d) *Rural Assistance.*—The Administrator is authorized to assist the Nation's fire services, directly or through contracts, grants, or other forms of assistance, to sponsor and encourage research into approaches, techniques, systems, and equipment to improve fire prevention and control in the rural and remote areas of the Nation.

(e) *Coordination.*—In establishing and conducting programs under this section, the Administrator shall take full advantage of applicable technological developments made by other departments and agencies of the Federal Government, by State and local governments, and by business, industry, and nonprofit associations.

NATIONAL FIRE DATA CENTER

SEC. 9. (a) *General.*—The Administrator shall operate, directly or through contracts or grants, an integrated, comprehensive National Fire Data Center for the selection, analysis, publication, and dissemination of information related to the prevention, occurrence, control, and results of fires of all types. The program of such Data Center shall be designed to (1) provide an accurate nationwide analysis of the fire problem, (2) identify major problem areas, (3) assist in setting priorities, (4) determine possible solutions to problems, and (5) monitor the progress of programs to reduce fire losses. To carry out these functions, the Data Center shall gather and analyze—

(1) information on the frequency, causes, spread, and extinguishment of fires;

(2) information on the number of injuries and deaths resulting from fires, including the maximum available information on the specific causes and nature of such injuries and deaths, and information on property losses;

(3) information on the occupational hazards faced by firefighters, including the causes of deaths and injuries arising, directly and indirectly, from firefighting activities;

(4) information on all types of firefighting activities, including inspection practices;

(5) technical information related to building construction, fire properties of materials, and similar information;

(6) information on fire prevention and control laws, systems, methods, techniques, and administrative structures used in foreign nations;

(7) information on the causes, behavior, and best method of control of other types of fire, including, but not limited to, forest fires, brush fires, fire underground, oil blow-out fires, and waterborne fires; and

(8) such other information and data as is deemed useful and applicable.

(b) *Methods.*—In carrying out the program of the Data Center, the Administrator is authorized to—

(1) develop standardized data reporting methods;

(2) encourage and assist State, local, and other agencies, public and private, in developing and reporting information; and

(3) make full use of existing data gathering and analysis organizations, both public and private.

(c) *Dissemination.*—The Administrator shall insure dissemination to the maximum extent possible of fire data collected and developed by the Data Center, and shall make such data, information, and analysis available in appropriate form to Federal agencies, State and local governments, private organizations, industry, business, and other interested persons.

MASTER PLANS

SEC. 10. (a) *General.*—The establishment of master plans for fire prevention and control are the responsibility of the States and the political subdivisions thereof. The Administrator is authorized to encourage and assist such States and political subdivisions in such planning activities, consistent with his powers and duties under this Act.

(b) *Report.*—Four years after the date of enactment of this Act, the Secretary shall submit to the Congress a report on the establishment and effectiveness of master plans in the field of fire prevention and control throughout the Nation. Such report shall include, but need not be limited to—

(1) a summary of the extent and quality of master planning activities;

(2) a summary and evaluation of master plans that have been prepared by States, and political subdivisions thereof. Such summary and evaluation shall consider, with respect to each such plan

(A) the characteristics of the jurisdiction adopting it, including, but not limited to, density and distribution of population; ratio of volunteer versus paid fire services; geographic location, topography, and climate; per capita rate of death and property loss from fire; size and characteristics of political subdivisions of the governmental units thereof; and socio-economic composition; and

(B) the approach to development and implementation of the master plans;

(3) an evaluation of the best approach to the development and implementation of master plans (e.g., central planning by a State agency, regionalized planning within a State coordinated by a State agency, or local planning supplemented and coordinated by a State agency);

(4) an assessment of the costs and benefits of master plans;

(5) a recommendation to Congress on whether Federal financial assistance should be authorized in order that master plans can be developed in all States; and

(6) a model master plan or plans suitable for State and local implementation.

(c) *Definition.*—For the purposes of this section, a "master plan" is one which will result in the planning and implementation in the area involved of a general program of action for fire prevention and control. Such master plan is reasonably expected to include—

(1) a survey of the resources and personnel of existing fire services and an analysis of the effectiveness of the fire and building codes in such area;

(2) an analysis of short and long term fire prevention and control needs in such area;

(3) a plan to meet the fire prevention and control needs in such area; and

(4) an estimate of cost and realistic plans for financing the implementation of the plan and operation on a continuing basis and a summary of problems that are anticipated in implementing such master plan.

REIMBURSEMENT FOR COSTS OF FIREFIGHTING ON FEDERAL PROPERTY

SEC. 11. (a) *Claim.*—Each fire service that engages in the fighting of a fire on property which is under the jurisdiction of the United States may file a claim with the Administrator for the amount of direct expenses and direct losses incurred by such fire service as a result of fighting such fire. The claim shall include such supporting information as the Administrator may prescribe.

(b) *Determination.*—Upon receipt of a claim filed under subsection (a) of this section, the Administrator shall determine—

(1) what payments, if any, to the fire service or its parent jurisdiction, including taxes or payments in lieu of taxes, the United States has made for the support of fire services on the property in question;

(2) the extent to which the fire service incurred additional firefighting costs, over and above its normal operating costs, in connection with the fire which is the subject of the claim; and

(3) the amount, if any, of the additional costs referred to in paragraph (2) of this subsection which were not adequately covered by the payments referred to in paragraph (1) of this subsection.

(c) *Payment.*—The Secretary shall forward the claim and a copy of the Administrator's determination under subsection (b) (3) of this section to the Secretary of the Treasury. The Secretary of the Treasury shall, upon receipt of the claim and determination, pay such fire service or its parent jurisdiction, from any moneys in the Treasury not otherwise appropriated but subject to reimbursement (from any appropriations which may be available or which may be made available for the purpose) by the Federal department or agency under whose jurisdiction the fire occurred, a sum no greater than the amount determined with respect to the claim under subsection (b) (3) of this section.

(d) *Adjudication.*—In the case of a dispute arising in connection with a claim under this section, the Court of Claims of the United States shall have jurisdiction to adjudicate the claim and enter judgment accordingly.

REVIEW OF CODES

SEC. 12. The Administrator is authorized to review, evaluate, and suggest improvements in State and local fire prevention codes, building codes, and any relevant Federal or private codes and regulations. In evaluating any such code or codes, the Administrator shall consider the human impact of all code requirements, standards, or provisions in terms of comfort and habitability for residents or employees, as well as the fire prevention and control value or potential of each such requirement, standard, or provision.

FIRE SAFETY EFFECTIVENESS STATEMENTS

SEC. 13. The Administrator is authorized to encourage owners and managers of residential multiple-unit, commercial, industrial, and transportation structures to prepare Fire Safety Effectiveness Statements, pursuant to standards, forms, rules, and regulations to be developed and issued by the Administrator.

ANNUAL CONFERENCE

SEC. 14. The Administrator is authorized to organize, or to participate in organizing, an annual conference on fire prevention and control. He may pay, in whole or in part, the cost of such conference and the expenses of some or all of the participants. All of the Nation's fire services shall be eligible to send representatives to each such conference to discuss, exchange ideas on, and participate in educational programs on new techniques in fire prevention and control. Such conferences shall be open to the public.

PUBLIC SAFETY AWARDS

SEC. 15. (a) *Establishment.*—There are hereby established two classes of honorary awards for the recognition of outstanding and distinguished service by public safety officers—

(1) the President's Award For Outstanding Public Safety Service ("President's Award"); and

(2) the Secretary's Award For Distinguished Public Safety Service ("Secretary's Award").

(b) *Description.*—(1) The President's Award shall be presented by the President of the United States to public safety officers for extraordinary valor in the line of duty or for outstanding contribution to public safety.

(2) The Secretary's Award shall be presented by the Secretary, the Secretary of Defense, or by the Attorney General to public safety officers for distinguished service in the field of public safety.

(c) *Selection.*—The Secretary, the Secretary of Defense, and the Attorney General shall advise and assist the President in the selection of individuals to whom the President's Award shall be tendered and in the course of performing such duties they shall seek and review nominations for such awards which are submitted to them by Federal, State, county, and local government officials. They shall annually transmit to the President the names of those individuals determined by them to merit the award, together with the reasons therefor. Recipients of the President's Award shall be selected by the President.

(d) *Limitation.*—(1) There shall not be presented in any one calendar year in excess of twelve President's Awards.

(2) There shall be no limitation on the number of Secretary's Awards presented.

(e) *Award.*—(1) Each President's Award shall consist of—

(A) a medal suitably inscribed, bearing such devices and emblems, and struck from such material as the Secretary of the Treasury, after consultation with the Secretary, the Secretary of Defense, and the Attorney General deems appropriate. The Secretary of the Treasury shall cause the medal to be struck and furnished to the President; and

(B) an appropriate citation.

(2) Each Secretary's Award shall consist of an appropriate citation.

(f) *Regulations.*—The Secretary, the Secretary of Defense, and the Attorney General are authorized and directed to issue jointly such regulations as may be necessary to carry out this section.

(g) *Definitions.*—As used in this section, the term "public safety officer" means a person serving a public agency, with or without compensation, as—

(1) a firefighter;

(2) a law enforcement officer, including a corrections or court officer; or

(3) a civil defense officer.

ANNUAL REPORT

SEC. 16. The Secretary shall report to the Congress and the President not later than June 30 of the year following the date of enactment of this Act and each year thereafter on all activities relating to fire prevention and control, and all measures taken to implement and carry out this Act during the preceding calendar year. Such report shall include, but need not be limited to—

(a) a thorough appraisal, including statistical analysis, estimates, and long-term projections of the human and economic losses due to fire;

(b) a survey and summary, in such detail as is deemed advisable, of the research and technology program undertaken or sponsored pursuant to this Act;

(c) a summary of the activities of the Academy for the preceding 12 months, including, but not limited to—

(1) an explanation of the curriculum of study;

(2) a description of the standards of admission and performance;

(3) the criteria for the awarding of degrees and certificates; and

(4) a statistical compilation of the number of students attending the Academy and receiving degrees or certificates;

(d) a summary of the activities undertaken to assist the Nation's fire services;

(e) a summary of the public education programs undertaken;

(f) an analysis of the extent of participation in preparing and submitting Fire Safety Effectiveness Statements;

(g) a summary of outstanding problems confronting the administration of this Act, in order of priority;

(h) such recommendations for additional legislation as are deemed necessary or appropriate; and

(i) a summary of reviews, evaluations, and suggested improvements in State and local fire prevention and building codes, fire services, and any relevant Federal or private codes, regulations, and fire services.

AUTHORIZATION OF APPROPRIATIONS

SEC. 17. There are authorized to be appropriated to carry out the foregoing provisions of this Act, except section 11 of this Act, such sums as are necessary, not to exceed $10,000,000 for the fiscal year ending June 30, 1975, and not to exceed $15,000,000 for the fiscal year ending June 30, 1976.

FIRE RESEARCH CENTER

SEC. 18. The Act of March 3, 1901 (15 U.S.C. 278), is amended by striking out sections 16 and 17 (as added by title I of the Fire Prevention and Control Act of 1968) and by inserting in lieu thereof the following new section:

"SEC. 16. (a) There is hereby established within the Department of Commerce a Fire Research Center which shall have the mission of performing and supporting research on all aspects of fire with the aim of providing scientific and technical knowledge applicable to the prevention and control of fires. The content and priorities of the research program shall be determined in consultation with the Administrator of the National Fire Prevention and Control Administration. In implementing this section, the Secretary is authorized to conduct, directly or through contracts or grants, a fire research program, including—

"(1) basic and applied fire research for the purpose of arriving at an understanding of the fundamental processes underlying all aspects of fire. Such research shall include scientific investigations of—

"(A) the physics and chemistry of combustion processes;

"(B) the dynamics of flame ignition, flame spread, and flame extinguishment;

"(C) the composition of combustion products developed by various sources and under various environmental conditions;

"(D) the early stages of fires in buildings and other structures, structural subsystems and structural components in all other types of fires, including, but not limited to, forest fires, brush fires, fires underground, oil blowout fires, and waterborne fires, with the aim of improving early detection capability;

"(E) the behavior of fires involving all types of buildings and other structures and their contents (including mobile homes and highrise buildings, construction materials, floor and wall coverings, coatings, furnishings, and other combustible materials), and all other types of fires, including forest fires, brush fires, fires underground, oil blowout fires, and waterborne fires;

"(F) the unique fire hazards arising from the transportation and use, in industrial and professional practices, of combustible gases, fluids, and materials;

"(G) design concepts for providing increased fire safety consistent with habitability, comfort, and human impact in buildings and other structures; and

"(H) such other aspects of the fire process as may be deemed useful in pursuing the objectives of the fire research program;

"(2) research into the biological, physiological, and psychological factors affecting human victims of fire, and the performance of individual members of fire services, including—

"(A) the biological and physiological effects of toxic substances encountered in fires;

"(B) the trauma, cardiac conditions, and other hazards resulting from exposure to fire;

"(C) the development of simple and reliable tests for determining the cause of death from fires;

"(D) improved methods of providing first aid to victims of fires;

"(E) psychological and motivational characteristics of persons who engage in arson, and the prediction and cure of such behavior;

"(F) the conditions of stress encountered by firefighters, the effects of such stress, and the alleviation and reduction of such conditions; and

"(G) such other biological, psychological, and physiological effects of fire as have significance for purposes of control or prevention of fires; and

"(3) operation tests, demonstration projects, and fire investigations in support of the activities set forth in this section.

"The Secretary shall insure that the results and advances arising from the work of the research program are disseminated broadly. He shall encourage the incorporation, to the extent applicable and practicable, of such results and advances in building codes, fire codes, and other relevant codes, test methods, fire service operations and training, and standards. The Secretary is authorized to encourage and assist in the development and adoption of uniform codes, test methods, and standards aimed at reducing fire losses and costs of fire protection.

"(b) For the purposes of this section there is authorized to be appropriated not to exceed $3,500,000 for the fiscal year ending June 30, 1975 and not to exceed $4,000,000 for the fiscal year ending June 30, 1976."

VICTIMS OF FIRE

SEC. 19. (a) *Program.*—The Secretary of Health, Education, and Welfare shall establish, within the National Institutes of Health and in cooperation with the Secretary, an expanded program of research on burns, treatment of burn injuries, and rehabilitation of victims of fires. The National Institutes of Health shall—

(1) sponsor and encourage the establishment throughout the Nation of twenty-five additional burn centers, which shall comprise separate hospital facilities providing specialized burn treatment and including research and teaching programs, and twenty-five additional burn units, which shall comprise specialized facilities in general hospitals used only for burn victims;

(2) provide training and continuing support of specialists to staff the new burn centers and burn units;

(3) sponsor and encourage the establishment of ninety burn programs in general hospitals which comprise staffs of burn injury specialists;

(4) provide special training in emergency care for burn victims;

(5) augment sponsorship of research on burns and burn treatment;

(6) administer and support a systematic program of research concerning smoke inhalation injuries; and

(7) sponsor and support other research and training programs in the treatment and rehabilitation of burn injury victims.

(b) *Authorization of Appropriation.*—For purposes of this section, there are authorized to be appropriated not to exceed $5,000,000 for the fiscal year ending June 30, 1975 and not to exceed $8,000,000 for the fiscal year ending June 30, 1976.

PUBLIC ACCESS TO INFORMATION

SEC. 20. Copies of any document, report, statement, or information received or sent by the Secretary or the Administrator shall be made available to the public pursuant to the provisions of section 552 of title 5, United States Code: *Provided,* That, notwithstanding the provisions of subsection (b) of such section and of section 1905 of title 18, United States Code, the Secretary may disclose information which concerns or relates to a trade secret—

(1) upon request, to other Federal Government departments and agencies for official use;

(2) upon request, to any committee of Congress having jurisdiction over the subject matter to which the information relates;

(3) in any judicial proceeding under a court order formulated to preserve the confidentiality of such information without impairing the proceedings; and

(4) to the public when he determines such disclosure to be necessary in

order to protect health and safety after notice and opportunity for comment in writing or for discussion in closed session within fifteen days by the party to which the information pertains (if the delay resulting from such notice and opportunity for comment would not be detrimental to health and safety).

ADMINISTRATIVE PROVISIONS

SEC. 21. (a) *Assistance.*—Each department, agency, and instrumentality of the executive branch of the Federal Government and each independent regulatory agency of the United States is authorized and directed to furnish to the Administrator upon written request, on a reimbursable basis or otherwise, such assistance as the Administrator deems necessary to carry out his functions and duties pursuant to this Act, including, but not limited to, transfer of personnel with their consent and without prejudice to their position and ratings.

(b) *Powers.*—With respect to this Act, the Administrator is authorized to—

(1) enter into, without regard to section 3709 of the Revised Statutes, as amended (41 U.S.C. 5) such contracts, grants, leases, cooperative agreements, or other transactions as may be necessary to carry out the provisions of this Act;

(2) accept gifts and voluntary and uncompensated services, notwithstanding the provisions of section 3679 of the Revised Statutes (31 U.S.C. 665(b));

(3) purchase, lease, or otherwise acquire, own, hold, improve, use, or deal in and with any property (real, personal, or mixed, tangible or intangible), or interest in property, wherever situated; and sell, convey, mortgage, pledge, lease, exchange, or otherwise dispose of property and assets;

(4) procure temporary and intermittent services to the same extent as is authorized under section 3109 of title 5, United States Code, but at rates not to exceed $100 a day for qualified experts; and

(5) establish such rules, regulations, and procedures as are necessary to carry out the provisions of this Act.

(c) *Audit.*—The Secretary and the Comptroller General of the United States, or any of their duly authorized representatives, shall have access to any books, documents, papers, and records of the recipients of contracts, grants, or other forms of assistance that are pertinent to its activities under this Act for the purpose of audit or to determine if a proposed activity is in the public interest.

(d) *Inventions and Discoveries.*—All property rights with respect to inventions and discoveries, which are made in the course of or under contract with any government agency pursuant to this Act, shall be subject to the basic policies set forth in the President's Statement of Government Patent Policy issued August 23, 1971, or such revisions of that statement of policy as may subsequently be promulgated and published in the Federal Register.

(e) *Coordination.*—To the extent practicable, the Administrator shall utilize existing programs, data, information, and facilities already available in other Federal Government departments and agencies and, where appropriate, existing research organizations, centers, and universities. The Administrator shall provide liaison at an appropriate organizational level to assure coordination of his activities with State and local government agencies, departments, bureaus, or offices concerned with any matter related to programs of fire prevention and control and with private and other Federal organizations and offices so concerned.

ASSISTANCE TO CONSUMER PRODUCT SAFETY COMMISSION

SEC. 22. Upon request, the Administrator shall assist the Consumer Product Safety Commission in the development of fire safety standards or codes for consumer products, as defined in the Consumer Product Safety Act (15 U.S.C. 2051 et seq.).

CONFORMING AMENDMENTS

SEC. 23. Section 12 of the Act of February 14, 1903, as amended (15 U.S.C. 1511), is amended to read as follows:

"BUREAUS IN DEPARTMENT

"SEC. 12. The following named bureaus, administrations, services, offices, and programs of the public service, and all that pertains thereto, shall be under the jurisdiction and subject to the control of the Secretary of Commerce:

"(a) National Oceanic and Atmospheric Administration;
"(b) United States Travel Service;
"(c) Maritime Administration;
"(d) National Bureau of Standards;
"(e) Patent Office;
"(f) Bureau of the Census;
"(g) National Fire Prevention and Control Administration; and
"(h) such other bureaus or other organizational units as the Secretary of Commerce may from time to time establish in accordance with law."

Approved October 29, 1974

FIRELITER—REVIEW OF 1974 FIRE RELATED JOURNAL LITERATURE
(Indexing Fire Articles from Titles)

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The FIRELITER feature following this article is a collection of 1974 tables of contents of several journals that are prominent in fire science and technology. A subject index has been prepared from individual words and word strings in the titles. FIRELITER is the result of an effort on the part of the editorial staff of FRAR to broaden the coverage of the journal. If this feature proves as useful as we anticipate, it will be repeated for the 1975 fire journal literature. We encourage readers to comment on the result.

At this stage, the effort to bring the contents of current literature to the attention of the FRAR readership is experimental. FIRELITER is essentially an attempt to develop an economical means of access to recent journal articles dealing with fire. Our aim was to produce the best index possible at the least cost and with the least effort.

Indexing a thousand or so articles is not a trivial task, no matter how it is done. So to make the work as easy as possible, we chose to use either the KWIC (Key Word In Context) or the KWOC (Key Word Out of Context) method. With the programs we used, either of these indexes can be generated from the identical input file. For either index, article titles are entered into a computer file and the program selects words from the titles, displays them in alphabetical order, and prints the entire title and its reference. In the KWIC version, the alphabetized words are arranged down the center of the page, and the remainder of the title is printed to the right. If the title cannot fit into the space at the right of the alphabetized word, it is continued on the same line at the left. If the title is too long to fit on one line, it is often truncated. Some KWIC programs allow a second line for the continuation of long titles. In the KWOC version, the individual words in the title are displayed at the left margin on the page, and the entire title and reference is printed below. In effect, the result is a two-level index in which the title serves to explicate the displayed term.

On the surface, the only work required for either of these indexes is keyboarding the titles and references into a computer file and the program does the rest.

For the first index we wanted to include a representative sample of periodical fire literature. Our selection thus includes US, British, and Soviet journals, as well as scientific, technical, and news-type publications. Our final list contained 18 titles, for a total of 104 issues. All of these together form what we believe to be a reasonable cross-section. We have included complete tables of contents of the scientific journals, but only selected titles from the news-oriented publications. We consistently omitted brief, nonsubstantive and ephemeral articles.

After having selected the journals to be included, we designed a simple coding system and keyboarded several tables of contents, whereupon we ran a test printout. We elected to use the KWOC version, since it appears to be somewhat more orderly than KWIC and is a bit more conservative of space. As we anticipated, the index was peppered with meaningless terms: articles, prepositions, verbs, pronouns, and the like. Also there were a number of high-frequency words such as METHOD, TECHNIQUE, and SYSTEM that had little index value. Curiously, but understandably, words such as COMBUSTION, FLAME, and the like begin to lose their meanings in an index devoted primarily to these subjects.

Since many of the useless words are four letters or less, we instructed the program to ignore all words with less than five letters. In order not to lose important 2-, 3-, or 4-letter words, we simply coupled them to an adjacent term with a non-printing character. The hyphen also was used as a coupling device; other punctuation marks were ignored by the program. Useless indexing terms of 5 letters and more were stopped by entering them on a stop list. The final stop list contained about 800 words. In many cases singular and plural versions of the same word had to be stopped. Words such as DETERMINED, DETERMINATION, DETERMINING, DETERMINES, and DETERMINE contributed significantly to the size of the stop list.

At the beginning we were concerned about how freely we could add to the stop list, since stopping a term for any title would stop it for all titles. This turned out to be needless worry. Examination of the final stop list showed that a decision to stop a word in any title was generally valid for all titles. It should be noted that any change in spelling or orthography causes the program to treat a word as entirely different. For example, if the word 'firefighter' is in the stop list, 'Firefighter' and 'fire-fighter' remain valid index terms because of the initial capital and the hyphen. Desirable terms of less than 5 characters were preserved for printing in the index by lengthening them with hyphens or nonprinting characters.

From the initial test runs it soon became evident that even when all of the nonsignificant words were stopped, the repeated printing of entire titles below each entry fattened the page count enormously. It was therefore deicded to try KWANC (Key Word And No Context). In this version, indexing terms are displayed with references only. A reader has to look up the reference in the tables of contents themselves to read the title and determine whether the context fits his interest.

While the page count of the KWANC index decreased to almost half that of KWOC, the indexing value of many of the terms fell even more. Although some terms seemed to lose little, others, such as ACCIDENT, DYNAMICS, and INSTRUMENT suffered almost total loss of meaning as index pointers. Moreover, there was a noticeable change in user behavior. Whereas the eye tended to drop down to the title to read explications in KWOC, in KWANC, hazy entries tended to be passed over and ignored.

It would serve little purpose on these pages to discuss index preparation in depth; nevertheless, we would like to share some of the highlights of our experience and insights that we gained from the exercise.

We all know that single words take on different meanings from associations with other words. Thus, two words as a rule are more meaningful than one, and three more than two. As more and more words are combined, they acquire increasing specificity from each other. In some cases, however, special terms or expressions can acquire extrinsic meaning. Author names, for example, are useful index entries because users can often contribute meaning to a name. Knowledge of a particular author's work or knowing that a specific paper is attributed to a given author is sufficient to specify an article uniquely. An author entry is thus identified extrinsically in two ways: either by foreknowledge of his work, or because he has authored a particular paper.

In the case of a subject index, the situation is not as straightforward. True, some individual terms have a high degree of specificity due to rarity or reader's foreknowledge. CONFLAGRATION and FLIXBOROUGH serve as examples. How frequently do conflagrations occur? And under what circumstances would Flixborough be featured in the fire literature?

The majority of single terms, however, tend to be ambiguous to one degree or another, and are, therefore, either useless or marginal as index entries.

Term coupling in general serves to increase specificity, and, therefore, reduces ambiguity, but other problems arise. For example, the terms FIRE, SERVICE, and EDUCATION by themselves exhibit unique dimensions of ambiguity. FIRE is unacceptably vague in an index devoted largely to fire, and SERVICE is less specific than EDUCATION. The three terms coupled together, however, make up an adequately specific index entry.

Permutation of these terms can be used to illustrate how meaning fluctuates with word order. Consider such combinations as FIRE SERVICE, FIRE EDUCATION, EDUCATION SERVICE, SERVICE FIRE, etc. In using titles as sources of index terms, one is obliged to accept the word order as it exists. If an article dealing with fire service education has these three terms in proper sequence in the title, one merely needs to couple them to obtain a legitimate index entry. But what if another term intrudes? (e.g., FIRE SERVICE PROMOTES EDUCATION). Suddenly, FIRE SERVICE and EDUCATION take on different nuances of meaning. We have three alternatives: we can couple all of them together to make one entry; we can couple the first two words and stop PROMOTES, to make two index entries; or we can stop the first three words and print EDUCATION alone in the index.

Any of these alternatives might be acceptable if it were not for other similar articles with quite different titles. It turns out that some articles on fire service education fall in the index under terms other than FIRE SERVICE and EDUCATION. This particular problem is aggravated by normal usage, which places modifiers ahead of nouns. Thus we have plain "nozzles," "automatic nozzles," "radio-controlled nozzles," as well as many other kinds. We found it impossible, in our experience, to treat such terms consistently. Consider also the use of paraphrastic expressions—phrases used instead of simpler terms. The variations we encountered in free language titles were simply too numerous to deal with expeditiously.

As a result, we can either give up the use of titles and prepare a true index or ask the reader to search every entry point he can think of in order to find what he is looking for. In a very real sense a user of a title index must learn how to read and interpret it properly.

A problem with similar consequences arises from synonomy. Quite similar articles may contain synonyms or near synonyms in their titles; e.g., CLOTHING, GARMENTS, APPAREL, and so on. Moreover, relevant articles may be indexed under more remote headings, such as TEXTILES, FABRICS, CLOTH; or even under COATS, SLEEPWEAR, DRESSING GOWNS, and any number of other less obvious terms. The reader must, therefore, summon a great deal of ingenuity to think of all the possible rubrics under which his topic might be cited.

This problem may be mitigated by suitable cross-references, and a few have been supplied.

A good index enables one to approach any item from at least two directions. Using the earlier example, it would be useful to generate the two strings: FIRE SERVICE EDUCATION and EDUCATION—FIRE SERVICE. An index taken directly from titles does not permit this. One must be content with the word order as it appears.

Another cumbersome problem occurs when two or more subjects are treated in the same title or when the same subject has two or more specifications. Consider the title: "Thermal Degradation and Spontaneous Ignition of Paper Sheets in Air by Irradiation," which has elements of both characteristics. An unconstrained indexer would probably make each concept: "Thermal Degradation," "Spontaneous Ignition," "Ignition," "Paper Sheets," and "Irradiation," suitably modified, a separate entry in an index. This is not possible in the KWANC index without modifying the title itself or enriching it with appropriately permuted terms. The word order problem and the absence of the remainder of the title are the two features that distinguish KWANC from KWIC and KWOC and which make KWANC so much more difficult to prepare and use.

The significance of this should be apparent. Whereas KWIC and KWOC make no pretense of being anything more than crude substitutes for an index prepared by a human indexer, KWANC wears a disguise: it looks like an index that has been prepared through intellectual effort. In fact, however, if left untouched and unaided, KWANC is poorer than KWIC or KWOC, which perform much better under much looser conditions.

In a few instances we modified titles where wording made it convenient to do so. For the sake of uniformity we modified terms such as "highrise" and "firefighter," writing them as one word regardless of how they were written in the original title. In these and other instances, we sometimes supplied additional indexing terms as described below.

As we coupled terms into more meaningful pairs, triplets, and longer strings, we encountered another kind of problem. A number of titles simply made no sense when separated from the articles they headed. For example, "Father's Cast-Off Apparatus" deals with the renovation and return to service of used equipment. "Suddenly, You're Dead" is an article on first aid. "Firefighters Get Moving" concerns fire prevention and burns treatment. "A New Image—A New Role" describes delivery of emergency health care services. In such cases we felt obliged to add a few words in parentheses to make the title more meaningful. In other cases we embedded nonprinting index terms in the titles for printing only in the index.

The final KWANC index to the 1974 fire journal article titles turned out to be a hybrid: largely a title index, but also containing intellectual intervention. It is thus not as bad as the one might be, nor as good as the other usually is.

The cost and effort invested in producing the improved KWANC is about half that needed for an index prepared by a human indexer. Under present circumstances a title index is feasible, whereas a true index is not, owing to the lack of experienced indexing manpower.

We are well aware that whatever has been saved in indexing time and effort is false in one respect. What is saved in indexing is undoubtedly spent many times over by the collective users. The so-called "bottom-line," therefore, is whether a title-generated index is better than no index at all. We conclude that it is, despite its faults.

The references in the indexes consist of a mnemonic abbreviation of the journal title, volume number, issue number in parentheses, and page number. For example, ComFla22(1) 1 refers to *Combustion and Flame*, Volume 22, No. 1, page 1.

TABLE OF CONTENTS

COMBUSTION AND FLAME
Vol. 22, No. 1 26
Vol. 22, No. 2 27
Vol. 22, No. 3 27
Vol. 23, No. 1 28
Vol. 23, No. 2 29
Vol. 23, No. 3 29
COMBUSTION SCIENCE AND TECHNOLOGY
Vol. 9, Nos. 1-2 30
Vol. 9, Nos. 3-4 30
Vol. 9, Nos. 5-6 31
FIRE CHIEF MAGAZINE
Vol. 18, No. 1 32
Vol. 18, No. 2 32
Vol. 18, No. 3 32
Vol. 18, No. 4 32
Vol. 18, No. 5 32
Vol. 18, No. 6 33
Vol. 18, No. 7 33
Vol. 18, No. 8 33
Vol. 18, No. 9 33
Vol. 18, No. 10 33
Vol. 18, No. 11 34
Vol. 18, No. 12 34
FIRE COMMAND!
Vol. 41, No. 1 34
Vol. 41, No. 2 34
Vol. 41, No. 3 34
Vol. 41, No. 4 35
Vol. 41, No. 5 35
Vol. 41, No. 6 35
Vol. 41, No. 7 35
Vol. 41, No. 8 36
Vol. 41, No. 9 36
Vol. 41, No. 10 36
Vol. 41, No. 11 36
Vol. 41, No. 12 36

FIRE ENGINEERING
Vol. 127, No. 1 36
Vol. 127, No. 2 37
Vol. 127, No. 3 37
Vol. 127, No. 4 37
Vol. 127, No. 5 37
Vol. 127, No. 6 37
Vol. 127, No. 7 38
Vol. 127, No. 8 38
Vol. 127, No. 9 38
Vol. 127, No. 10........ 38
Vol. 127, No. 11........ 39
Vol. 127, No. 12........ 39
FIRE ENGINEERS JOURNAL
Vol. 34, No. 93 39
Vol. 34, No. 94 40
Vol. 34, No. 95 40
Vol. 34, No. 96 40
FIRE INTERNATIONAL
Vol. 4, No. 43 40
Vol. 4, No. 44 41
Vol. 4, No. 45 41
Vol. 4, No. 46 41
FIRE JOURNAL
Vol. 68, No. 1 41
Vol. 68, No. 2 42
Vol. 68, No. 3 42
Vol. 68, No. 4 42
Vol. 68, No. 5 43
Vol. 68, No. 6 43
FIRE PREVENTION SCIENCE AND TECHNOLOGY
No. 8 44
No. 9 44
FIRE PROTECTION REVIEW
Vol. 37, No. 398 44
Vol. 37, No. 399 44
Vol. 37, No. 400 44
Vol. 37, No. 401 44
Vol. 37, No. 402 45
Vol. 37, No. 403 45
Vol. 37, No. 404 45
Vol. 37, No. 405 45
Vol. 37, No. 406 45
Vol. 37, No. 407 45
Vol. 37, No. 408 46
Vol. 37, No. 409 46

FIRE TECHNOLOGY
Vol. 10, No. 1 46
Vol. 10, No. 2 46
Vol. 10, No. 3 46
Vol. 10, No. 4 47
JOURNAL OF FIRE AND FLAMMABILITY
Vol. 5, No. 1 47
Vol. 5, No. 2 47
Vol. 5, No. 3 48
Vol. 5, No. 4 48
JOURNAL OF FIRE AND FLAMMABILITY/COMBUSTION TOXICOLOGY SUPPLEMENT
Vol. 1, No. 1 48
Vol. 1, No. 2 48
Vol. 1, No. 3 49
Vol. 1, No. 4 49
JOURNAL OF FIRE AND FLAMMABILITY/CONSUMER PRODUCT FLAMMABILITY
Vol. 1, No. 1 49
Vol. 1, No. 2 49
Vol. 1, No. 3 50
Vol. 1, No. 4 50
JOURNAL OF FIRE AND FLAMMABILITY/FIRE RETARDANT CHEMISTRY
Vol. 1, No. 1 50
Vol. 1, No. 2 50
Vol. 1, No. 3 51
Vol. 1, No. 4 51
LAB DATA
Vol. 5, No. 1 51
Vol. 5, No. 2 51
Vol. 5, No. 3 51
Vol. 5, No. 4 52
NATIONAL SAFETY NEWS
Vol. 109, No. 6 52
PHYSICS OF COMBUSTION AND EXPLOSION
Vol. 10, No. 1 52
Vol. 10, No. 2 54
Vol. 10, No. 3 55
Vol. 10, No. 4 56
Vol. 10, No. 5 57
Vol. 10, No. 6 59

INDEX TO AUTHORS 62

INDEX TO ARTICLE TITLES 74

COMBUSTION AND FLAME

Vol. 22, No. 1 February 1974

The Role of Surface Reactions in Hypergolic Ignition of Liquid-Solid Systems/ Bernard ML, Cointot A, Auzanneau M, Sztal E. 1
Comments on the Equation of State of the Products of High Density Explosives/ Bracco FV. 9
The Thermal Decomposition of 1, 3, 5 Trinitro Hexahydro 1, 3, 5 Triazine (RDX) - Part I. The Products and Physical Parameters/ Cosgrove JD, Owen AJ 13
The Thermal Decomposition of 1, 3, 5 Trinitro Hexahydro 1, 3, 5 Triazine (RDX) - Part II: The Effects of the Products/ Cosgrove JD, Owen AJ. 19
A Model Relating Extinction of the Opposed Flow Diffusion Flame to Reaction Kinetics/Ablow CM, Wise H. 23
Physical Factors in the Study of the Spontaneous Ignition of Hydrocarbons in Static Systems/ Barnard JA, Harwood BA. 35
The Effects of Electrical Fields upon Electron Energy Exchanges in Flame Gases/ Bradley D, Ibrahim SMA. 43
Initiation Patterns Produced in Explosives by Low Pressure, Long Duration Shock Waves/ Walker FE, Wasley RJ. 53
A Model for the Combustion and Extinction of Composite Solid Propellants during Depressurization/ Mong HC, Ambs II. 59
Effect of Composition and Temperature on the Burning Velocity of Nitric Oxide - Hydrogen Flame/ Magnus AJ, Chintapalli PS, VanPee M. 71
Catalytic Effect of Ferrous Oxide on Burning Rate of Condensed Mixtures/ Bakhman NN, Nikiforov VS, Avdyunin VI, Fogel'zang AYe, Kichin YuS. 77
Laminar Burning Velocities and Weak Flammability Limits under Engine-Like Conditions/ Halstead MP, Pye DB, Quinn CP. 89
The Uniform Distortion of a Turbulent Flame/ Chomiak J. 99
The Ignition of Gases by Rapidly Heated Surfaces/ Cutler DP. 105
Studies in the Transition from Deflagration to Detonation in Granular Explosives - I: Experimental Arrangement and Behavior of Explosives Which Fail to Exhibit Detonation/ Bernecker RR, Price D. 111
Studies in the Transition from Deflagration to Detonation in Granular Explosives - II: Transitional Characteristics and Mechanisms Observed in 91/9 RDX-Wax/ Bernecker RR, Price D. 119

Brief Communications

Cool Flame Quench Distances/ Ryason PR, Hirsch E. 131
C2 Band Emission from Diffusion Flames of Alkali Metals and Halogenated Methanes/ Hsu CJ, Palmer HE, Aten CF. 133

Vol. 22, No. 2 April 1974

Electromagnetically Induced Motion of Spark Ignition Kernels/ Bradley D, Critchley IL 143
Kinetics and Mechanisms of Formaldahyde Oxidation - II/ Vardanyan IA, Sachyan GA, Philiposyan AG, Nalbandyan AB 153
Studies in the Transition from Deflagration to Detonation in Granular Explosives - III: Proposed Mechanisms for Transition and Comparison with other Proposals in the Literature/ Bernecker RR, Price D 161
Theoretical Investigation of Hybrid Rocket Combustion by Numerical Methods/ Helman D, Wolfshtein M, Manheimer-Timnat Y 171
An Investigation of Iron and Rhenium Additives in Unseeded and Potassium Seeded Hydrogen-Oxygen Flames/ Farber M, Harris SP, Srivastava RD 191
The Measurement of Heat-Loss Rates from a Stirred Reactor Using a Thermochemical Method/ Griffiths JF, Gray P 197
Inhibition of Gas-Phase Oxidation Reactions by Aliphatic Amines and Related Compounds/ Jones PW, Selby K, Tidball MF, Waddington DJ 209
Burning Velocity Measurement by Bomb Method/ Nair MRS, Gupta MC 219
Thermal Degradation and Spontaneous Ignition of Paper Sheets in Air by Irradiation/ Shivadev UK, Emmons HW 223
Population Inversion in Blast Waves Propagating in Hydrogen-Fluorine-Helium Mixtures/ Guenoche H, Lee JHS, Sedes C 237
Observation of C (3) O (2) (Carbon Suboxide) during Atmospheric Reentry/ Sheahen TP 243
Turbulent Mixing and NOx Formation in Gas Turbine Combustors/ Vranos A 253

Brief Communications

Low Nitric Oxide Emissions Via Unsteady Combustion/ Peters B, Borman G . . 259
A Note on Electromagnetically Induced Motion of Spark Ignition Kernels/ Harrison AJ, Weinberg FJ 263
Influence of Electric Fields on Burning Velocity/ Fox JS, Mirchandani I 267
Detonation Calculations with a Percus-Yevick Equation of State/ Edwards JC, Chaikin RF 269
Ignition Waves in PYRO Propellant/ Soper WG 273
Effect of Recirculated Products on Burning Velocity and Critical Velocity Gradient/ Putnam AA 281

Vol. 22, No. 3 June 1974

The Ignition Front of a Fuel Jet Flame Stabilized by a Step/ Kawamura T 283
Observations on the Role of Lead Modifiers in Super-Rate Burning of Nitrocellulose Propellants/ Suh NP, Adams GF, Lenchitz C 289
The Temperature Dependence of Some Third-Order Reactions of Atomic Lead - $Pb(6^3(O))$/ Husain D, Littler JGF 295
Rate Constrained Partial Equilibrium Models of the Formation of Nitric Oxide

from Organic Fuel Nitrogen/Flagan RC, Galant S, Appleton JP 299
Flame Length in the Wake of a Burning Hydrocarbon Drop/Gollahalli SR, Brzustowski TA 313
Ignition Characteristics of Gasless Reactions/Phung PV, Hardt AP 323
The Electronic Excitation of Nitrogen and Burning Velocity Measurements in Low-Pressure, Pre-Mixed Ammonia-Fluorine Flames/Cashin KD, Chintapalli PS, VanPee M, Vidaud P 337
Quenched Carbon Monoxide in Fuel-Lean Flame Gas/Fenimore CP, Moore J 343
Postulations of Flame Spread Mechanisms Hirano T, Noreikis SE, Waterman TE 353
A Theory for Spherical and Cylindrical Laminar Premixed Flames/Vance GM, Krier H 365
Burning of Fuel Droplets in Pressures Greater than Atmospheric/Rush JH, Krier H 377
Combustion of Magnesium Particles in Oxygen-Inert Atmospheres/Law CK, Williams FA 383
The Influence of Additives on the Burning of Clouds of Coal Particles in Shocked Gases/Nettleton MA 407

Brief Communications

The Measure of the Inhibition of Quenched Premixed Flames/Iya KS, Wollowitz S, Kaskan WE 415

Vol. 23, No. 1 August 1974

The Measurement and Use of Oxygen Index/Abbott C 1
Dynamics of Droplets in Burning and Isothermal Kerosene Sprays/Chigier NA, McCreath CG, Makepeace RW 11
Exact Solution to the One-Dimensional Stationary Energy Equation for a Self-Heating Slab/Shouman AR, Donaldson AB, Tsao HY 17
Study of the Electric Conductivity of Plasma of Combustion Products with Seedings in the U-O2 MHD Generator Channel and on a Laboratory Installation/Gaponov IM, Poberezhsky IP, Chernov YuG 29
The Heat and Products of Detonation in a Calorimeter of C-N-O, H-N-O, C-H-N-O, C-H-N-O-F, and C-H-N-O-Si Explosives/Ornellas DL 37
Electron Spin Resonance Studies of Gas-Phase Oxidation Reactions. The Hydrogen-Oxygen System at Atmospheric Pressure/Agkpo A, Sochet LR ...47
Velocity Measurements in the Recirculation Region of an Industrial Burner Flame by Laser Anemometry with Light Frequency Shifting/Baker RJ, Hutchinson P, Whitelaw JH 57
Molecular Beam Mass Spectrometry Applied to Determining the Kinetics of Reactions in Flames. I. Empirical Characterization of Flame Perturbation by Molecular Beam Sampling Probes/Biordi JC, Lazzara CP, Papp JF 73
Measured Velocity Profiles and Temperature Profiles near Flames Spreading over

a Thin Combustible Solid/ Hirano T, Noreikis SE, Waterman TE 83
On the Explosion, Glow, and Oscillation Phenomena in the Oxidation of Carbon Monoxide/ Yang CH 97
The "Point Source" Technique Using Upstream Sampling for Rate Constant Determinations in Flame Gases/ Hart LW, Grunfelder C, Fristrom RM 109
Ionization Associated with Solid Particles in Flames II. Electron Number Density/ Page FM, Woolley DF 121

Brief Communications

Time-Resolved Spectra of Bulk Titanium Combustion/ Runyon CC, Moulder JC, Clark AF 129

Vol. 23, No. 2 October 1973

Combustion in Swirling Flows: A Review/ Syred N, Beer JM 143
An Investigation of the Minimum Ignition Energies of Some C (1) to C (7) Hydrocarbons/ Moorhouse J, Williams A, Maddison TE 203
An Evaluation of the Rate Data for the Reaction CO + OH - CC (2) + H/ Baulch DL, Drysdale DD 215
The Emission Spectra and Burning Velocity of the Premixed Cyanogen-Fluorine Flame/ VanPee M, Vidaud P, Cashin KD 227
Kinetics of Oxygen Atom Formation during the Oxidation of Methane behind Shock Waves/ Jachimowski CJ 233
A Stochastic Model of Turbulent Mixing with Chemical Reaction: Nitric Oxide Formation in a Plug-Flow Burner/ Flagan RC, Appleton JP 249
A Simple Premixed Flame Model including an Application to Hydrogen-Air Flames/ Brown NJ, Fristrom RM, Sawyer RF 269

Brief Communications

Nitric Oxide Formation during the Combustion of Coal/ Haynes BS, Kirov NY 277

Vol. 23, No. 3 December 1974

An Experimental and Theoretical Investigation of Turbulent Mixing in a Cylindrical Furnace/ Lockwood FC, El-Mahalowy FM, Spalding DB 283
Low-Temperature Oxidation in a Stirred-Flow Reactor - I. Propane/ Gray BF, Felton PG 295
Investigating the Flame with the Aid of Self-Reversed Contours of Spectral Lines/ Vasilieva IA, Deputatova LV, Nefedov AP 305
The Interaction of Hot Spots/ Zaturska MB 313
Self-Heating in Exothermic Reactions: Electrical Calibration of Heat Losses from a Stirred Reactor/ Thompson D, Gray P 319
On the Problem of Thermal Instability of Explosive Materials/ Bailey PB 329
Liquid Fuel Fires in the Laminar Flame Region/ Nakakuki A 337

Studies of the Spontaneous Ignition in Air of Binary Hydrocarbon Mixtures/ Cullis CF, Foster CD 347
Heats of Reaction of Pyrotechnic Compositions Containing Potassium Chlorate/ Scanes FS, Martin RAM 357
Thermal Analysis of Pyrotechnic Compositions Containing Potassium Chlorate and Lactose/ Scanes FS 363
Discrete Simulation Methods in Combustion Kinetics/ Bunker DL, Garrett B, Kleindienst T, Long III GS 373
Solid Propellant Burning Rate Measurement in a Closed Bomb/ Celmins A... 381

Brief Communications

Thermal Diffusion and Flame Stoichiometry/ Barnes MH, Fletcher EA 399

COMBUSTION SCIENCE AND TECHNOLOGY

Vol. 9, Nos. 1-2 1974

On the Flame Spreading over a Polymer Surface/ Ohki Y, Tsugze S 1
Flame Retardants and Particulate from Wood Fires/ Philpot CW 13
Role of Turbulent Fluctuations in NO Formations/ Gouldin FC 17
Concentration Fluctuations in Turbulent Jet Diffusion Flames/ Bilger RW, Kent JH 25
Mass Regression in the Pyrolysis of Pine Wood Macrocylinders in A Nitrogen Atmosphere - An Experimental Study/ Kanury AM 31
A Theoretical Criterion for Dynamic Extinction of Solid Propellants by Fast Depressurization/ T'ien JS 37
Radiant Heating from a Cylindrical Fire Column/ Dayan A, Tien CL 41
Measurements of Wall Heat Transfer in the Presence of Large Amplitude Combustion-Driven Oscillations/ Perry EH 49
Ignition of Cellulose Nitrate by High Velocity Particles/ Grossmann ED, Rele PJ 55
Effect of Metallic Additives on the NOx Emissions from a Small Oil Burner/ Altwicker ER, Shen TT 61

Short Communications

Blow-Off and Flame Spread in Liquid Fuel Fires/ Nakakuki A 71
Effect of Orientation and External Flow Velocity on Flame Spreading over Thermally Thin Paper Strips/ Sibulkin M, Ketelhut W, Feldman S 75

Vol. 9, Nos. 3-4 1974

Determinations of the Rate Constants for the Reaction O+NO-N+O2 Hanson RK, Flower WI, Kruger CH 79
The Reactivity of a Porous Brown Coal Char between 630 and 1812 °K Smith IW, Tyler RJ 87

Further Considerations on the Interaction of Sound and Flow in Rocket Motors and T-Burners/Coates RL, Horton MD 95
Aerodynamics of a Confined Burning Jet/Guruz AG, Guruz HK, Osuwan S, Steward FR 103
Mixing Processes in a Free Turbulent Diffusion Flame/Chigier NA, Strokin V 111
Hybrid Gas Phase Two Phase Detonations/Pierce TH, Nicholls JA 119
Variation of Atomic Hydrogen Density in a Propane-Oxygen Flame as a Function of Chamber Pressure/Collins LW, Downs WR 129
Low Emission Combustors for Gas Turbine Powerplants/Spadaccini LJ 133
Flame Propagation Measurements and Energy Feedback Analysis for Burning Cylinders/Sibulkin M, Lee CK 137
Rocket Propellant Combustion Studies in a Constant Volume Bomb/Mukunda HS, Raghurandan BN 149
The Refractive Indices of Isolated and of Aggregated Soot Particles/Graham SC 159

Short Communications

Spray Combustion from an Air-Assist Nozzle/Mellor AM 165
Ignition of Cellulosic Solids; Minimum Surface Temperature Criterion/Kanury AM 171
Flame Spreading from a Point Source of Ignition on a Vertical Fuel Surface/Hansen A, Sibulkin M 173
On Premixed Turbulent Flames/Basu P, Bhaduri D 177

Vol. 9, Nos. 5-6 1974

Temperature Sensitivity of the Burning Rate of Composite Solid Propellants/Cohen-Nir E 183
Comment on Solid Propellant Burning Rate during a Transient/Krier H, Ben-Reuven M 195
Flame Propagation in a One-Dimensional Liquid Fuel Spray/Polymeropoulos CE 197
Analytic Scaling of Flowfield and Nitric Oxide in Combustors/Quan V, Kliegel JR, De Volo NB, Teixeira DP 209
The Role of Energy-Releasing Kinetics in NOx Formation: Fuel-Lean, Jet-Stirred CO-Air Combustion/Malte PC, Pratt DT 221
Ignition of Partially Shattered Liquid Fuel Drops in a Reflected Shock Wave Environment/Wierzba AS, Kauffman CW, Nicholls JA 233
The Formation and Combustion of Iso-Octane Sprays in Hot Gases/Dombrowski N, Borne W, Williams A 247
Pressurization with Nitrogen as an Extinguishant for Fires in Confined Spaces. II. Cellulosic Fuels and Fabric Fuels/Tatem PA, Gann RG, Carhart HW 255
Nitrogen Dioxide Formation in Gas Turbine Engines: Measurements and Measurement Methods/Tuttle JH, Shisler RA, Mellor AM 261

Short Communications

Exact and Mean Beam Length Calculations for Radiative Heat Transfer in Gases/ Mandell DA 273

FIRE CHIEF MAGAZINE

Vol. 18, No. 1 January 1974

New Fire Retardant Emulsion/ Pearson TF 36
Fire Prevention Starts on the Drawing Board/ Buresh RJ 41
Helicopter Response to Medical Emergencies/ Rosenhan AK 44

Vol. 18, No. 2 February 1974

Pre Fire Science Training for High School Students 24
Apparatus Designed for Firefighter Safety/ Loeb DL 26
Fire in Garden Apartment under Construction/ Rankin JL 32
Communications System Reduces Response Time for Volunteers 34

Vol. 18, No. 3 March 1974

Public Safety in Durham/ Ulrich RI 28
Human Behavior in Highrise Fires/ Phillips AW 30
Foam Kills Fire in Old Saw Mill/ Flaherty JR 32
Use Surfboards for Sea Rescue 34
Fire Department Leads the Way in Developing City Highrise Code/ Stinchcomb HR 36

Vol. 18, No. 4 April 1974

Should the Fire Department Provide Full Emergency Medical Service? 34
Emergency Medical Care and the Fire Servce/ Waters JM 37
Two Physicians Discuss Fire Department Emergency Care/ Kreymborg OC, Irwin CW 41
Public Safety in Durham/ Ulrich RL 46
A Look at the New Automatic Nozzles/ Loeb DI 50

Vol. 18, No. 5 May 1974

Planning Fire Protection for Expo-74 30
All Out Effort Prevents Conflagration 35
Army Aids Volunteers in Firefighting Training 39
A Look at the New Automatic Nozzles/ Loeb DL 42
Public Safety in Durham/ Ulrich RL 45

Vol. 18, No. 6 June 1974

Students Against Fires Competition (SCORE) 30
Bomb Explosion in Rail Yard/ Klehs JW, Pieracci E 32
The Volunteer Fire Department Secretary/ Lundy SP 35
Safe Streets Act Helps Fund Alarm System 37
A Look at New Automatic Nozzles/ Loeb DL 40

Vol. 18, No. 7 July 1974

Fire Department Operations Involving Radioactive Materials/ Purington RG .. 16
A Fire Department Training Reorganization Plan/ Waide DC 21
Labor Department Hearings on Overtime Requirements for Fire Fighters 24
Fire in Amusement Park 27

Vol. 18, No. 8 August 1974

A Master Plan for Fire Protection/ Jensen GS 48
Anti-Discrimination Suits - A Complex Issue for Fire Departments 50
Fire Department Operations Involving Radioactive Materials/ Purington RG .. 53
Modernizing a Fire and Rescue System for Cost-Effectiveness/ Waters JM 58
What Fire Chiefs Should Know About General Revenue Sharing/ Atkisson Jr CT 64
Johns Hopkins Conference on Fireground Command 64

Vol. 18, No. 9 September 1974

The Women of the Hartfield Volunteer Fire Company/ Loeb DL 20
Volunteer Photo Team Aids County Fire Department Training and Fire Department Publicity/ Carpenter DJ 22
Modernizing a Fire and Rescue System for Cost-Effectiveness/ Waters JM 26
College ROTC Cadets Form Fire Brigade 32

Vol. 18, No. 10 October 1974

Syracuse Updated - A Look at the Mini-Maxi Pumper Concept in Action Loeb DL 27
A Seminar for Volunteer Administrative Officers/ Weldon WC 31
Pre-Fire Planning Pays Off/ Kotowski RC, Daveler III JP 34
A Rung Testing Device You Can Build/ Huber W 36
Father's Cast Off Apparatus/ Loeb DL 38
Modernizing a Fire and Rescue System for Cost-Effectiveness/ Waters JM 42

Vol. 18, No. 11 November 1974

When Seconds Count . . . Computer Finds Water Fast/ Redden JM 24
Volunteers Fight Gas Well Fire - Learn from the Experience/ McNeight N 27
Syracuse Updated - A Look at the Mini-Maxi Pumper Concept in Action/ Loeb DL 29
7000 Gallon Tanker/ Rosenhan AK 39

Vol. 18, No. 12 December 1974

A Report: The Federal Fire Prevention and Control Act of 1974 23
High School Fire Science Course Prepares Tomorrow's Fire Fighters/ Verburg D 26
Montgomery County's Modern Fire Training Center/ Isman WE 30
Volunteer Fire Department in Retirement Community 33

FIRE COMMAND!

Vol. 41, No. 1 January 1974

FIFI and the Fire Service (Fire Service Education) 12
Elk Grove Village, Illinois Fire Department 16
Kumamoto, Japan Department Store Fire 18
Fitness and the Fire Fighter 20
Federal Vehicle Standards 20

Vol. 41, No. 2 February 1974

Propane Cloud and a Lot of Luck/ Ellis IL 18
Ten Die in Wayne, Pennsylvania Nursing Home Fire/ Sharry JA 24
National Professional Qualifications Board for the Fire Service 26
Tactics for a Tough Chemical Processing Plant Fire/ Conlon JP 28
UFIRS - The New Management Tool for Chiefs/ Peterson CF 30

Vol. 41, No. 3 March 1974

Flammable Liquids and Combustible Liquids 8
Research Analysis - Conflagration Fire Behavior. The 1973 Chelsea, Massachusetts Fire 12
High Expansion Foam 15
Central Fire Station in Stamford 26
Kit for Highrise Buildings 19
Fire Service Management Exercises 20
Natural Gas Explosion 22
A Quick Rundown on the Elevating Platform 28

Vol. 41, No. 4 April 1974

Hazardous Materials Transportation Accidents 11
Suddenly You're Dead (First Aid) 30
What About Burn Injuries? 31
Fire Fighters - Get Moving (Fire Prevention and Burn Treatment) 32
No A-Bomb - Just Paint and Chemicals 34
What Causes Firefighter Fatalities? 35
The Psychology of the Fire Fighter 36
Air Cushions in Vehicles - What Are the Firefighting Aspects? 38
Use of Self-Contained Breathing Apparatus at Pressures Greater than Atmospheric 40
How Dependable Is Your Electrical Ground? 42
Standards-Making Revised 47
Volunteer Fire Department Uses Radio-Controlled Pumper 50
Safety First a Management Challenge 52
Abrasive Saw Blades - A Cautionary Note 60
Delivery System for Air Drops (Helicopter) 68
Tank Truck Fire in Richmond, Virginia 70

Vol. 41, No. 5 May 1974

The Terrible Blast of a Bleve: Firefighter Casualties in LP-Gas Tank Rupture Incidents 14
Hazard Reduction during Emergency Response 20
Visibility of Fire Fighters 22

Vol. 41, No. 6 June 1974

Allentown's New Emergency Communications Center 22
New Communications Center Improves Command-Control in Orlando, Florida Fire Department 28
Communications Center 36
Hotel Fires Test Mutual Aid Operations (Twice) 40
How Do You Match Men and Performance? 42

Vol. 41, No. 7 July 1974

"Small" Fire in Highrise Building One Million Dollar Loss 16
A New Image - A New Role (How Long Beach Emergency Health Care is Delivered) 20
How Canonsburg Designed Its New Pumper 26
Occupational Emotional Stress and the Fire Fighter 27
Radio Fire Alarm Box 31

Vol. 41, No. 8	August 1974
Fire Fighters Injured in LP-Gas Bleve	34
Hazardous Cargo	36
Fire Combat	38
Color of Fire Apparatus	43
Heart Test	50
How Do We Justify Driver Training?	52
Emergency Medical Service and the Fire Service	60

Vol. 41, No. 9	September 1974
Fire Tactics Training	13
Seattle's Spectacular Fire	18
Fast Spread in Polyester Polyurethane	20
LP-Gas Plus Gasoline	22
Some Twentieth Century Fire Service Problems	28
Multiple Problems during Jet Plane Fire	31

Vol. 41, No. 10	September 1974
Trauma in Westwood	16
Fireground Procedures: Information Systems for Decision Making	18
Tank Car Explosion	21
Marina Fire	22
Fire Prevention: A Real Ho Hummer	24

Vol. 41, No. 11	November 1974
Firefighters Self-Image, Projected Image, and Public Image	26
Calgary Tries 5-Inch Hose	28
How Do You Load the Hose?	30
Mutual Aid for Merchantile Fire	31

Vol. 41, No. 12	December 1974
The Fire Prevention and Control Act of 1974	16
Interview: Paramedics in West Allis	20
Applied Imagination: An Articulated Pumper	22
Marine Gas Hazards Fire Control	26

FIRE ENGINEERING

Vol. 127, No. 1	January 1974
Heavy Streams Save Exposure as Fire Levels Old Warehouse	45
NASA Develops Breathing Unit for Full 30 Minutes of Fireground Work	47

Vol. 127, No. 2	February 1974

Radio-Controlled Mutual Aid Speeds Tornado Rescue Work 26
Amphibian Converted to Fireboat 29
Precautions Can Avert Death in Manhole Rescues, Tunnel Rescues 35
Chemical Plants with Hazards to Spare 37
Drill Motor, Cylinder Jig Are Key to Opening Locked Doors 41
Teletypwriter Alarm System 42

Vol. 127, No. 3	March 1974

Disaster on Fireground a Lesson in Identifying Victims 40
80-Hour Basic Training Program Developed in Kentucky 41
Polyurethane Insulation Blazes Explosively, Ruins Steel Warehouse 44
Angled Truck-Bays Solve Fire Station Site Problem 45
Fire Protection Facilities Get Star Billing at Disney World 48
Attendance Rules Set for Qualifications Board 54
Department of Transportation Adopts Star of Life for Medical Aid Vehicles 57

Vol. 127, No. 4	April 1974

Fireground Control Improved by Spacing Multiple Alarms 49
Education Tradition Continues at Site of New York State Fire Academy 51
Denver Fire Department Uses 5-Inch Hose as Supply Lines to Engines 52
Fire Line for Camper 53
Readiness for Aircraft Incidents Demands Pre-Fire Planning 54
Rescue Work at Fire Limits Nursing Home Death Toll to 14 55
Women Volunteers Win Respect as Fire Fighters 59
Prepare for Incidents Involving Hazardous Materials in Transit 61
.... 63
New Air Tanker System Passes Tests by Fire 64
Fire Protection for Superdome 66
Radio Teleprinter Dispatching in Worcester, Massachusetts 68
Incentive Pay Plan for Education in Upland, California Fire Department 69

Vol. 127, No. 5	May 1974

Tool Cuts Holes in Concrete Floors for Hose Stream Access 32
Flow Meters Hailed for Easing Pressure on Pump Operators 44
College Program in New Jersey 51

Vol. 127, No. 6	June 1974

Warehouse Fire Jumps Street, Threatens LP-Gas Tank Farm (Camden, New Jersey) 20

Old Trailer Becomes Mobile Unit for Breathing Apparatus Training 26
Performance Appraisal Systems - Advantages and Weaknesses 28
Air Conditioner Magnifies Smoke Damage of TV Fire 52
Code of Ethics Developed by Fire Service Instructors 58

Vol. 127, No. 7 July 1974

Sao Paulo, Brazil Adds to Highrise Fire History 18
Seattle Fire Department Gets Federal Grant to Study Marine Fire Protection ... 28
SOP for 4-Inch Supply Hose, 2-Inch Hand Lines Speeds Attack 32
Long Beach Builds AFFF Units 34
Propane Tank Blast Kills Four 35
Fire Fighters Learn to Handle Gas Line Incidents in Philadelphia 38
Fire Service Urged to Accept Greater Role in NBS Research 38
Proposed Standard for Coats Offered for Review by NBS 45
Bay State Touches Off Drive to Cool Increase in Arson 54

Vol. 127, No. 8 August 1974

HI System Nears Adoption by Department of Transportation for Identifying Hazardous Materials 43
Higher Pressure Compressors and Breathing Air 46
Keeping State OSHA Plan Records 53
Field-Testing Stage Reached by NASA Breathing Apparatus Project 68
State Firefighters Certified at City Training Center 96
Federal Communications Commission Allocates UHF Bands for Medical Services 164
Carbon Dioxide Use Saves Wheat in Elevator Fire 170
Night Vision Systems May Extend Use of Helicopters on Wildfires 178
Ultrahigh-Speed Fire Detection Used at Army Ammunition Plant 181

Vol. 127, No. 9 September 1974

School Activities Can Get Pupils Excited About Fire Prevention 18
The 4 F's of Fire Prevention 22
What to Look for in TV Fires - Part I 33
Weight, Quantity of Water on Floor Determined by Using 2 Formulas 38
8-Axle Vehicle in 2 Parts Built for Wildfire Fighting 42
Evaluating Foam Characteristics 48

Vol. 127, No. 10 October 1974

39-Hour Pump Operators Course Combines Theory, Practical Work 18
80-Hour Blaze in Tunnel after Freight Train Derails 24

Specifying Efficiency without Frills Can Put Lid on Apparatus Costs 27
Grading Schedule Demands Eased for Fire Service, Water Supplies 30
What to Look for in TV Fires - Part 2 40
Fort Worth Modernizes Dispatching, Radio System 46
Women Drive Apparatus, Assist Men on Fireground 50
Relationship of Alarm Bell to Heart Disease Studied 52

Vol. 127, No. 11 November 1974

Emergency Medical Care in Miami Today 24
Tornado Hits Xenia, Ohio, Leaves 33 Dead, 1,000 Hurt 30
Paramedic Service Is Established with Aid of Public in City of 75,000 34
Training, Fire Service, Funding is Life Blood of Emergency Medical Service in Delaware 38
Car Door Locks Opened Quickly with Air Chisel 50
Pump Operated from Distance with Hand Held Radio Control................ 52
Houston Electrocardiogram Telemetry System 56
Latch Straps Keep Self-Locking Doors Open, Mark Search Areas 68

Vol. 127, No. 12 December 1974

Blast Peels Skin off Highrise Building 18
Going to the Dogs Safely (Unfriendly Dogs) 22
Volunteers Develop Cliff Rescue Equipment 28
Firefighting Strategy 31
Inflatable Smoke Barriers to Enclose Stairs, Halls 36
High School Fire Science Course 40
Management Development Program Proposed by IL Fire Chiefs 42

FIRE ENGINEERS JOURNAL
(Selected Titles)

Vol. 34, No. 93 March 1974

Three Causes of Fire - Men, Women, and Children 15
The Government's Dilemma in Framing Legislation 18
The Cost Effectiveness of Salvage Operations 22
Fire Strategy Essential to Cut Industrial Losses 25
Applications for Batch, On Line, and Real Time Processing 30
Mobilizing by Computer 35
Computer Application to Fire Prevention 38
Fire Prevention and Administrative Uses of the Computer and Business Machines 39
Operational Use of Computers in the Fire Service 41

Fire Prevention in Hamburg 41
Fire Protection Standards in the UK 47

Vol. 34, No. 94	June 1974

A Forward Look at Fire Protection 22
Preplanning for Fire Emergencies in the Chemical Industry 24
Accidents, Injuries, and Illnesses to Firemen in Great Britain 32
Hydraulic Calculations for Sprinkler Installations 40
Incident Involving Oleum Leakage from Road Tanker 47

Vol. 34, No. 95	September 1974

Closed Circuit Television 10
Digital Transmission of Automatic Fire Alarms 15
The Management of Information 16
Recruiting and Recruits Training 20
Automatic Fire Ventilation 22
Report on the IFE 1974 Examinations 27
Hospital Fire Statistics 44
Disasters - Past and Future 46
Air Conditioning and Ventilation Systems as a Fire Hazard 56

Vol. 34, No. 96	December 1974

The Summerland Fire and Inquiry 8
New Chemical Textbook from the IFE 14
IFE Annual Conference 17

FIRE INTERNATIONAL

Vol. 4, No. 43	March 1974

Fire Protection in Large Aircraft Hangars/ de Queros AB 18
Fire Safety on Merchant Vessels 36
Fire Rages through City: 360 Buildings Destroyed (in Chelsea, MA) 45
Protecting Open Air Parking Structures 49
Foamed Plastics: the Hazards that Face the Fire Fighter/ Watters P 55
Danish Hotel Fire Kills 35/ Ammitzboll J 60
Deck Cargo Problems as British Fire Crews Fight Blaze in Canadian Bulk Carrier 69
Singapore Department Store Fire: 9 Found Dead in Lift 74
The Flammability of Plastics: an Evaluation of the LOI Test German Standards Association 78

Medical Aid: a Worldwide Emergency Service (France) 85
Fabric Flammability Tests to be Studied (US) 91

Vol. 4, No. 44 June 1974

Why 50 People Died at a Leisure Center 18
Sao Paulo, Brazil - the Tragedy that Cost 187 Lives 24
Actuators: Their Potential in Fire Engineering/ Medlock LE 29
Hangar Protection at the New Paris Airport 36
Smoke Control in Highrise Buildings/ Anghinetti JR 49
German Fire Brigades: Their Aims and Organization/ Seegerer K 65
Danish Firemen Tackle Ship Fire 91

Vol. 4, No. 45 September 1974

Experts Differ on Possible Cause of Flixborough Explosion 18
Oil Bulk Ore Carrier: Why Explosions May Occur 25
Using Synthetic Foam Compound with Low Induction Rates 34
Some Case Histories of Hydrocarbon Fires 45
Base Injection with Fluoroprotein Foam 57
Fire Engineering in Relation to Process Plant Design 69
Industrial Fire Protection with High-Pressure Installations 79
New Monitor is Mounted on Tracks 87

Vol. 4, No. 46 December 1974

The Fire Protection of Russian Power Stations 18
Fires in Electric Cables 41
Industrial Role for Aircraft Fire Extinguishing Agent 50
Fire Research and Regulations in Europe 61
Inflatable Smoke Shutter from Japan 73
Smoke Extraction Systems and Heat Extraction Systems: A Critical Look at Dimensions Problems 85

FIRE JOURNAL

Vol. 68, No. 1 January 1974

Eight Fatality Mobile Home Fire, Jerry City, Ohio Sharry JA 5
Smoke, Atrium, and Stairways Boyd H 9
The Upstairs Lounge Fire, New Orleans, Louisiana Willey AE 16
The Effect of Structural Characteristics on Dwelling Fire Fatalities Christian WJ 22
LP-Gas Distribution Plant Fire Sharry JA, Walls WI 52

Office Building: Sprinklers Considered Too Costly - Fire Loss $565,000/ Stone WR 61
Safer Electrical Installations for Residential Occupancies / Stone WR 71

Vol. 68, No. 2	March 1974

Motel Fire Kills Two, Injures Eleven / Sharry JA, Stone WR 5
Accidental Power Cross Results in Improved Alarm System Design/ Jacobsen ER 7
School's "Haunted House" Burns, One Killed, Two injured/Sharry JA, Stone WR 14
Space-Age Contribution to Residential Fire Safety (Full-Scale Fire Tests of Bedroom Furnishings) 18
Fatal Hotel Fire, Bath, Maine / Stone WR 31
Development of Flammability Specifications for Furnishings / Schafran E 36
Limitations of Smokeproof Towers in Highrise Buildings / Fabiani AD 46
Life Safety in the Santa Clara County Office Buildings / Bocook BH 65
Sprinklers Control High-Piled Tire Warehouse Fire / Proudfoot EN 70
Standards for Refuse-Handling in Apartment Houses / Schulz JF 82

Vol. 68. No. 3	May 1974

Military Personnel Records Center Fire/Sharry JA, Culver C, Crist R, Hillelson JP 5
Another Pennsylvania Nursing Home Fire / Sharry JA 11
Light Fixtures for Use in Spray Booths 14
The Burning of Chelsea 17
Apartment Fire, Indianapolis, Indiana / Sharry JA 37
Taiyo Department Store Fire, Kumamoto, Japan 42
Materials First Ignited in Residential Fires 56
Multiple-Death Fires, 1973 69
Field Investigation of Natural Gas Pipeline Accident, Canterbury Woods, Annandale, Virginia / Beausoliel RW, Phillips CW, Snell JE 77
Safe Use and Hazards of Coal and Wood Stoves / Stone WR 87

Vol. 68, No. 4	July 1974

One of Several TV Set Fires, Motel, Pine Castle, Florida / Sharry JA 5
Gasoline Service Station Explosion, Saint John, New Brunswick, Canada / Lathrop JK 10
Group Fire, Indianapolis, Indiana / Sharry JA 13
Human Contribution to Fire Origins / Ottoson J 19
South America Burning / Sharry JA 23
Military Personnel Records Center Fire, Overland, Missouri (Part 2) / Walker E, Stender WW, Nelson HE 65

1973 Large-Loss Fires, United States and Canada 77
Recent Major Floating Roof Tank Fires and Their Extinguishment/ Herzog GR 93
Sound-Deadening Board Hazard/ Peterson AO 100
Apartment Fire, Los Angeles, California/ Sharry JA 105

Vol. 68, No. 5 September 1974

Dwelling Fire, Scotch Plains, New Jersey/ Sharry JA 5
A New Look at the Hazards of Electric Heat Tape and Cables/ Smith DC 11
Fires Involving LP-Gas Tank Trucks in Repair Garages/ Lathrop JK, Walls WL 18
Rest Home Fire Kills Two, Felton, California/ Sharry JA 22
Household Fire Warning Equipment Laws/ Gallagher EL 28
Fires and Fire Losses Classified, 1973 33
Building Under Construction, Westbrook, Maine/ Lathrop JK 37
Tavern Fire, Allentown, Pennsylvania/ Sharry JA 38
In Quest of an Economical, Automatic Fire Suppression System for Single-Family Residences/ Foehl JM 42
SLRP Analysis of Recommended Protection for Foamed Plastic Wall-Ceiling Building Insulations/ Maroni WF 51

Vol. 68, No. 6 November 1974

Discotheque Fire, Twenty-Four Dead (Port Chester, New York)/ Lathrop JK 5
Escape Planning (A Key to Survival in Dwelling Fires)/ O'Neill AR 10
Foamed Plastics Fire, Three Million Dollar Loss/ Lathrop JK 16
Fire Research into Plastics: A Progress Report/ Blair JA 23
Gas Explosion, New York, New York/ Sharry JA 28
One Approach to Fire Safety in Medical Facilities/ Brown R 33
Automatic Sprinklers: The Past, the Present, and a Glimpse toward the Future/ Rhodes J 42
Large-Loss Fires, School Fire, Westport, Connecticut/ Lathrop JK 50
Day-Care Center, Huntington, West Virginia/ Sharry JA 54
Selecting a Fire Extinguisher for Your Home 58
International Fire Losses, 1973 67
Recent Advances in Residential Smoke Detection/ Bright RG 69
Automatic Recall of Elevators by Smoke Detectors in Highrise Buildings/ Chandler LT 79
Fireworks Incidents, 1974 86
The Development of the National Fire Data System/ Tovey H 91
Testing a Total Flooding Halon 1301 System in a Computer Installation/ Brenneman JJ, Charney M 105

FIRE PREVENTION SCIENCE AND TECHNOLOGY

No. 8 March 1974

The Oxygen Index Test and Its Applications to Laminated Plastics in Buildings/ Mead SF 4
Present and Future Design Philosophy for Fire Hazards and Explosion Hazards in the Chemical Industry/ Rasbash DJ 16
Base Injection of Foam to Fight Oil-Tank Fires/ Evans EM 21

No. 9 July 1974

Fire Protection Methods for Extenal Steelwork/ Cocke GME 4
Fires in Oil-Soaked Lagging/ Bowes PC 13
Design of Explosion Reliefs/ Munday G 23

FIRE PROTECTION REVIEW

Vol. 37, No. 398 January 1974

Jury's Recommendations on Oban Hotel Fire 8
Menace of Fire Damage 12
Hazardous Chemicals Blaze 22
Interbild Conference on Fire Risk of Plastics 25

Vol. 37, No. 399 February 1974

Fire Appliance Feature 47
Ship Fire Unit for Merchant Navy Training 61
Fire Loss Figures 63

Vol. 37, No. 400 March 1974

Report on Accidents to Firemen 77
Fire Hazards in Shopping Complexes 78
Straw Burning 81
Radiation Incident 88
Firefighting - Monnex, Fluorocarbon Surfactants 92

Vol. 37, No. 401 April 1974

Fire Damage in 1973 115
Emergency Lighting Feature 119

Propylene Oxide Tanker Trailers 130
Glasgow's Computer System for Firefighting 139
New Safety Bill 145

Vol. 37, No. 402 — May 1974

Pneumatic Puller Rescue Device 162
Explosive Actuators - Sprinkler Heads 182

Vol. 37, No. 403 — June 1974

Fire Service Management 206
New Advance in Fire Protection for Fuel Storage 221
Fire Protection in Europe 223

Vol. 37, No. 404 — July 1974

Summerland Enquiry 249
Fire Service Technical College 250
Rescue Tenders 267

Vol. 37, No. 405 — August 1974

Communications Feature - Mobile Communications Systems 289
The Flixborough Disaster 296
Pollution Control for Industrial Environments 307
Fire Loss Figures 309

Vol. 37, No. 406 — September 1974

Industrial Society and Fire Disasters 346
Foam Tender for Oil Risks 349
Fire Detector System for Bodleian Library 351
New Concept for Concorde Fire Protection 355

Vol. 37, No. 407 — October 1974

Oil Refinery Firefighting Facilities 382
Industrial Flooring Fire Protection 392
Fire Safety in Domestic Dwellings 394
Blind People Evacuation in Fire 397

Vol. 37, No. 408 November 1974

Protective Clothing Feature 425
IFE Annual Conference 434
Solvent Factory Fire 442
Australian Fire Detection Device 447
Mobile Casualty Center 449

Vol. 37, No. 409 December 1974

Cost Effectiveness Symposium 463
Domestic Fires Seminar 464
Airliner Protection 483

FIRE TECHNOLOGY

Vol. 10, No. 1 February 1974

Best Choice of Fire Protection: An Airport Study/ Shpilberg D, de Neufville R ... 5
Life Support without Combustion Hazards/ McHale ET 15
Methane Flame Extinguishment with Layered Halon or Carbon Dioxide/ Strasser A, Liebman I, Kuchta JM 25
Fire Spread and Smoke Control in Highrise Fires/ Zinn BT, Bankston CP, Cassanova RA, Powell EA, Koplon NA 35
Heat Radiation from Fires of Aviation Fuels/ Fu TT 54
Buoyancy Characteristics of a Fire Heat Source/ Byram GM, Nelson Jr RM 68

Vol. 10, No. 2 May 1974

Explicit Equations for Two-Phase Carbon Dioxide Flow/ Noronha JA, Schiffhauer Jr FJ 101
Projections Separating Spandrel Spaces/ Van Bower Jr J, Major RW 110
Effluent Fire Product - A Crude Approach to Fire Gas Hazard Assessment/ Robertson AF 115
Characteristics of Invisible Particles Generated by Precombustion and Combustion/ Van Luik Jr FW 129
Passive and Active Fire Protection - the Optimum Combination/ Baldwin R, Thomas PH 140
Calculating Thermal Radiation Hazards in Large Fires/ Parker RO 147
Radiative Characteristics of Fire Fighters' Coat Fabrics/ Quintiere J 153

Vol. 10, No. 3 August 1974

Application of Release Rate Data to Hazard Load Calculations/ Smith EE 181

Smoke Development at Different Energy Flux Levels in an NBS Smoke Density Chamber/ Chien WP, Seader JD 187
Extinguishment of Selected Metal Fires Using Carbon Microspheroids/ McCormick JW, Schmitt CR 197
The Role of Magnesium Oxychloride as a Fire-Resistive Material/ Montle JF, Mayhan KG 201
Fire Tests of Building Interior Covering Systems/ Waksman D, Ferguson JB ... 211
False Fire Alarms in Urban Public Schools/ Kroventka SJ 221
A Discussion of Compartment Fires/ Magnusson SE, Thelandersson S 228
Closure to Discussion of Compartment Fires/ Harmathy TZ 247

Vol. 10, No. 4 — November 1974

Na-X, a New Fire Extinguishing Agent for Metal Fires/ Riley JF 269
A Fire Danger Rating System for Hawaii/ Burgan RE, Fujioka FM, Hirato GH 275
Two Smoke Test Methods - A Comparison of Data/ Robertson AF 282
A Study - Early Warning Fire Detection Performance in the Hospital Patient Room/ Waterman TE, Degenkolb JG, Stickney CW 287
Mathematical Model for Analyzing the Trade-Offs in Aircraft Hangar Deluge Sprinkler Systems Design/ Shpilberg D 304
Characteristic Temperature Curves for Various Fire Severities/ Lie TT 315

THE JOURNAL OF FIRE AND FLAMMABILITY

Vol. 5, No. 1 — 1974

A Schlieren System for Fire Spread Studies/ Butler PC 4
The Influence of Oxygen Enriched Atmospheres on the Combustion Behavior of Polymers/ Stepniczka HE 16
The Combustion Products from Synthetic and Natural Products/ O'Mara MM . 34
A Unified View of Fire Suppression/ Williams FA 54
Smoke-Producing Characteristics of Materials/ Tsuchiya Y, Sumi K 64
Determination of the True Decomposition Temperature in Pyrolysis Experiments Wolf CJ, Levy RI, Fanter DL 76
Measurement of Flame Spread Velocities 85

Vol. 5, No. 2 — 1974

The Piloted Ignition of Cotton Fabrics/ Rangaprasad N, Sliepcevich CM, Welker JR 107
Pyrolysis and Combustion of Cellulose, Part VI. The Chemical Nature of the Char/ Drews MJ, Barker RH 116
Smoke Evolution: Thermoplastics/ Nelson GL 125

Oxidation of Methane at Elevated Pressures I. Ignition Delay/Bauerle GI, Lott JI, Sliepcevich CM 136
Mass Optical Density as a Correlating Parameter for the NBS Smoke Density Chamber/Seader JD, Chien WP 151

Vol. 5, No. 3 1974

Fire Spread over Paper/Campbell AS 167
Model for Evaluating Fire Hazard/Smith EF 179
Oxidation of Methane at Elevated Pressures II. A Reaction Mechanism/Bauerle GI, Lott JL, Sliepcevich CM 190
The Nature of Various Fire Environments and the Application of Modern Material Approaches for Fire Protection of Exterior Structural Steel in Them/Castle GK 203
Carbon Microspheroids as Extinguishing Agents for Metal Fires/Schmitt CR . 223

Vol. 5, No. 4 October 1974

Flammability Behavior of Polyester-Cellulosic Fiber Blends/Pensa IE, Sello SB, Brenner W 227
Thermal Oxidative Degradation Studies of Woods/Paciorek KL, Kratzer RH, Kaufman J, Nakahara J, Hartstein AM 243
An Investigation of the Extinction of Diffusion Flames by Halons/Bajpai SN ..255
Carpet Flammability: A Pill Ignition Test Procedure/Day M, Mitton MT, Wiles DM 268
Chemistry, Combustion and Flammability/Fristrom RM 289
Self-Heating of Organic Compounds with Thermal Insulation/Hilado CJ 321

JOURNAL OF FIRE AND FLAMMABILITY
COMBUSTION TOXICOLOGY SUPPLEMENT

Vol. 1, No. 1 February 1974

Aspects and Methodology for the Evaluation of Toxicological Parameters during Fire Exposure/Kimmerle G 4
Toxicological and Environmental Factors Involved in the Selection of Decabromodiphenyl Oxide as a Fire Retardant Chemical/Norris JM, Ehrmantraut JW, Gibbons CL, Kociba RJ, Schwetz BA, Rose JQ, Humiston CG, Jewett GI, Crummett WB, Gehring PJ, Tirsell JP, Brosier JS 52
Automatic Gas-Chromatographic Monitoring of Combustion Products/Liebman SA, Ahlstrom DH, Sanders CI, Quinn EJ, Nauman CD 78

Vol. 1, No. 2 May 1974

A Bibliography of Published Information on Combustion Toxicology/Hilado CJ 91

Application of the Ohio State University Release Rate Apparatus to Combustion Gas Studies/ Smith EE 95
Toxicities of Combustion Products/ Kishitani K, Nakamura K 104
Toxicology of Polymeric Materials Exposed to Heat and Fires/ Nunez LJ, De SK, Autian J 124

Vol. 1, No. 3 August 1974

A Comparison of Combustion Products Obtained from Various Synthetic Polymers/ O'Mara MM 141
A Chemical-Mathematical Model for Predicting the Potential Physiological Hazard of a Changing Fire Environment/ Armstrong GW 157
The Effects of Carbon Monoxide on Man/ Stewart RD 167
Emission of Smoke and Fumes at Temperatures up to 500° C/ Christopher AJ, Fear EJP, Fennel TRFW 177

Vol. 1, No. 4 November 1974

Mass Life Fire Hazard: Experimental Study of the Life Hazard of Combustion Products in Structural Fires/ Pryor AJ, Fear FA, Wheeler RJ, ... 191
Relative Toxicity of Thermal Decomposition Products of Expanded Polystyrene/ Hofmann HTh, Oettel H 236
Further Investigations into the Relative Toxicity of Decomposition Products Given Off from Smouldering Plastics/ Hofmann HTh, Sand H 250
The Production of Free Tolylene Diisocyanate (TDI) from the Thermal Decomposition of Flexible Polyurethane Foams/ Woolley WD 259
A Bibliography of Published Information on Combustion Toxicology/ Hilado CJ, Shabdua CI 268

JOURNAL OF FIRE AND FLAMMABILITY
CONSUMER PRODUCT FLAMMABILITY

Vol. 1, No. 1 March 1974

Human Activity Pattern and Injury Severity in Fire Incidents Involving Apparel/ Buchbinder LB 4
Fire Behavior of Garments on Mannequins/ Finley EI, McDermott FG, Carter WH 19
Experimental and Analytical Studies of Floor-Covering Flammability with a Model Corridor/ Denyes W, Quintiere J 32

Vol. 1, No. 2 June 1974

A Full-Scale Fire Program to Evaluate New Furnishings and Textile Materials/ Hillenbrand LJ, Wray JA 115

Fire Losses and the Consumer/ Yuill CH 181
Fire Hazards of Plastics in Furniture and Furnishings; Ignition Studies/ Palmer KN, Taylor W 186
Experimental and Analytical Studies of Floor-Covering Flammability with a Model Corridor/ Denyes W, Quintiere J 221

Vol. 1, No. 3 September 1974

The Special Case of Textiles in the Flammability of Polymeric Materials/ Rebenfeld L, Miller B 225
Meeting the Mattress Flammability Standard FF 4-2 with Boron Treated Cotton Batting Products/ Knoepfler NE, Neumeyer JP, Madacsi JP 240
Flammability on Blends of Flame Retardant Fiber/ Ishibashi H, Horiushi C ...265
The MVSS-02 Burning Rates of LDPE and Ethylene Copolymers/ Johnston NW 295

Vol. 1, No. 4 December 1974

Development of a Radiant Panel Test for Flooring Materials/ Hartzell LG 305
The Consumer Product Safety Commission/ Ryan JV 354
Experimental Observation of Flame Spread Characteristics over Selected Carpets/ Kashiwagi T 367
Clothing as a Factor in Combustible Content/ Hilado CJ, Callison JS 390

JOURNAL OF FIRE AND FLAMMABILITY FIRE RETARDANT CHEMISTRY

Vol. 1, No. 1 February 1974

Mechanism of Flame Inhibition I: The Role of Halogen/ Larsen ER 4
Alumina Hydrate as a Flame Retardant Filler for Thermoplastics/ Sobolev I, Woycheshin EA 13
Flame Retardancy of Styrene Polymers/ Deets GL 26
The Effects of Fire Retardants on the Combustion of Rigid Urethane Foams/ Birky MM, Einhorn IN, Seader JD, Kanakia MD, Chien WP 31

Vol. 1, No. 2 May 1974

Flame Retarded Urethane Foams/ Stepniczka HE 61
Fire Retardant and Smoke Suppressant Additives for Polyvinylchloride/ Schwarcz JM 78
Effect of Fire Retardant Impregnations on Wood Charring Rate/ Schaffer EL...96
A Look at Flame Retardants Based on Phosphorus Compounds/ Drake Jr GL, Chance LH, Reeves WA 110

Vol. 1, No. 3 August 1974

Phosphorus-Containing Vinyl and Allyl Monomers in Flame Retardancy Weil ED 125
Dimethyl Phosphoramidates and Diethyl Phosphoramidates as Flame Retardants for Cotton/Gonzales EJ, Vail SL 142
Effects of Flame Retardant and Smoke Retardant Additives in Polymer Systems Lindstrom RS, Sidman KR, Sheth SG, Howarth JT 152

Vol. 1, No. 4 November 1974

Boron Compounds and Antimony Compounds as Flame Retardants in Rigid Polyurethane Foam/Hilado CJ, Kuryla WC, McLaughlin RW, Proops WA5 175
Flame Retarding Plastics with Halogen-Containing Compounds/Green J, Versnel J 185
Toxicology of Tris (2,3-Dibromopropyl) Phosphate/Korst AF 205
Fire Retardant Bisphenolic Polymers/Brzozowski ZK 218
Magnesium Oxychloride as a Fire Retardant Material/Montle JF, Mayhan KG 243

LAB DATA

Vol. 5, No. 1 Winter 1974

A Large Step in Testing Progress: Development of UL's Small-Scale Furnace Parks RL 5
All in a Day's Work: UI's Follow-Up Service Department Mruk J 8
Safety in Sight (Exit Signs Visibility)/Beyreis JR, Castino TG 14

Vol. 5, No. 2 Spring 1974

The National Electrical Code: Function and Operation Seelbach RW 4
To Catch a Thief: UI's Testing of Household Burglar Alarm Warning Systems Horn LH 6
The Metric Conversion Angonese AN 9
Kindling a Safe Flame: UI's Testing of Prefabricated Fireplaces and Fireplace Stoves/Teller H 10
Fire Resistance Rating: What's That? Malcomson RW 15
UL Listed Safety Cars 20

Vol. 5, No. 3 Summer 1974

A View from the Top: UL's Testing of Roof Trusses for Mobile Homes Teller H ... 4

The Engineer and Professional Engineering/ Carroll JR 6
Flammable Gases and Vapors: How Explosive Are They?/ Alroth FD 9
To Sink or Swim: UL's Marine Department Testing of Wearable Personal Flotation Devices/ Bieloblocki JM 17

Vol. 5, No. 4	Fall 1974

The Shape of Things - The Anatomy of a UL Testing Program for Molded Plastic Parts/ Bogue RJ 4
Room to Burn: A Report on UL's Gas Burner Facilities and Oil Burner Facilities/ Christian WJ 10
The National Bureau of Standards - Its Role in the Maintenance of Consumer Product Safety/ Hoffman SD 15
With Your Safety in Mind: Flammable Fabric Ignition Requirements/ Teller H . 17

NATIONAL SAFETY NEWS

Vol. 109, No. 6	June 1974

Portable Fire Extinguisher Guidelines - Selection, Maintenance, and Operation .57
OSHAct Regulations for Portable Fire Extinguishers 69
Costs of Firefighter Injuries 73
Fire Equipment Traditions: What's Wrong with Red and Black? 79
Pressure Vessels 80
How Computer Aids Hotel Security 82
Treatment of Extraneous Electricity in Electric Blasting (Data Sheet 644) 95
Signs and Symbols 102
A Sign of the Times: Greater Use of Safety Symbols by Industry Predicted 104
The Art of Creating Safety Symbols 106

PHYSICS OF COMBUSTION AND EXPLOSION

Vol. 10, No. 1	January-February 1974

Gasless Combustion of Powder Mixtures of the Transition Metals with Boron/ Borovinskaya IP, Merzhanov AG, Novikov NP, Filonenko AK 4
Spectroscopic Study of Carbon Disulfide-Air Explosions/ Gordon YeB, Drozdov MS, Shatrov VD, Tal'rose VI 15
On the Theory of Polymerization Front Propagation/ Khanukayev BB, Kozhushner MA, Yenikolopyan NS, Chechilo NM 22
On the Mechanism of Gravitational Influence on the Combustion of Dispersed Condensed Substances/ Yukhvid VI, Maksimov EI, Merzhanov AG, Kozlov VS 28
On the Dispersion Mechanism of Burning Condensed Substances/ Konev EV ... 34

Analysis of Low-Frequency Vibrations in a Propellant Burning in a Semiconfined Volume/Novikov SS, Ryazantsev YuS, Tul'skikh VYe 38
Effect of Specific Surface and Catalyst Dispersion on the Combustion of PHA Mixture Models/Demenkova LI, Kundo NN, Kadcchnikova NF 41
Effect of Multicomponent Diffusion on the Normal Gas Mixture Burning Rate/Grishin AM, Zelenskiy YeYe 45
Integral Method for Calculating Heterogeneous Ignition Characteristics/Rozenband VI, Barzykin VV 52
On Some Mathematical Models of Supersonic Gas Flows with Solid Particles/Ginsburg IP, Ryabinina TN, Shub LI, Korobkov VA 56
Calculation of Hydrogen Ignition and Hydrogen Combustion in Air with a Finite Chemical Reaction Rate/Bayev VK, Golovichev VI, Dimitrov VI, Yasakov VA 65
Ignition Modes of a Reacting Gas Mixture in an Electric Field/Grishin AM, Zelenskiy YeYe, Yakimov AS 74
Study of Flame Front Formation and Flame Front Development in Air Dispersed Systems/Todes OM, Gol'tsiker AD, Ionushas KK 83
Ignition Limit of Monodispersed Particles Suspended in a Gas/Gurevich MA, Czerova GYe, Stepanov AM 88
Study of a Quasistationary Concentration Method in a Problem of Cold Flame Propagation/Novozhilov BV, Posvyanskiy VS 94
Effect of Structural Characteristics of Individual and Mixed Copper Oxide and Iron Oxide Mixtures on Their Activity in an Ignition Reaction of Isobutene-Perchloric Acid Mixtures/Bogdanova VV, Komarov VF, Lesnikovich AI, Sviridov VV 99
Measurements of Detonation Front Perturbations in Gaseous Mixtures at Elevated Pressures/Manzhaley VI, Mitrofanov VV, Subbotin VA 102
Effect of Low-Dispersed Fillers on Detonation Wave Parameters and Detonation Wave Structure in Gas/Gladilin AM 110
High Power Light PulseSource with a Continuous Spectrum/Kiselev YuN, Khristoforov BD 116
Cumulation of Detonation Products of a Hollow Cylindrical Explosive/Lobanov VF, Fadeyenko YuI 119
Plane Destructive Waves/Kuznetsov VM 124
Explosive Destruction of Tubes/Ivanov AG, Kochkin LI, Vasil'yev LV, Kustov VS 127
Explosive Hardening of Mild Steel at Different Points in a Detonation Front/Teslenko AG, Didyk RP, Gryaznova LV, Legeza VN 132
Calculations of Oscillating Characteristics in a Wake/Skurin LI 137

Brief Communications

On Remote Ignition of Explosives through Dense Media/Arinichev VA, Popova VA, Ryabinin AG 142
Effect of Inert Additives on Igdanite Detonation Properties/Vovk AA, Gnutov VV, Pluzhnik VI, Parshukov PA 144

Explosive Circuit Breakers/Voytenko AYe, Zherebnenko VI, Zakharenko ID, Isakov VP, Faleyev VA 145

Vol. 10, No. 2 March-April 1974

Calculation of Diffusion Flame Structure/Vulis LA, Yarin LP 151
Heterogeneous System Combustion in a Mass Force Field/Yukhvid VI, Maksimov FI, Kozlov VS 162
Effect of Acceleration on the Burning of Metallized Compositions/Maksimov YuM, Maksimov EI, Vilyunov VN 169
Burning Stability of Heterogeneous Condensed Systems in a Semiconfined Volume/Tul'skikh VYe 178
Hydrazine Chloride Combustion/Zhevlakov AF, Strunin VA, Manelis GB 185
Experimental Studies of the Heterogeneous Ignition Process/Isakov GN, Grishin AM 191
Effect of Ferrous Oxide and Cobalt Oxide on Propellant Burning Laws/Denisyuk AF, Zhevlakov AF, Lobkovskiy VP, Tokarev NP, Shamshina CL 197
Dependence of Product Composition and Burning Rate in Metal-Boron Systems on Reactant Relationships/Novikov NP, Borovinskaya IP, Merzhanov AG . 201
Reducer Inhibition of Ammonium Perchlorate Combustion/Glazkova AP 206
Metal Parts Ignition in an Oxygen-Rich Atmosphere/Rozenband VI 212
Calculation of Diffusive Turbulent Combustion of Premixed Jets and Diffusion Jets with Concentration Fluctuations by the Integral Method/Zimont VL, Meshcheryakov YeA 220
On the Effect of Nitric Oxide on Hydrogen Ignition in Air/Strokin VN, Khaylov VM 230
Autoignition of Methane-Oxygen Mixtures at Atmospheric Pressure/Shchemelev GV, Shevchuk VU, Mulyava MP, Moin FB 235
Interaction of Characteristics of a Turbulent Field and a Hydrogen Diffusion Flame in a Closed Channel/Sokolenko VF, Tyul'Panov RS, Morin OV, Ignatenko YuV 240
Studies of the Kinetics of Tantalum-Oxygen Interaction by the Ignition Method/Gal'chenko YuA, Grigor'yev YuM 245
Optimal Characteristics of an Electric Gas Burner/Mamina NK, Nefedova MG, Polonskiy IYa, Popov VA, Snyatkov YuI 253
Effect of Laser Radiation on Soot Particles in Flames/Burakov VS, Zheludok VV, Stavrov AA 256
Effect of Hammer Rigidity on the Mechanical Heating of a Fluid Layer/Dubovik AV, Bobolev VK 260
Application of an Electrical Junction Effect to Pressure Measurement in a Quasi-Isentropic Compression Wave/Bordzilovskiy SA, Karakhanov SM, Titov VM 265
Hydrazine Azide Detonation Velocity/Yakovleva GS, Kurbangalina RKh, Stesik LN 270
Relaxation Wave Velocity in Shocked Porous Sodium Chloride/Belinskiy IV, Struchenko AN, Khristoforov BD 274

Implosion of Thin-Walled Tubes by Explosive Loading/Mikhaylov AN, Gordopolov YuA, Dremin AN 277
Studies of Surface Cleanliness in Explosion Welding/Gel'man AS, Pervukhin LB, Tsemakhovich BD 284

Brief Communications

Model Description of the Thermophysical Properties of Non-Ideal Plasma/ Kovalev BM, Kulik PP, Lomakin BN, Ryabyy VA, Fortov VYe 289
Measurement of Recombination Rate Constants of Charged Particles in Flames/ Karachevtsev GV 291
Metal Plate Acceleration by Explosions/Bichenkov YeI, Lobanov VA 292
Electrode Erosion by Combustion Products/Viktorov VN, Nefedova MG, Popov VA, Mironov EA 294
Combustion Theory Seminar - USSR 297

Vol. 10, No. 3 May-June 1974

Kinetics of Thermodissociation of Diatomic Molecules I. Small Admixtures of Diatomic Molecules in Monatomic Inert Gas/Osipov AI, Stupochenko YeV 303
On the Theory of Burning of Mixtures Forming Condensed Reaction Products/ Aldushin AP, Khaykin BI 313
The Effect of Catalysts on the Burning of Explosives/Glazkova AP 323
Experimental Study of Nonacoustic Pulsations of Burning Nitroglycerine/ Ilyukhin VS, Mysov VG, Novikov SS 334
On the Correlation of the Catalytic Effect on the Thermal Decomposition and Combustion of Propellants/Androsov AS, Denisyuk AF, Kuvshinov VM, Tokarev IP 338
Nonstationary Propellant Erosion/Medvedev YuI, Revyagin LN 341
Study of the Surface Structure of Catalyzed PNA PMMA Mixtures/ Korobeynikov OP, Viktorenko AM, Tereshchenko AG, Kolomeychuk NN . 345
On the Stability and Transitional Processes of Surface Formation with Increased Local Gasification Rate in a Semiconfined Volume/Bobylev VM, Bril' SV, Gusachenko IK, Dolmatov GI 354
Calculation of the Vapor Phase Diffusive Burning Rate of a Metallic Particle/ Gurevich MA, Ozerov YeS, Rybina LS 363
Chain Explosion in Hydrogen Oxidation at High Degrees of Conversion/ Babushok VI, Bunev VA, Babkin VS, Lovachev LA 372
Quasistationary Concentration Method for Determination of the Critical Conditions for Thermal Explosion in the Case of Branching Chain Reactions/ Gontkovskaya VT 376
Laminar Flame Radiation from Acetylene Decomposition/Granovskiy EA, Knorre VG, Tesner PA, Piskunov BG 383
High-Frequency Processes in a Spin Detonation Core/Denisov YuN 386
Study of Liquid Transformations in Shock Waves/Afanasenkov AN, Voskoboynikov IM, Gogulya MF, Katkov AI 392

Interaction of a Chemical Peak with a Thin Plate Kuznetsov OA, Solov-yev VS 401
Excitation of Supercompressed Detonation Waves in Condensed Explosives/ Teslenko AG, Didyk RP 405
Surface Effects at Oblique Collisions of Metal Plates/Deribas AA, Zakharenko ID 409
Nickel Hardening by Shock Waves and Nickel Softening by Subsequent Annealing/Sikorov VN, Pershin SV 421
Shock Wave Effects on Silicon Dioxide I. Quartz/Anan'in AV, Breusov ON, Dremin AN, Pershin SV, Tatsiy VF 426
Medium Behavior in the Destruction Zone of an Explosion/Sisov IA, Spivak AA, Tsvetkov VM 437
Compression Waves in Solids due to the Explosion of Shallow Explosives/ Spivak AA 440

Brief Communications

Combustion Zones of Self-Propagating Eaves in Refractory Synthesis/ Azatyan TS, Mal-tsev VM, Merzhanov AG, Seleznev VA 445
Autoignition of Premixed Methane-Oxygen in Acetylene Production Processes and Methane Conversion/Kovalivnich AM, Glikin MA, Nuzhda LI 446
Study of Diazo Salt Combustion/Fogel'zang AYe, Adzhemyan VYa, Svetlov BS 449
Studies of Structural Change in Polycrystals by Explosions/Guz'IS, Peretyat'ko VN, Demina GS 452

Vol. 10, No.4 July-August 1974

Kinetics of Thermal Dissociation of Diatomic Molecules II. Single-Component System and Mixtures of Polyatomic Gases/Osipov AI, Stupochenko YeV 459
Effects of Medium Composition and Temperatures on the Thermal Excitation Efficiency in Obtaining Population Inversions by Mixing in a Supersonic Flow/ Kroshko VN, Soloukhin RI, Fomin NA 473
On Diffusion Flame Lengths Bayev VK, Kuznetsov PP, Mogil'nyy IA, Tret'yakov PK, Yasakov VA 485
On a Method of Gas Sampling in a Supersonic Reacting Flow/Rozhitskiy SI, Strokin VN 492
On the Thermal Theory of Heterogeneous Ignition/Averson AE, Barzykin VV, Martemyanova TM 498
Condensed Media Ignition in the Presence of Heat Losses/Vilyunov VN, Khlevnoy SS 512
Gasless Systems Ignition by Combustion Waves/Strunina AG, Martemyanova TM, Barzykin VV, Yermakov VI 518
On an Ignition Mechanism in Heterogeneous Systems/Kuznetsov VT, Marusin, VP, Skorik AI 526
Nonisothermic Thermographic Studies of Heat-Evolution Kinetics in Heterogeneous Reactions/Rozenband VI 530

On a Possibility of Quasistationary Approximation for the Calculation of Drop Ignition Limits/ Gurevich MA, Sirkunen GI, Stepanov AM 534
Boron Particle Ignition/ Grigor'yev AI, Sigimov VI, Grigor'yeva ID 539
DINA Propellant Combustion at Atmopsheric Pressure and the Effect of Some Additives/ Aleksandrov VV, Tukhtayev RK, Boldyreva AV, Boldyrev VV ...543
Study of Condensed Combustion Products of Magnesium Powders. I. Pressure Dependence/ Gusachenko YeI, Stesik LN, Fursov VP, Shvetsov VI 548
Changes in Particle Distribution in a Two Phase Solid Propellant Combustion Flow/ Kirsanova ZV 554
Detonation Initiation by Shock Waves in Waterfilled Trotil/ Shvedov KK, Dremin AN, Krivchenko AL, Murashova NA, Kozlov VS 561
Shock Compression of Porous Cylindrical Solids/ Deribas AA, Staver AM 568
Effect of Shock Waves on Silicon Dioxide. II. Quartz Glass/ Anan'in AV, Breusov ON, Dremin AN, Pershin SV, Rogacheva AI, Tatsiy VF 578
Acrylonitrile Physical Properties and Transformation at High Dynamic Pressure/ Yakushev VV, Nabotov SS, Yakusheva OV 583
Effect of Shock Waves on Residual Magnetic Properties of Armco Iron and Nickel/ Kiselev AN, Sobolenko TM, Teslenko TS 594
Effect of a Jacket on Detonation Velocities in Composite Explosives/ Tarasenko NN 598
Plasticity, Destruction, and Scale Effects in Explosion Loading of Steel Tubes/ Ivanov AG, Mineyev VN, Tsypkin VI, Kochkin LI, Vasil'yev LV, Kleshchevnikov OA 603

Brief Communications

Population Inversion of Excited States in Stationary Combustion/ Kostritsa AA, Savel'yev VI 608
Measurement of Normal Burning Velocities of Rich Methane-Oxygen Mixtures/ Shohemelev GV, Mulyava MP, Shevchuk VU, Moin FB...................612
Radiation of Acetylene-Air Flames Activated by a D-C Discharge/ Glushko LN, Kovalenko IA, Tverdokhlebov VI 614
Boron Oxide Gasification/ Vovchuk YaI, Zolotko AN, Klyachko LA, Polishchuk DI, Shevchuk VG 615

Vol. 10, No. 5 September-October 1974

Laser-Schlieren Method Investigation of Energy Yield Kinetics in Exothermic Reactions behind Shock Waves/ Zaslonko IS, Kogarko SM, Mozzhukhin YeV, Mukoseyev YuK 629
Theory of Combustion for a Condensed Fuel with a Plane Heat Conducting Element/ Rybanin SS, Stesik LN 634
Polymerization Front Propagation Theory/ Khanukayev BB, Kozhushner MA, Yenikolopyan NS 643
Methylamine Perchlorate Combustion/ Viktorenko AM, Ivanov GV, Markov OM 650

Infrared Spectroscopy of Nitroester Combustion Zones in Vacuum/ Davidchuk YeL, Mal'tsev VM 656
On the Critical Combustion Diameter of Condensed Substances/ Kondrikov EN, Novozhilov BV 661
Study of Condensed Combustion Products of Magnesium Powders. II. Particle Size/ Gusachenko YeI, Stesik LN, Fursov VP, Shvetsov VI 669
Effect of Burn-Out on the Ignition Limit of a Single Component Gas Suspension/ Gurevich MA, Ozerova GYe 676
Ignition in a Hot Channel/ Shishkayev SM, Leont'yev AK 684
On the Spherical Combustion Propagation Process in Fuel Air Mixtures at High Initial Pressures and Temperatures/ Podgrebenkov AI, Kogarko SM 691
On the Electrical Field of a Laminar Flame/ Kindin NI, Librovich VB 696
On Probe Measurements of Ionization in Flames/ Eogoslovskiy VP, Zaychikov VV, Samoylov IB 705
On the Existence of a Minimum Drop Size in an Oxidizing Gas Flow Necessary for a Detonation/ Vezhba A 710
Radiated Heat from a Hydrogen Diffusion Flame at M=1/ Ktalkherman MG, Mogil'nyy IA, Kharitonova YaI, Kholyavin VS, Yasakov VA 717
Experimental Determination of the Turbulent Characteristics of Supersonic Flow by the Diffusion Method/ Alekseyev NM, Tyul'panov RS 723
Compressed Detonation Waves in Condensed Explosives/ Al'tshuler LV, Zubarev VN, Telegin GS 728
On Plane Shock Wave Decay in a Condensed Nonhomogeneous Medium/ Romanova VI 732
Study of Tube Wall Motion under the Effect of the Detonation Products of an Internal Explosive Charge/ Tarasenko NN 737
On the Kinematics of Compressed Powdered Materials by Shock Waves/ Kuz'min GYe 746
On the Thermal Wave in Shock Loaded BismuthBismuth-Shock Loaded/ Nesterenko VF 752
Investigation of Plane Jet Breakup/ Mali VI, Pay VV, Skovpin AI 755
Instrument for Studying the Emission Spectrum of the Combustion Products of Condensed Particles in the 0.5 to 8 Micron Range/ Davidchuk YeL, Mal'tsev VM 762
On Stationary Combustion Extinction of Burning Propellant by a Radiant Heat Pulse/ Gostintsev YuA 764
Soot Formation in Acetylene Detonation/ Knorre VG, Kopylov MS, Tesner PA 767
Note on the Vibrational Combustion of Falling Drops/ Podymov VN, Gabidovskiy AG, Serikov VI 772
Interaction of Explosion Welded Copper-Zirconium at the Contact Boundary/ Staver AM, Sobolenko TM, Teslenko TS 774
Determination of the Electron Distribution Function from Their Energies and Flame Plasma by the Method of Increments of the Constant Component of the Probe Current/ Zaytsev AS 779

On the Feasibility of Experimental Determination of Heating Temperature of Porous Bodies during Explosion Loading/ Pikus IM, Roman OV 782
On the Flow Behind a Detonation Wave Front in a Transverse Magnetic Field at Small Reynolds Numbers/ Kuznetsov AP, Pleshanov AS 784

Vol. 10, No. 6 November-December 1974

Calculation of the Composition and Thermodynamic Functions of the Explosion Products of Condensed Explosives/ Kuznetsov NM, Okunev VYe, Popov VM 791
Gas Boundary Layer Stability with Chemical Reactions on a Catalytic Surface/ Petrov GV 797
Influence of the Polymorphic Transition of Ammonium Perchlorate on the Catalytic Effect of Some Homogeneous and Heterogeneous Additives in Thermal Degradation/ Kaydymov BI, Gavazova VS 801
Burning of Porous Condensed Systems and Propellants/ Dubovitskiy VF, Korostelev VG, Korotkov AI, Prolov YuV, Firsov AN, Shkadinskiy KG, Khomik SV 811
On the Stability Theory of Solid Propellant Burning in a Semi-confined Volume/ Gostintsev YuA, Sukhanov LA 818
Transition to Normal Burning in a Multicomponent Fuel Mixture/ Grishin AM, Subbotin AN 826
Effect of Bouyant Forces on Diffusion Flame Length/ Bayev VK, Yasakov VA .835
Low-Temperature Zone of a Hydrocarbon Flame Front. I. Propane Oxidation near a Flame Front/ Ksandopulo GI, Kolesnikov BYa, Odnorog DS 841
Shift of the Inhibited Explosion Limit of Hydrogen due to Inhibitor Consumption/ Azatyan VV, Namoradze MA 847
Metal Cutting by Gas Laser/ Bystrova TV, Kozlov GI, Kuznetsov VA, Iisitsyn VI, Trishkin VM 857
Measurement of the Electrical Conductivity Profile in a Detonation Front of Condensed Explosives/ Yershov AP, Zubkov PI, Luk'yanchikov LA 864
P E T N Burning to Detonation Transition Length/ Ashchepkov NV, Sten'gach VV 874
Experimental Study of the Flight Velocity of a Plate Accelerated by the Explosion Products of Oblique Detonation/ Dremin AN, Mikhaylov AN 877
Explosion Acceleration of Plates/ Kanel' GI, Molodets AM, Vorob'yev AA 884
Fracture Velocity in Solids due to Strong Shock Waves/ Bobrovskiy SV, Gogolev VM, Zamyshlyayev BV, Iozhkina VP 891
Study of the Thermochemical Cycle of an Explosion Welded Junction Zone/ Gel'man AS 898
Temperature Measurements at Metal Interfaces during Shock Loading/ Nesterenko VP, Staver AM 904
Method for Making Vertical Cylindrical Soil Cavities/ Krivtsov VA 907
Mechanism of Low Speed Detonation Propagation at Low Speed in Spark Initiated P E T N/ Andreyev VV, Luk'yanchikov IA 912

Experimental Study of Weak Shock Waves in Air from Unconfined Explosions/ Smoliy NI, Tseytlin YaI .... 919 On
Abelian Transformations for Interferometric Holography of Point Source Explosions/ Pikalov VV, Preobrazhenskiy NG 923

Brief Communications

Metal Embossing by Shock Waves/ Deribas AA, Zakharov VS, Sobolenko TM, Teslenko TS 931
Weak Discontinuity Propagation Velocity in a Turbulent Flow/ Nikolayev YuA 933
Laser-Instrument for Determining Explosion Limit Temperature of Vapor-Air Mixtures of Organic Substances/ Mullayanov FI, Khakimov VS, Akmanov AG, Varlamov GA 934
Supersonic Flow of a Nonuniform Reactive Gas around a Wedge/ Grachev VA, Strokin NV 936
Holography of Shock Waves in Round Tubes/ Gordeyev VYe, Matveyev YuS, Ryskin MYe 939

EXPANSIONS OF REFERENCE ABBREVIATIONS

ComFla	Combustion and Flame
ComSciT	Combustion Science and Technology
FirChf	Fire Chief Magazine
FirCom	Fire Command
FirEng	Fire Engineering
FEngJ	Fire Engineers Journal
FirInt	Fire International
FirJrn	Fire Journal
FPSTech	Fire Prevention Science and Technology
FPRev	Fire Protection Review
FirTec	Fire Technology
JFFLAO	Journal of Fire and Flammability
JFFCT	JFF/Combustion Toxicology Supplement
JFFCPF	JFF/Consumer Product Flammability Supplement
JFFFRC	JFF/Fire Retardant Chemistry Supplement
LabDat	Lab Data
NSNews	National Safety News
PhysCE	Physics of Combustion and Explosion

INDEX TO AUTHORS

Abbott C .... ComFla23(1) 1
Ablow CM .... ComFla22(1) 23
Adams GF .... ComFla22(3) 289
Adzhemyan VYa .. PhysCE10(3) 449
Afanasenkov AN .. PhysCE10(3) 392
Agkpo A .... ComFla23(1) 47
Ahlstrom DH .... JFFCT1(1) 78
Akmanov AG ..... PhysCE10(6) 934
Al'tshuler LV ..... PhysCE10(5) 728
Aldushin AP ...... PhysCE10(3) 313
Aleksandrov VV ... PhysCE10(4) 543
Alekseyev NM .... PhysCE10(5) 723
Alroth FD .... LabDat5(3) 9
Altwicker ER .... ComSciT9(1-2) 61
Ambs II .... ComFla22(1) 59
Ammitzboll J .... FirInt4(43) 60
Anan'in AV .... PhysCE10(3) 426,
.... PhysCE10(4) 578
Andreyev VV ..... PhysCE10(6) 912
Androsov AS ..... PhysCE10(3) 338
Anghinetti JR .... FirInt4(44) 49
Angonese AN .... LabDat5(2) 9
Appleton JP ..... ComFla22(3) 299,
.... ComFla23(2) 249
Arinichev VA ..... PhysCE10(1) 142
Armstrong GW .... JFFCT1(3) 157
Ashchepkov NV ... PhysCE10(6) 874
Aten CF .... ComFla22(1) 133
Atkisson Jr CT ...... FirChf18(8) 64
Autian J .... JFFCT1(2) 124
Auzanneau M .... ComFla22(1) 1
Avdyunin VI .... ComFla22(1) 77
Averson AE ...... PhysCE10(4) 498
Azatyan TS .... PhysCE10(3) 445
Azatyan VV ...... PhysCE10(6) 847

Babkin VS .... PhysCE10(3) 372
Babushok VI ...... PhysCE10(3) 372
Bailey PB .... ComFla23(3) 329
Bajpai SN .... JFFLAO5(4) 255
Baker RJ .... ComFla23(1) 57
Bakhman NN ...... ComFla22(1) 77
Baldwin R .... FirTec10(2) 140
Bankston CP .... FirTec10(1) 35
Barker RH .... JFFLAO5(2) 116
Barnard JA .... ComFla22(1) 35
Barnes MH .... ComFla23(3) 399
Barzykin VV ...... PhysCE10(1) 52,
.. PhysCE10(4) 498, PhysCE10(4) 518
Basu P .... ComSciT9(3-4) 177
Bauerle GL ...... JFFLAO5(2) 136,
.... JFFLAO5(3) 190
Baulch DI .... ComFla23(2) 215
Bayev VK .... PhysCE10(1) 65,
.. PhysCE10(4) 485, PhysCE10(6) 835
Beausoliel RW ...... FirJrn68(3) 77
Beer JM .... ComFla23(2) 143
Belinskiy IV ...... PhysCE10(2) 274
Ben-Reuven M .. ComSciT9(5-6) 195
Bernard ML .... ComFla22(1) 1
Bernecker RR .... ComFla22(1) 111,
.. ComFla22(1) 119, ComFla22(2) 161
Beyreis JR .... LabDat5(1) 14
Bhaduri D ...... ComSciT9(3-4) 177
Bichenkov YeI .... PhysCE10(2) 292
Bieloblocki JM ...... LabDat5(3) 17
Bilger RW .... ComSciT9(1-2) 25
Biordi JC .... ComFla23(1) 73
Birky MM .... JFFFRC1(1) 31
Blair JA .... FirJrn68(6) 23
Bobolev VK ...... PhysCE10(2) 260
Bobrovskiy SV .... PhysCE10(6) 891
Bobylev VM ...... PhysCE10(3) 354
Bocook BH .... FirJrn68(2) 65
Bogdanova VV ..... PhysCE10(1) 99
Bogoslovskiy VP .. PhysCE10(5) 705

Bogue RJ .... LabDat5(4) 4
Boldyrev VV ...... PhysCE10(4) 543
Boldyreva AV ..... PhysCE10(4) 543
Bordzilovskiy SA .. PhysCE10(2) 265
Borman G .... ComFla22(2) 259
Borne W .... ComSciT9(5-6) 247
Borovinskaya IP ... PhysCE10(1) 4,
.... PhysCE10(2) 201
Bowes PC .... FPSTech(9) 13
Boyd H .... FirJrn68(1) 9
Bracco FV .... ComFla22(1) 9
Bradley D .... ComFla22(1) 43,
.... ComFla22(2) 143
Brenneman JJ ...... FirJrn68(6) 105
Brenner W .... JFFLAO5(4) 227
Breusov ON ..... PhysCE10(3) 426,
.... PhysCE10(4) 578
Bright RG .... FirJrn68(6) 69
Bril'SV .... PhysCE10(3) 354
Brosier JS .... JFFCT1(1) 52
Brown NJ .... ComFla23(2)
Brown R .... FirJrn68(6) 33
Brzozowski ZK .... JFFFRC1(4) 218
Brzustowski TA ... ComFla22(3) 313
Buchbinder LB ...... JFFCPF1(1) 4
Bunev VA .... PhysCE10(3) 372
Bunker DI .... ComFla23(3) 373
Burakov VS ...... PhysCE10(2) 256
Buresh RJ .... FirChf18(1) 41
Burgan RE .... FirTec10(4) 275
Butler PC .... JFFLAO5(1) 4
Byram GM .... FirTec10(1) 68
Bystrova TV ...... PhysCE10(6) 857

Callison JS .... JFFCPF1(4) 390
Campbell AS ..... JFFLAO5(3) 167
Carhart HW .... ComSciT9(5-6) 255
Carpenter DJ .... FirChf18(9) 22
Carroll JR .... LabDat5(3) 6
Carter WH .... JFFCPF1(1) 19
Cashin KD ...... ComFla22(3) 337,
.... ComFla23(2) 227
Cassanova RA ...... FirTec10(1) 35
Castino TG .... LabDat5(1) 14
Castle GK .... JFFLAO5(3) 203
Celmins A .... ComFla23(3) 381
Chaikin RF .... ComFla22(2) 269
Chance LH .... JFFFRC1(2) 110
Chandler LT .... FirJrn68(6) 79
Charney M .... FirJrn68(6) 105
Chechilo NM ...... PhysCE10(1) 22
Chernov YuG ...... ComFla23(1) 29
Chien WP .... FirTec10(3) 187,
... JFFFRC1(1) 31, JFFLAO5(2) 151
Chigier NA .... ComFla23(1) 11,
.... ComSciT9(3-4) 111
Chintapalli PS .... ComFla22(1) 71,
.... ComFla22(3) 337
Chomiak J .... ComFla22(1) 99
Christian WJ .... FirJrn68(1) 22,
.... LabDat5(4) 10
Christopher AJ ..... JFFCT1(3) 177
Clark AF .... ComFla23(1) 129
Coates RI .... ComSciT9(3-4) 95
Cohen-Nir E .... ComSciT9(5-6) 183
Cointot A .... ComFla22(1) 1
Collins LW ..... ComSciT9(3-4) 129
Conlon JP .... FirCom41(2) 28
Cooke GME .... FPSTech(9) 4
Cosgrove JD ...... ComFla22(1) 13,
.... ComFla22(1) 19
Crist R .... FirJrn68(3) 5
Critchley IL ...... ComFla22(2) 143
Crummett WB....... JFFCT1(1) 52
Cullis CF .... ComFla23(3) 347
Culver C .... FirJrn68(3) 5
Cutler DP .... ComFla22(1) 105

Daveler III JP ...... FirChf18(10) 34
Davidchuk YeL ... PhysCE10(5) 656,
.... PhysCE10(5) 762
Day M .... JFFLAO5(4) 268
Dayan A .... ComSciT9(1-2) 41
de Neufville R .... FirTec10(1) 5
de Queros AB .... FirInt4(43) 18
De SK .... JFFCT1(2) 124
De Volo NB .... ComSciT9(5-6) 209
Deets GI .... JFFFRC1(1) 26
Degenkolb JG ..... FirTec10(4) 287
Demenkova LI ..... PhysCE10(1) 41
Demina GS .... PhysCE10(3) 452
Denisov YuN ..... PhysCE10(3) 386

Denisyuk AF ..... PhysCE10(3) 338
Denisyuk AP ..... PhysCE10(2) 197
Denyes W .... JFFCPF1(1) 32,
.... JFFCPF1(2) 221
Deputatova LV ... ComFla23(3) 305
Deribas AA ...... PhysCE10(3) 409,
.. PhysCE10(4) 568, PhysCE10(6) 931
Didyk RP .... PhysCE10(1) 132,
.... PhysCE10(3) 405
Dimitrov VI .... PhysCE10(1) 65
Dolmatov GI ..... PhysCE10(3) 354
Dombrowski N .. ComSciT9(5-6) 247
Donaldson AB ..... ComFla23(1) 17
Downs WR ..... ComSciT9(3-4) 129
Drake Jr GI .... JFFFRC1(2) 110
Dremin AN ...... PhysCE10(2) 277,
PhysCE10(3) 426, PhysCE10(4) 561,
.. PhysCE10(4) 578, PhysCE10(6) 877
Drews MJ .... JFFLAO5(2) 116
Drozdov MS .... PhysCE10(1) 15
Drysdale DD ..... ComFla23(2) 215
Dubovik AV ...... PhysCE10(2) 260
Dubovitskiy VF ... PhysCE10(6) 811

Edwards JC ...... ComFla22(2) 269
Ehrmantraut JW .... JFFCT1(1) 52
Einhorn IN .... JFFFRC1(1) 31
El-Mahalowy FM . ComFla23(3) 283
Ellis DL .... FirCom41(2) 18
Emmons HW ..... ComFla22(2) 223
Evans FM .... FPSTech(8) 21

Fabiani AD .... FirJrn68(2) 46
Fadeyenko YuI .... PhysCE10(1) 119
Faleyev VA .... PhysCE10(1) 145
Fanter DL .... JFFLAO5(1) 76
Farber M .... ComFla22(2) 191
Fear EJP .... JFFCT1(3) 177
Fear FA .... JFFCT1(4) 191
Feldman S .... ComSciT9(1-2) 75
Felton PG .... ComFla23(3) 295
Fenimore CP ..... ComFla22(3) 343
Fennel TRFW ...... JFFCT1(3) 177
Ferguson JB .... FirTec10(3) 211
Filonenko AK ...... PhysCE10(1) 4
Finley EL .... JFFCPF1(1) 19
Firsov AN .... PhysCE10(6) 811
Flagan RC ...... ComFla22(3) 299,
.... ComFla23(2) 249
Flaherty JR .... FirChf18(3) 32
Fletcher EA ...... ComFla23(3) 399
Flower WI .... ComSciT9(3-4) 79
Foehl JM .... FirJrn68(5) 42
Fogel'zang AYe ... ComFla22(1) 77,
.... PhysCE10(3) 449
Fomin NA .... PhysCE10(4) 473
Fortov VYe .... PhysCE10(2) 289
Foster CD .... ComFla23(3) 347
Fox JS .... ComFla22(2) 267
Fristrom RM .... ComFla23(1) 109,
..... ComFla23(2), JFFLAO5(4) 289
Frolov YuV .... PhysCE10(6) 811
Fu TT .... FirTec10(1) 54
Fujioka FM .... FirTec10(4) 275
Fursov VP .... PhysCE10(4) 548,
.... PhysCE10(5) 669

Gabidovskiy AG .. PhysCE10(5) 772
Gal'chenko YuA ... PhysCE10(2) 245
Galant S .... ComFla22(3) 299
Gallagher EL .... FirJrn68(5) 28
Gann RG .... ComSciT9(5-6) 255
Gaponov IM .... ComFla23(1) 29
Garrett B .... ComFla23(3) 373
Gavazova VS ..... PhysCE10(6) 801
Gehring PJ .... JFFCT1(1) 52
Gel'man AS ..... PhysCE10(2) 284,
.... PhysCE10(6) 898
German Standards Association ....
.... FirInt4(43) 78
Gibbons CL .... JFFCT1(1) 52
Ginsburg IP .... PhysCE10(1) 56
Gladilin AM ...... PhysCE10(1) 110
Glazkova AP .... PhysCE10(2) 206,
.... PhysCE10(3) 323
Glikin MA .... PhysCE10(3) 446
Glushko LN ...... PhysCE10(4) 614
Gnutov VV .... PhysCE10(1) 144
Gogolev VM ...... PhysCE10(6) 891
Gogulya MF ...... PhysCE10(3) 392
Gol'tsiker AD ...... PhysCE10(1) 83
Gollahalli SR ..... ComFla22(3) 313

Golovichev VI ..... PhysCE10(1) 65
Gontkovskaya VT . PhysCE10(3) 376
Gonzales EJ ...... JFFFRC1(3) 142
Gordeyev VYe .... PhysCE10(6) 939
Gordon YeB .... PhysCE10(1) 15
Gordopolov YuA .. PhysCE10(2) 277
Gostintsev YuA .. PhysCE10(5) 764, ... PhysCE10(6) 818
Gouldin FC ...... ComSciT9(1-2) 17
Grachev VA ...... PhysCE10(6) 936
Graham SC ..... ComSciT9(3-4) 159
Granovskiy EA .... PhysCE10(3) 383
Gray BF .... ComFla23(3) 295
Gray P .... ComFla22(2) 197, ... ComFla23(3) 319
Green J .... JFFFRC1(4) 185
Griffiths JF .... ComFla22(2) 197
Grigor'yev AI ..... PhysCE10(4) 539
Grigor'yev YuM ... PhysCE10(2) 245
Grigor'yeva ID .... PhysCE10(4) 539
Grishin AM ...... PhysCE10(1) 45, ... PhysCE10(1) 74, PhysCE10(2) 191, ... PhysCE10(6) 826
Grossmann ED ... ComSciT9(1-2) 55
Grunfelder C ...... ComFla23(1) 109
Gryaznova LV .... PhysCE10(1) 132
Guenoche H ...... ComFla22(2) 237
Gupta MC .... ComFla22(2) 219
Gurevich MA ..... PhysCE10(1) 88, .. PhysCE10(3) 363, PhysCE10(4) 534, ... PhysCE10(5) 676
Guruz AG ...... ComSciT9(3-4) 103
Guruz HK ...... ComSciT9(3-4) 103
Gusachenko LK ... PhysCE10(3) 354
Gusachenko YeI .. PhysCE10(4) 548, ... PhysCE10(5) 669
Guz' IS .... PhysCE10(3) 452

Halstead MP ...... ComFla22(1) 89
Hansen A ...... ComSciT9(3-4) 173
Hanson RK ...... ComSciT9(3-4) 79
Hardt AP .... ComFla22(3) 323
Harmathy TZ ..... FirTec10(3) 247
Harris SP .... ComFla22(2) 191
Harrison AJ ...... ComFla22(2) 263
Hart LW .... ComFla23(1) 109
Hartstein AM ..... JFFLAO5(4) 243
Hartzell LG .... JFFCPF1(4) 305
Harwood BA ...... ComFla22(1) 35
Haynes BS .... ComFla23(2) 277
Helman D .... ComFla22(2) 171
Herzog GP .... FirJrn68(4) 93
Hilado CJ .... JFFCPF1(4) 390, ... JFFCT1(2) 91, JFFCT1(4) 268, .. JFFFRC1(4) 175, JFFLAO5(4) 321
Hillelson JP .... FirJrn68(3) 5
Hillenbrand IJ ..... JFFCPF1(2) 115
Hirano T .... ComFla22(3) 353, ... ComFla23(1) 83
Hirato GH .... FirTec10(4) 275
Hirsch E .... ComFla22(1) 131
Hoffman SD .... LabDat5(4) 15
Hofmann HTh .... JFFCT1(4) 236, ... JFFCT1(4) 250
Horiushi C .... JFFCPF1(3) 265
Horn LH .... LabDat5(2) 6
Horton MD ...... ComSciT9(3-4) 95
Howarth JT ...... JFFFRC1(3) 152
Hsu CJ .... ComFla22(1) 133
Huber W .... FirChf18(10) 36
Humiston CG .... JFFCT1(1) 52
Husain D .... ComFla22(3) 295
Hutchinson P ..... ComFla23(1) 57

Ibrahim SMA ..... ComFla22(1) 43
Ignatenko YuV ... PhysCE10(2) 240
Ilyukhin VS ...... PhysCE10(3) 334
Ionushas KK ...... PhysCE10(1) 83
Irwin CW .... FirChf18(4) 41
Isakov GN .... PhysCE10(2) 191
Isakov VP .... PhysCE10(1) 145
Ishibashi H .... JFFCPF1(3) 265
Isman WE .... FirChf18(12) 30
Ivanov AG .... PhysCE10(1) 127, ... PhysCE10(4) 603
Ivanov GV .... PhysCE10(5) 650
Iya KS .... ComFla22(3) 415

Jachimowski CJ .. ComFla23(2) 233
Jacobsen ER .... FirJrn68(2) 7
Jensen GS .... FirChf18(8) 48
Jewett GI .... JFFCT1(1) 52

Johnston NW ..... JFFCPF1(3) 295
Jones PW .... ComFla22(2) 209

Kadochnikova NF . PhysCE10(1) 41
Kanakia MD ...... JFFFRC1(1) 31
Kanel' GI .... PhysCE10(6) 884
Kanury AM ..... ComSciT9(1-2) 31.
.... ComSciT9(3-4) 171
Karachevtsev GV . PhysCE10(2) 291
Karakhanov SM .. PhysCE10(2) 265
Kashiwagi T .... JFFCPF1(4) 367
Kaskan WB ...... ComFla22(3) 415
Katkov AI .... PhysCE10(3) 392
Kauffman CW ... ComSciT9(5-6) 233
Kaufman J .... JFFLAO5(4) 243
Kawamura T ..... ComFla22(3) 283
Kaydymov BI .... PhysCE10(6) 801
Kent JH .... ComSciT9(1-2) 25
Ketelhut W ...... ComSciT9(1-2) 75
Khakimov VS .... PhysCE10(6) 934
Khanukayev BB ... PhysCE10(1) 22.
.... PhysCE10(5) 643
Kharitonova YaI .. PhysCE10(5) 717
Khaykin BI ...... PhysCE10(3) 313
Khaylov VM ..... PhysCE10(2) 230
Khlevnoy SS ..... PhysCE10(4) 512
Kholyavin VS .... PhysCE10(5) 717
Khomik SV ...... PhysCE10(6) 811
Khristoforov BD .. PhysCE10(1) 116.
.... PhysCE10(2) 274
Kichin YuS .... ComFla22(1) 77
Kimmerle G .... JFFCT1(1) 4
Kindin NI .... PhysCE10(5) 696
Kirov NY .... ComFla23(2) 277
Kirsanova ZV .... PhysCE10(4) 554
Kiselev AN .... PhysCE10(4) 594
Kishitani K .... JFFCT1(2) 104
Kisilev YuN ...... PhysCE10(1) 116
Klehs JW .... FirChf18(6) 32
Kleindienst T ..... ComFla23(3) 373
Kleshchevnikov OA ....
.... PhysCE10(4) 603
Kliegel JR ...... ComSciT9(5-6) 209
Klyachko LA ..... PhysCE10(4) 615
Knoepfler NB ..... JFFCPF1(3) 240
Knorre VG .... PhysCE10(3) 383.
.... PhysCE10(5) 767
Kochkin II .... PhysCE10(1) 127.
.... PhysCE10(4) 603
Kociba RJ .... JFFCT1(1) 52
Kogarko SM ..... PhysCE10(5) 629.
.... PhysCE10(5) 691
Kolesnikov BYa .. PhysCE10(6) 841
Kolomeychuk NN . PhysCE10(3) 345
Komarov VF ...... PhysCE10(1) 99
Kondrikov BN .... PhysCE10(5) 661
Konev EV .... PhysCE10(1) 34
Koplon NA .... FirTec10(1) 35
Kopylov MS ..... PhysCE10(5) 767
Korobeynikov OP . PhysCE10(3) 345
Korobkov VA ..... PhysCE10(1) 56
Korostelev VG .... PhysCE10(6) 811
Korotkov AI ..... PhysCE10(6) 811
Korst AF .... JFFFRC1(4) 205
Kostritsa AA ..... PhysCE10(4) 608
Kotowski RC .... FirChf18(10) 34
Kovalenko LA .... PhysCE10(4) 614
Kovalev BM ..... PhysCE10(2) 289
Kovalivnich AM .. PhysCE10(3) 446
Kozhushner MA ... PhysCE10(1) 22.
.... PhysCE10(5) 643
Kozlov GI .... PhysCE10(6) 857
Kozlov VS .... PhysCE10(1) 28.
... PhysCE10(2) 162. PhysCE10(4) 561
Kratzer RH ...... JFFLAO5(4) 243
Kreymborg OC ..... FirChf18(4) 41
Krier H .... ComFla22(3) 365.
.... ComFla22(3) 377.
.... ComSciT9(5-6) 195
Krivchenko AI .... PhysCE10(4) 561
Krivtsov VA ..... PhysCE10(6) 907
Kroshko VN ..... PhysCE10(4) 473
Krovontka SJ ...... FirTec10(3) 221
Kruger CH .... ComSciT9(3-4) 79
Ksandopulo GI ... PhysCE10(6) 841
Ktalkherman MG . PhysCE10(5) 717
Kuchta JM .... FirTec10(1) 25
Kulik PP .... PhysCE10(2) 289
Kundo NN .... PhysCE10(1) 41
Kurbangalina RKh PhysCE10(2) 270

Kuryla WC ...... JFFFRC1(4) 175
Kustov VS .... PhysCE10(1) 127
Kuvshinov VM ... PhysCE10(3) 338
Kuz'min GYe ..... PhysCE10(5) 746
Kuznetsov AP .... PhysCE10(5) 784
Kuznetsov NM ... PhysCE10(6) 791
Kuznetsov OA .... PhysCE10(3) 401
Kuznetsov PP .... PhysCE10(4) 485
Kuznetsov VA .... PhysCE10(6) 857
Kuznetsov VM .... PhysCE10(1) 124
Kuznetsov VT .... PhysCE10(4) 526

Larsen ER .... JFFFRC1(1) 4
Lathrop JK .... FirJrn68 (4) 10, ... FirJrn68(5) 18, FirJrn68(5) 37, ... FirJrn68(6) 5, FirJrn68(6) 16, ... FirJrn68(6) 50
Law CK .... ComFla22(3) 383
Lazzara CP .... ComFla23(1) 73
Lee CK .... ComSciT9(3-4) 137
Lee JHS .... ComFla22(2) 237
Legeza VN .... PhysCE10(1) 132
Lenchitz C .... ComFla22(3) 289
Leont'yev AK .... PhysCE10(5) 684
Lesnikovich AI .... PhysCE10(1) 99
Levy RL .... JFFLAO5(1) 76
Librovich VB ..... PhysCE10(5) 696
Lie TT .... FirTec10(4) 315
Liebman I .... FirTec10(1) 25
Liebman SA .... JFFCT1(1) 78
Lindstrom RS .... JFFFRC1(3) 152
Lisitsyn VI .... PhysCE10(6) 857
Littler JGF .... ComFla22(3) 295
Lobanov VA ...... PhysCE10(2) 292
Lobanov VF ..... PhysCE10(1) 119
Lobkovskiy VP ... PhysCE10(2) 197
Lockwood FC .... ComFla23(3) 283
Loeb DL .... FirChf18(2) 26, ... FirChf18(4) 50, FirChf18(5) 42, ... FirChf18(6) 40, FirChf18(9) 20, FirChf18(10) 27, FirChf18(10) 38, ... FirChf18(11) 29
Lomakin BN ..... PhysCE10(2) 289
Long III GS ...... ComFla23(3) 373
Lott JL .... JFFLAO5(2) 136, ... JFFLAO5(3) 190
Lovachev LA ..... PhysCE10(3) 372
Lozhkina VP ..... PhysCE10(6) 891
Luk'yanchikov LA .... PhysCE10(6) 864, PhysCE10(6) 912
Lundy SP .... FirChf18(6) 35

Madacsi JP .... JFFCPF1(3) 240
Maddison TE .... ComFla23(2) 203
Magnus AJ .... ComFla22(1) 71
Magnusson SE ..... FirTec10(3) 228
Major RW .... FirTec10(2) 110
Makepeace RW ..... ComFla23(1) 11
Maksimov EI ...... PhysCE10(1) 28, .. PhysCE10(2) 162, PhysCE10(2) 169
Maksimov YuM .. PhysCE10(2) 169
Mal'tsev VM ..... PhysCE10(3) 445, .. PhysCE10(5) 656, PhysCE10(5) 762
Malcomson RW ..... LabDat5(2) 15
Mali VI .... PhysCE10(5) 755
Malte PC .... ComSciT9(5-6) 221
Mamina NK ..... PhysCE10(2) 253
Mandell DA .... ComSciT9(5-6) 273
Manelis GB ...... PhysCE10(2) 185
Manheimer-Timnat Y .... ComFla22(2) 171
Manzhaley VI .... PhysCE10(1) 102
Markov OM ..... PhysCE10(5) 650
Maroni WF .... FirJrn68(5) 51
Martemyanova TM .. PhysCE10(4), ... 498, PhysCE10(4) 518
Martin RAM ..... ComFla23(3) 357
Marusin VP ...... PhysCE10(4) 526
Matveyev YuS .... PhysCE10(6) 939
Mayhan KG .... FirTec10(3) 201, ... JFFFRC1(4) 243
McCormick JW .... FirTec10(3) 197
McCreath CG ..... ComFla23(1) 11
McDermott FG ..... JFFCPF1(1) 19
McHale ET .... FirTec10(1) 15
McLaughlin RW .. JFFFRC1(4) 175
McNeight N .... FirChf18(11) 27
Mead SF .... FPSTech(8) 4
Medlock LE .... FirInt4(44) 29
Medvedev YuI .... PhysCE10(3) 341
Mellor AM .... ComSciT9(3-4) 165, ... ComSciT9(5-6) 261

Merzhanov AG ..... PhysCE10(1) 4, .. PhysCE10(1) 28, PhysCE10(2) 201, ... PhysCE10(3) 445
Meshcheryakov YeA .... PhysCE10(2) 220
Mikhaylov AN ... PhysCE10(2) 277, ... PhysCE10(6) 877
Miller B .... JFFCPF1(3) 225
Mineyev VN ..... PhysCE10(4) 603
Mirchandani I .... ComFla22(2) 267
Mironov EA ..... PhysCE10(2) 294
Mitrofanov VV ... PhysCE10(1) 102
Mitton MT ...... JFFLAO5(4) 268
Mogil'nyy IA ..... PhysCE10(5) 485
Mogil'nyy IA ..... PhysCE10(5) 717
Moin FB .... PhysCe10(2) 235, ... PhysCE10(4) 612
Molodets AM .... PhysCE10(6) 884
Mong HC .... ComFla22(1) 59
Montle JF .... FirTec10(3) 201, ... JFFFRC1(4) 243
Moore J .... ComFla22(3) 343
Moorhouse J ..... ComFla23(2) 203
Morin OV .... PhysCE10(2) 240
Moulder JC ...... ComFla23(1) 129
Mozzhukhin YeV . PhysCE10(5) 629
Mruk J .... LabDat5(1) 8
Mukoseyev YuK .. PhysCE10(5) 629
Mukunda HS ... ComSciT9(3-4) 149
Mullayanov FI ... PhysCE10(6) 934
Mulyava MP ..... PhysCE10(2) 235, ... PhysCE10(4) 612
Munday G .... FPSTech(9) 23
Murashova NA ... PhysCE10(4) 561
Myslov VG ...... PhysCE10(3) 334

Nabotov SS ...... PhysCE10(4) 583
Nair MRS .... ComFla22(2) 219
Nakahara J ...... JFFLAO5(4) 243
Nakakuki A ...... ComFla23(3) 337, ... ComSciT9(1-2) 71
Nakamura K .... JFFCT1(2) 104
Nalbandyan AB .. ComFla22(2) 153
Namoradze MA .. PhysCE10(6) 847
Nauman CD .... JFFCT1(1) 78
Nefedov AP ...... ComFla23(3) 305
Nefedova MG .... PhysCE10(2) 253, ... PhysCE10(2) 294
Nelson GI .... JFFLAO5(2) 125
Nelson HE .... FirJrn68(4) 65
Nelson Jr RM ...... FirTec10(1) 68
Nesterenko VF ... PhysCE10(5) 752, ... PhysCE10(6) 904
Nettleton MA .... ComFla22(3) 407
Neumeyer JP ...... JFFCPF1(3) 240
Nicholls JA .... ComSciT9(3-4) 119, ... ComSciT9(5-6) 233
Nikiforov VS ...... ComFla22(1) 77
Nikolayev YuA ... PhysCE10(6) 933
Noreikis SE ...... ComFla22(3) 353, ... ComFla23(1) 83
Noronha JA .... FirTec10(2) 101
Norris JM .... JFFCT1(1) 52
Novikov NP .... PhysCE10(1) 4, ... PhysCE10(2) 201
Novikov SS .... PhysCE10(1) 38, ... PhysCE10(3) 334
Novozhilov BV .... PhysCE10(1) 94, ... PhysCE10(5) 661
Nunez IJ .... JFFCT1(2) 124
Nuzhda LI .... PhysCE10(3) 446

O'Mara MM ...... JFFCT1(3) 141, ... JFFLAO5(1) 34
O'Neill AR .... FirJrn68(6) 10
Odnorog DS ..... PhysCE10(6) 841
Oettel H .... JFFCT1(4) 236
Ohki Y .... ComSciT9(1-2) 1
Okunev VYe ..... PhysCE10(6) 791
Ornellas DL .... ComFla23(1) 37
Osipov AI .... PhysCE10(3) 303, ... PhysCE10(4) 459
Osuwan S .... ComSciT9(3-4) 103
Ottoson J .... FirJrn68(4) 19
Owen AJ .... ComFla22(1) 13, ... ComFla22(1) 19
Ozerov YeS ...... PhysCE10(3) 363
Ozerova GYe ...... PhysCE10(1) 88, ... PhysCE10(5) 676

Paciorek KL ..... JFFLAO5(4) 243
Page FM .... ComFla23(1)

Palmer HB .... JFFCPF1(2) 133
Palmer KN .... JFFCPF1(2) 186
Papp JF .... ComFla23(1) 73
Parker RO .... FirTec10(2) 147
Parks RL .... LabDat5(1) 5
Parshukov PA .... PhysCE10(1) 144
Pay VV .... PhysCE10(5) 755
Pearson TF .... FirChf18(1) 36
Pensa IE .... JFFLAO5(4) 227
Peretyat'ko VN ... PhysCE10(3) 452
Perry EH .... ComSciT9(1-2) 49
Pershin SV .... PhysCE10(3) 421,
.. PhysCE10(3) 426, PhysCE10(4) 578
Pervukhin LB .... PhysCE10(2) 284
Peters B .... ComFla22(2) 259
Peterson AO .... FirJrn68(4) 100
Peterson SE .... FirCom41(2) 30
Petrov GV .... PhysCE10(6) 797
Philiposyan AG ... ComFla22(2) 153
Phillips AW .... FirChf18(3) 30
Phillips CW .... FirJrn68(3) 77
Philpot CW ...... ComSciT9(1-2) 13
Phung PV .... ComFla22(3) 323
Pieracci E .... FirChf18(6) 32
Pierce TH .... ComSciT9(3-4) 119
Pikalov VV ...... PhysCE10(6) 923
Pikus IM .... PhysCE10(5) 782
Piskunov BG ..... PhysCE10(3) 383
Pleshanov AS .... PhysCE10(5) 784
Pluzhnik VI ...... PhysCE10(1) 144
Poberezhsky IP .... ComFla23(1) 29
Podgrebenkov AL PhysCE10(5) 691
Podymov VN ..... PhysCE10(5) 772
Polishchuk DI .... PhysCE10(4) 615
Polonskiy IYa .... PhysCE10(2) 253
Polymeropoulos CE ....
.... ComSciT9(5-6) 197
Popov VA .... PhysCE10(2) 253,
.... PhysCE10(2) 294
Popov VM .... PhysCE10(6) 791
Popova VA ...... PhysCE10(1) 142
Posvyanskiy VS ... PhysCE10(1) 94
Powell EA .... FirTec10(1) 35
Pratt DT .... ComSciT9(5-6) 221
Preobrazhenskiy NG ....
.... PhysCE10(6) 923
Price D .... ComFla22(1) 111,
.. ComFla22(1) 119, ComFla22(2) 161
Proops WA5 ..... JFFFRC1(4) 175
Proudfoot EN .... FirJrn68(2) 70
Pryor AJ .... JFFCT1(4) 191
Purington RG ...... FirChf18(7) 16,
.... FirChf18(8) 53
Putnam AA ...... ComFla22(2) 281
Pye DB .... ComFla22(1) 89

Quan V .... ComSciT9(5-6) 209
Quinn CP .... ComFla22(1) 89
Quinn EJ .... JFFCT1(1) 78
Quintiere J .... FirTec10(2) 153,
... JFFCPF1(1) 32, JFFCPF1(2) 221

Raghunandan BN ....
.... ComSciT9(3-4) 149
Rangaprasad N ... JFFLAO5(2) 107
Rankin JI .... FirChf18(2) 32
Rasbash DJ .... FPSTech(8) 16
Rebenfeld L .... JFFCPF1(3) 225
Redden JM .... FirChf18(11) 24
Reeves WA ...... JFFFRC1(2) 110
Rele PJ .... ComSciT9(1-2) 55
Revyagin LN ..... PhysCE10(3) 341
Rhodes J .... FirJrn68(6) 42
Riley JF .... FirTec10(4) 269
Robertson AF ..... FirTec10(2) 115,
.... FirTec10(4) 282
Rogacheva AI .... PhysCE10(4) 578
Roman OV ...... PhysCE10(5) 782
Romanova VI .... PhysCE10(5) 732
Rose JQ .... JFFCT1(1) 52
Rosenhan AK ...... FirChf18(1) 44,
.... FirChf18(11) 39
Rozenband VI ..... PhysCE10(1) 52,
.. PhysCE10(2) 212, PhysCE10(4) 530
Rozhitskiy SI ..... PhysCE10(4) 492
Runyan CC ...... ComFla23(1) 129
Rush JH .... ComFla22(3) 377
Ryabina IS .... PhysCE10(3) 363
Ryabinin AG ..... PhysCE10(1) 142
Ryabinina TN ..... PhysCE10(1) 56
Ryabyy VA ...... PhysCE10(2) 289
Ryan JV .... JFFCPF1(4) 354

Ryason PR ...... ComFla22(1) 131
Ryazantsev YuS ... PhysCE10(1) 38
Rybanin SS ...... PhysCE10(5) 634
Ryskin MYe ..... PhysCE10(6) 939

Sachyan GA ..... ComFla22(2) 153
Samoylov IB ..... PhysCE10(5) 705
Sand H .... JFFCT1(4) 250
Sanders CI .... JFFCT1(1) 78
Savel'yev VL ..... PhysCE10(4) 608
Sawyer RF .... ComFla23(2)
Scanes FS .... ComFla23(3) 357,
.... ComFla23(3) 363
Schaffer EL .... JFFFRC1(2) 96
Schafran E .... FirJrn68(2) 36
Schiffhauer Jr EJ ....
.... FirTec10(2) 101
Schmitt CR .... FirTec10(3) 197,
.... JFFLAO5(3) 223
Schulz JF .... FirJrn68(2) 82
Schwarcz JM ...... JFFFRC1(2) 78
Schwetz BA .... JFFCT1(1) 52
Seader JD .... FirTec10(3) 187,
... JFFFRC1(1) 31, JFFLAO5(2) 151
Sedes C .... ComFla22(2) 237
Seegerer K .... FirInt4(44) 65
Seelbach RW .... LabDat5(2) 4
Selby K .... ComFla22(2) 209
Seleznev VA ..... PhysCE10(3) 445
Sello SB .... JFFLAO5(4) 227
Serikov VI .... PhysCE10(5) 772
Shabdua CL .... JFFCT1(4) 268
Shamshina OL ... PhysCE10(2) 197
Sharry JA .... FirCom41(2) 24,
.... FirJrn68(1) 5, FirJrn68(1) 52,
.... FirJrn68(2) 5, FirJrn68(2) 14,
.... FirJrn68(3) 5, FirJrn68(3) 11,
.... FirJrn68(3) 37, FirJrn68(4) 5,
...... FirJrn68(4) 13, FirJrn68(4) 23,
...... FirJrn68(4) 105, FirJrn68(5) 5,
...... FirJrn68(5) 22, FirJrn68(5) 38,
.... FirJrn68(6) 28, FirJrn68(6) 54
Shatrov VD .... PhysCE10(1) 15
Shchemelev GV ... PhysCE10(2) 235,
.... PhysCE10(4) 612
Sheahen TP ...... ComFla22(2) 243
Shen TT .... ComSciT9(1-2) 61
Sheth SG .... JFFFRC1(3) 152
Shevchuk VG .... PhysCE10(4) 615
Shevchuk VU .... PhysCE10(2) 235,
.... PhysCE10(4) 612
Shishkayev SM ... PhysCE10(5) 684
Shisler RA ...... ComSciT9(5-6) 261
Shivadev UK ..... ComFla22(2) 223
Shkadinskiy KG .. PhysCE10(6) 811
Shouman AR ..... ComFla23(1) 17
Shpilberg D .... FirTec10(1) 5,
.... FirTec10(4) 304
Shub LI .... PhysCE10(1) 56
Shvedov KK ..... PhysCE10(4) 561
Shvetsov VI ...... PhysCE10(4) 548,
.... PhysCE10(5) 669
Sibulkin M ...... ComSciT9(1-2) 75,
.... ComSciT9(3-4) 137,
.... ComSciT9(3-4) 173
Sidman KR ...... JFFFRC1(3) 152
Sigimov VI ...... PhysCE10(4) 539
Sikorov VN ...... PhysCE10(3) 421
Sirkunen GI ...... PhysCE10(4) 534
Sizov IA .... PhysCE10(3) 437
Skorik AI .... PhysCE10(4) 526
Skovpin AI ...... PhysCE10(5) 755
Skurin LI .... PhysCE10(1) 137
Sliepcevich CM ... JFFLAO5(2) 107,
.. JFFLAO5(2) 136, JFFLAO5(3) 190
Smith DC .... FirJrn68(5) 11
Smith EE .... FirTec10(3) 181,
.... JFFCT1(2) 95, JFFLAO5(3) 179
Smith IW .... ComSciT9(3-4) 87
Smoliy NI .... PhysCE10(6) 919
Snell JE .... FirJrn68(3) 77
Snyatkov YuI .... PhysCE10(2) 253
Sobolenko TM ... PhysCE10(4) 594,
.. PhysCE10(5) 774, PhysCE10(6) 931
Sobolev I .... JFFFRC1(1) 13
Sochet LR .... ComFla23(1) 47
Sokolenko VF .... PhysCE10(2) 240
Soloukhin RI ..... PhysCE10(4) 473
Solov'yev VS ..... PhysCE10(3) 401
Soper WG .... ComFla22(2) 273
Spadaccini LJ ... ComSciT9(3-4) 133
Spalding DB ..... ComFla23(3) 283

Spivak AA .... PhysCE10(3) 437,
.... PhysCE10(3) 440
Srivastava RD .... ComFla22(2) 191
Staver AM .... PhysCE10(4) 568,
.. PhysCE10(5) 774, PhysCE10(6) 904
Stavrov AA ...... PhysCE10(2) 256
Sten'gach VV ..... PhysCE10(6) 874
Stender WW .... FirJrn68(4) 65
Stepanov AM ..... PhysCE10(1) 88,
.... PhysCE10(4) 534
Stepniczka HE ..... JFFFRC1(2) 61,
.... JFFLAO5(1) 16
Stesik LN .... PhysCE10(2) 270,
. PhysCE10(4) 548, PhysCE10(5) 634,
.... PhysCE10(5) 669
Steward FR ..... ComSciT9(3-4) 103
Stewart RD .... JFFCT1(3) 167
Stickney CW .... FirTec10(4) 287
Stinchcomb HR ..... FirChf18(3) 36
Stone WR .... FirJrn68(1) 61,
.... FirJrn68(1) 71, FirJrn68(2) 5,
...... FirJrn68(2) 14, FirJrn68(2) 31,
.... FirJrn68(3) 87
Strasser A .... FirTec10(1) 25
Strokin NV ...... PhysCE10(6) 936
Strokin V .... ComSciT9(3-4) 111
Strokin VN ...... PhysCE10(2) 230,
.... PhysCE10(4) 492
Struchenko AN ... PhysCE10(2) 274
Strunin VA ...... PhysCE10(2) 185
Strunina AG ..... PhysCE10(4) 518
Stupochenko YeV . PhysCE10(3) 303,
.... PhysCE10(4) 459
Subbotin AN ..... PhysCE10(6) 826
Subbotin VA ..... PhysCE10(1) 102
Suh NP .... ComFla22(3) 289
Sukhanov LA .... PhysCE10(6) 818
Sumi K .... JFFLAO5(1) 64
Svetlov BS .... PhysCE10(3) 449
Sviridov VV .... PhysCE10(1) 99
Syred N .... ComFla23(2) 143
Sztal B .... ComFla22(1) 1

T'ien JS .... ComSciT9(1-2) 37
Tal'rose VL .... PhysCE10(1) 15
Tarasenko NN .... PhysCE10(4) 598,
.... PhysCE10(5) 737
Tatem PA ...... ComSciT9(5-6) 255
Tatsiy VF .... PhysCE10(3) 426
Tatsyy VF .... PhysCE10(4) 578
Taylor W .... JFFCPF1(2) 186
Teixeira DP ..... ComSciT9(5-6) 209
Telegin GS .... PhysCE10(5) 728
Teller H .... LabDat5(2) 10,
.... LabDat5(3) 4, LabDat5(4) 17
Tereshchenko AG . PhysCE10(3) 345
Teslenko AG ..... PhysCE10(1) 132,
.... PhysCE10(3) 405
Teslenko TS ...... PhysCE10(4) 594,
.. PhysCE10(5) 774, PhysCE10(6) 931
Tesner PA .... PhysCE10(3) 383,
.... PhysCE10(5) 767
Thelandersson SE ... FirTec10(3) 228
Thomas PH .... FirTec10(2) 140
Thompson D ..... ComFla23(3) 319
Tidball MJ .... ComFla22(2) 209
Tien CI .... ComSciT9(1-2) 41
Tirsell JP .... JFFCT1(1) 52
Titov VM .... PhysCE10(2) 265
Todes CM .... PhysCE10(1) 83
Tokarev IP .... PhysCe10(3) 338
Tokarev NP ...... PhysCE10(2) 197
Tovey H .... FirJrn68(6) 91
Tret'yakov PK .... PhysCE10(4) 485
Trishkin VM ..... PhysCE10(6) 857
Tsao HY .... ComFla23(1) 17
Tsemakhovich BD PhysCE10(2) 284
Tseytlin YaI .... PhysCe10(6) 919
Tsuchiya Y .... JFFLAO5(1) 64
Tsugze S .... ComSciT9(1-2) 1
Tsvetkov VM ..... PhysCE10(3) 437
Tsypkin VI .... PhysCE10(4) 603
Tukhtayev RK .... PhysCE10(4) 543
Tul'skikh VYe ..... PhysCE10(1) 38,
.... PhysCE10(2) 178
Tuttle JH .... ComSciT9(5-6) 261
Tverdokhlebov VI . PhysCE10(4) 614
Tyler PJ .... ComSciT9(3-4) 87
Tyul'panov RS .... PhysCE10(2) 240,
.... PhysCE10(5) 723

Ulrich RI .... FirChf18(3) 28,
...... FirChf18(4) 46, FirChf18(5) 45

Vail SL .... JFFFRC1(3) 142
Van Bowen Jr J ..... FirTec10(2) 110
Van Luik Jr FW .... FirTec10(2) 129
Vance GM .... ComFla22(3) 365
VanPee M .... ComFla22(1) 71,
.. ComFla22(3) 337, ComFla23(2) 227
Vardanyan IA .... ComFla22(2) 153
Varlamov GA .... PhysCE10(6) 934
Vasil'yev LV ..... PhysCE10(1) 127,
.... PhysCE10(4) 603
Vasilieva IA ...... ComFla23(3) 305
Verburg D .... FirChf18(12) 26
Versnel J .... JFFFRC1(4) 185
Vezhba A .... PhysCE10(5) 710
Vidaud P .... ComFla22(3) 337,
.... ComFla23(2) 227
Viktorenko AM .. PhysCE10(3) 345,
.... PhysCE10(5) 650
Viktorov VN ..... PhysCE10(2) 294
Vilyunov VN ..... PhysCE10(2) 169,
.... PhysCE10(4) 512
Vorob'yev AA .... PhysCE10(6) 884
Voskoboynikov IM PhysCE10(3)392
Vovchuk YaI ..... PhysCE10(4) 615
Vovk AA .... PhysCE10(1) 144
Voytenko AYe .... PhysCE10(1) 145
Vranos A .... ComFla22(2)
Vulis LA .... PhysCE10(2) 151

Waddington DJ ... ComFla22(2) 209
Waide DC .... FirChf18(7) 21
Waksman D .... FirTec10(3) 211
Walker E .... FirJrn68(4) 65
Walker FE .... ComFla22(1) 53
Walls WL .... FirJrn68(1) 52,
.... FirJrn68(5) 18
Wasley RJ .... ComFla22(1) 53
Waterman TE .... ComFla22(3) 353,
.... ComFla23(1) 83, FirTec10(4) 287
Waters JM .... FirChf18(4) 37,
...... FirChf18(8) 58, FirChf18(9) 26,
.... FirChf18(10) 42
Watters P .... FirInt4(43) 55
Weil FD .... JFFFRC1(3) 125
Weinberg FJ ..... ComFla22(2) 263
Weldon WC .... FirChf18(10) 31
Welker JR ...... JFFLAO5(2) 107
Wheeler RJ .... JFFCT1(4) 191
Whitelaw JH ...... ComFla23(1) 57
Wierzba AS ..... ComSciT9(5-6) 233
Wiles DM .... JFFLAO5(4) 268
Willey AE .... FirJrn68(1) 16
Williams A .... ComFla23(2) 203,
.... ComSciT9(5-6) 247
Williams FA ..... ComFla22(3) 383,
.... JFFLAO5(1) 54
Wise H .... ComFla22(1) 23
Wolf CJ .... JFFLAO5(1) 76
Wolfshtein M .... ComFla22(2) 171
Wollowitz S ...... ComFla22(3) 415
Woolley DE .... ComFla23(1)
Woolley WD .... JFFCT1(4) 259
Woycheshin EA ... JFFFRC1(1) 13
Wray JA .... JFFGPF1(2) 115

Yakimov AS ...... PhysCE10(1) 74
Yakovleva GS .... PhysCE10(2) 270
Yakushev VV ..... PhysCE10(4) 583
Yakusheva OV ... PhysCE10(4) 583
Yang CH .... ComFla23(1) 97
Yarin IP .... PhysCE10(2) 151
Yasakov VA ...... PhysCE10(1) 65,
. PhysCE10(4) 485, PhysCE10(5) 717,
.... PhysCE10(6) 835
Yenikolopyan NS .. PhysCE10(1) 22,
.... PhysCE10(5) 643
Yermakov VI ..... PhysCE10(4) 518
Yershov AP ...... PhysCE10(6) 864
Yuill CH .... JFFCPF1(2) 181
Yukhvid VI ...... PhysCE10(1) 28,
.... PhysCE10(2) 162

Zakharenko ID ... PhysCE10(1) 145,
.... PhysCE10(3) 409
Zakharov VS ..... PhysCE10(6) 931
Zamyshlyayev BV . PhysCE10(6) 891
Zaslonko IS ...... PhysCE10(5) 629
Zaturska MB ..... ComFla23(3) 313
Zaychikov VV .... PhysCE10(5) 705

Zaytsev AS .... PhysCe10(5) 779
Zelenskiy YeYe .... PhysCE10(1) 45,
.... PhysCE10(1) 74
Zheludok VV ..... PhysCE10(2) 256
Zherebnenko VI... PhysCE10(1) 145
Zhevlakov AF .... PhysCE10(2) 185
Zhevlakov AP ..... PhysCE10(2) 197
Zimont VI .... PhysCE10(2) 220
Zinn BT .... FirTec10(1) 35
Zolotko AN ...... PhysCE10(4) 615
Zubarev VN .... PhysCe10(5) 728
Zubkov PI .... PhysCe10(6) 864

INDEX TO 1974 FIRE JOURNAL ARTICLE TITLES

Abelian Transformations .... PhysCE10(6) 923
Abrasive .... FirCom41(4) 60
Accidents .... FEngJ34(94) 32
Accidents to Firemen .... FPRev37(400) 77
Acetylene-Air Flames .... PhysCE10(4) 614
Acetylene Decomposition .... PhysCE10(3) 383
Acetylene Detonation .... PhysCE10(5) 767
Acetylene Production Processes ..... PhysCE10(3) 446
Acrylonitrile Physical Properties .... PhysCE10(4) 583
Actuators .... FirInt4(44) 29
Additives .... ComFla22(2) 191, .. ComFla22(3) 407, JFFFRC1(2) 78, . JFFFRC1(3) 152, PhysCE10(4) 543, PhysCE10(6) 801
Admixtures ...... PhysCE10(3) 303
Aerodynamics ... ComSciT9(3-4) 103
AFFF Units .... also see: Foam, FirEng127(7) 34
Air-Assist Nozzle .... ComSciT9(3-4) 165
Air Chisel .... FirEng127(11) 50
Air Conditioner .... FirEng127(6) 52
Air Conditioning .... FEngJ34(95) 56
Air Cushions .... FirCom41(4) 38
Air Dispersed Systems .... PhysCE10(1) 83
Air Drops .... FirCom41(4) 68
Air Tanker System .... FirEng127(4) 64
Aircraft .... FirInt4(46) 50
Aircraft Hangar .... FirTec10(4) 304
Aircraft Hangars ..... FirInt4(43) 18
Aircraft Incidents .... FirEng127(4) 54
Airliner Protection .... FPRev37(409) 483
Airport .... FirInt4(44) 36, FirTec10(1) 5
Alarm Bell .... FirEng127(10) 52
Alarm System ...... FirChf18(6) 37, FirEng127(2) 42
Alarm System Design .... FirJrn68(2) 7
Aliphatic Amines . ComFla22(2) 209
Alkali Metals ..... ComFla22(1) 133
Allyl Monomers .. JFFFRC1(3) 125
Alumina Hydrate .. JFFFRC1(1) 13
Ammonia-Fluorine Flames .... ComFla22(3) 337
Ammonium Perchlorate .... PhysCE10(6) 801
Ammonium Perchlorate Combustion PhysCE10(2) 206
Ammunition Plant .... FirEng127(8) 181
Amphibian .... FirEng127(2) 29
Amusement Park .... FirChf18(7) 27
Analytic Scaling .... ComSciT9(5-6) 209
Annealing .... PhysCE10(3) 421
Anti-Discrimination Suits .... FirChf18(8) 50
Antimony Compounds .... JFFFRC1(4) 175
Apartment Fire ..... FirJrn68(3) 37, FirJrn68(4) 105
Apartment Houses .... also see Garden Apartment, FirJrn68(2) 82

Apparatus Costs .. FirEng127(10) 27
Apparatus Standardization .... FPRev(399) 47
Apparatus - Used ... FirChf18(10) 38
Apparel .... JFFCPF1(1) 4
Armco Iron and Nickel .... PhysCE10(4) 594
Army Aids Volunteers .... FirChf18(5) 39
Arson .... FirEng127(7) 54
Articulated Pumper .... FirCom41(12) 22
Atmospheric Reentry .... ComFla22(2) 243
Atrium .... FirJrn68(1) 9
Attendance Rules .. FirEng127(3) 54
Autoignition ..... PhysCE10(2) 235, ... PhysCE10(3) 446
Automatic Fire Alarms .... FEngJ34(95) 15
Automatic Fire Ventilation .... FEngJ34(95) 22
Automatic Nozzles .... FirChf18(4) 50, FirChf18(5) 42, ... FirChf18(6) 40
Automatic Recall .... also see Elevators, ... FirJrn68(6) 79
Automatic Sprinklers .... FirJrn68(6) 42
Aviation Fuels .... FirTec10(1) 54

Base Injection .... FirInt4(45) 57, ... FPSTech(8) 21
Beam Length Calculations .... ComSciT9(5-6) 273
Bedroom Furnishings .... FirJrn68(2) 18
Bibliography .... JFFCT1(2) 91, ... JFFCT1(4) 268
Bismuth - Shock Loaded .... PhysCE10(5) 752
Bisphenolic Polymers .... JFFFRC1(4) 218
Blast Waves ...... ComFla22(2) 237
Bleve .... FirCom41(5) 14
Blind People Evacuation .... FPRev37(407) 397
Blow-Off .... ComSciT9(1-2) 71
Bodleian Library .... FPRev37(406) 351
BombExplosion ..... FirChf18(6) 32
Bomb Method .... ComFla22(2) 219
Boron .... JFFCPF1(3) 240, ... PhysCE10(1) 4
Boron Compounds JFFFRC1(4) 175
Boron Oxide Gasification .... PhysCE10(4) 615
Boron Particle Ignition .... PhysCE10(4) 539
Branching Chain Reactions .... PhysCE10(3) 376
Breathing Air ...... FirEng127(8) 46
Breathing Apparatus .... also see .... Self-Contained Breathing Apparatus. FirEng127(8) 68
Breathing Apparatus Training .... FirEng127(6) 26
Breathing Unit ..... FirEng127(1) 47
Building Insulations .... FirJrn68(5) 51
Building Interior Covering Systems .... FirTec10(3) 211
Building Under Construction .... FirJrn68(5) 37
Buildings .... FirInt4(43) 45, ... FPSTech(8) 4
Bulk Carrier .... FirInt4(43) 69
Buoyancy Characteristics .... FirTec10(1) 68
Buoyant Forces ... PhysCE10(6) 835
Burglar Alarm .... LabDat5(2) 6
Burn Injuries .... FirCom41(4) 31
Burn-Out .... PhysCE10(5) 676
Burn Treatment ..... FirCom41(4) 32
Burner Flame ..... ComFla23(1) 57
Burning Condensed Substances .... PhysCE10(1) 34
Burning Cylinders .... ComSciT9(3-4) 137

Burning Jet ..... ComSciT9(3-4) 103
Burning of Explosives .... PhysCE10(3) 323
Burning Rate ...... ComFla22(1) 77, ... ComSciT9(5-6) 183, ... ComSciT9(5-6) 195, ... PhysCE10(2) 201
Burning Rate Measurement .... ComFla23(3) 381
Burning Rates ..... JFFCPF1(3) 295
Burning Stability .... PhysCE10(2) 178
Burning to Detonation Transition Length .... PhysCE10(6) 874
Burning Velocities .... ComFla22(1) 89, PhysCE10(4) 612
Burning Velocity ... ComFla22(1) 71, . ComFla22(2) 267, ComFla22(2) 281, ... ComFla23(2) 227
Burning Velocity Measurement .... ComFla22(2) 219
Burning Velocity Measurements .... ComFla22(3) 337
Business Machines .. FEngJ34(93) 39

C-H-N-O .... ComFla23(1) 37
C-H-N-O-F .... ComFla23(1) 37
C-H-N-O-Si .... ComFla23(1) 37
C-N-O .... ComFla23(1) 37
C2 Band Emission . ComFla22(1) 133
Cable - Electrical Fire Hazards .... FirJrn68(5) 11
Calorimeter .... ComFla23(1) 37
Camper .... FirEngl27(4) 53
Canterbury Woods ... FirJrn68(3) 77
Carbon Dioxide .. FirEngl27(8) 170, ... FirTec101(1)25, FirTec10(2) 101
Carbon Disulfide-Air Explosions .... PhysCE10(1) 15
Carbon Microspheroids .... FirTec10(3) 197, JFFLAO5(3) 223
Carbon Monoxide ComFla22(3) 343, ... ComFla23(1) 97, JFFCT1(3) 167
Carbon Suboxide . ComFla22(2) 243
Cargo Problems ..... FirInt4(43) 69
Carpet Flammability .... JFFLAO5(4) 268
Carpets .... also see Floor Covering, ... JFFCPF1(4) 367
Carpets - Flame Spread .... JFFCPF1(4) 367
Catalyst Dispersion .... PhysCE10(1) 41
Catalysts .... PhysCE10(3) 323
Catalytic Effect .... ComFla22(1) 77, .. PhysCE10(3) 338, PhysCE10(6) 801
Catalytic Surface .... PhysCE10(6) 797
Causes of Fire ...... FEngJ34(93) 15
Cellulose .... JFFLAO5(2) 116
Cellulose Nitrate .... ComSciT9(1-2) 55
Cellulosic Fuels .... ComSciT9(5-6) 255
Cellulosic Solids .... ComSciT9(3-4) 171
Chain Explosion .. PhysCE10(3) 372
Chamber Pressure .... ComSciT9(3-4) 129
Char - Cellulose ... JFFLAO5(2) 116
Charged Particles .... PhysCE10(2) 291
Chelsea .... FirCom41(3) 12, ... FirInt4(43) 45, FirJrn68(3) 17
Chemical Industry .... FEngJ34(94) 24, FPSTech(8) 16
Chemical-Mathematical Model .... JFFCT1(3) 157
Chemical Peak ... PhysCE10(3) 401
Chemical Plants ... FirEngl27(2) 37
Chemical Processing Plant Fire .... FirCom41(2) 28
Chemical Reaction Rate .... PhysCE10(1) 65
Chemical Reactions .... PhysCE10(6) 797
Chemical Textbook . FEngJ34(96) 14
Chemicals .... FirCom41(4) 34
Chemistry .... JFFLAO5(4) 289

Children .... FEngJ34(93) 15
Circuit Breakers .. PhysCE10(1) 145
Cliff Rescue Equipment .... FirEng127(12) 28
Closed Bomb ..... ComFla23(3) 381
Closed Circuit Television .... FEngJ34(95) 10
Clothing .... also see Garments, ... JFFCPF1(4) 390
CO-Air Combustion .... ComSciT9(5-6) 221
Coal Char .... ComSciT9(3-4) 87
Coal - Nitric Oxide Formation .... ComFla23(2) 277
Coal Particles .... ComFla22(3) 407
Coal Stove Hazards .... FirJrn68(3) 87
Coat Fabrics ...... FirTec10(2) 153
Coats .... FirEng127(7) 45
Cobalt Oxide ..... PhysCE10(2) 197
Code of Ethics ..... FirEng127(6) 58
Cold Flame Propagation .... PhysCE10(1) 94
College Program ... FirEng127(5) 51
Combustible Content .... JFFCPF1(4) 390
Combustible Liquids .... FirCom41(3) 8
Combustible Solid . ComFla23(1) 83
Combustion .... ComFla22(1) 59, . ComFla22(3) 383, ComFla23(1) 129, . ComFla23(2) 143, ComFla23(2) 277, ... ComSciT9(5-6) 247, ... FirTec10(2) 129, JFFCT1(4) 268, .. JFFFRC1(1) 31, JFFLAO5(2) 116, .. JFFLAO5(4) 289, PhysCE10(1) 28, .. PhysCE10(1) 41, PhysCE10(3) 338, ... PhysCE10(5) 634
Combustion Behavior .... JFFLAO5(1) 16
Combustion Diameter .... PhysCE10(5) 661
Combustion-Driven Oscillations .... ComSciT9(1-2) 49
Combustion Extinction .... PhysCE10(5) 764
Combustion Flow . PhysCE10(4) 554
Combustion Gas Studies .... JFFCT1(2) 95
Combustion Hazards .... FirTec10(1) 15
Combustion Kinetics .... ComFla23(3) 373
Combustion Products .... ComFla23(1) 29, JFFCT1(1) 78, ... JFFCT1(2) 104, JFFCT1(3) 141, ... JFFCT1(4) 191, JFFLAO5(1) 34, . PhysCE10(2) 294, PhysCE10(4) 548, ... PhysCE10(5) 762
Combustion Theory Seminar - USSR . ... PhysCE10(2) 297
Combustion Toxicology .... JFFCT1(2) 91
Combustion Waves . PhysCE10(4) 518
Combustion Zones PhysCE10(3) 445
Combustors .... ComSciT9(3-4) 133, ... ComSciT9(5-6) 209
Command-Control .. FirCom41(6) 28
Communications Center .... FirCom41(6) 22, FirCom41(6) 28, ... FirCom41(6) 36
Communications Feature .... FPRev37(405) 289
Communications System .... FirChf18(2) 34
Compartment Fires .... FirTec10(3) 228, FirTec10(3) 247
Composite Explosives .... PhysCE10(4) 598
Compression Wave PhysCE10(2) 265
Compression Waves .... PhysCE10(3) 440
Compressors ...... FirEng127(8) 46
Computer .... FEngJ34(93) 39, ... FirChf18(11) 24, NSNews109(6) 82
Computer Application .... FEngJ34(93) 38
Computer Applications .... FEngJ34(93) 30
Computer Installation .... FirJrn68(6) 105
Computer System FPRev37(401) 139

Computers .... FEngJ34(93) 41
Concentration Fluctuations .... ComSciT9(1-2) 25, PhysCE10(2) 220
Concorde Fire Protection FPRev37 (406) 355
Concrete Floors ... FirEng127(5) 32
Condensed Combustion Products .... PhysCE10(5) 669
Condensed Explosives .... PhysCE10(3) 405, PhysCE10(5) 728, .. PhysCE10(6) 791, PhysCE10(6) 864
Condensed Fual .. PhysCE10(5) 634
Condensed Media Ignition .... PhysCE10(4) 512
Condensed Mixtures .... ComFla22(1) 77
Condensed Nonhomogeneous Medium .... PhysCE10(5) 732
Condensed Particles .... PhysCE10(5) 762
Condensed Reaction Products .... PhysCE10(3) 313
Condensed Substances .... PhysCE10(5) 661
Confined Spaces .... ComSciT9(5-6) 255
Conflagration ...... FirChf18(5) 35, ... FirCom41(3) 12
Constant Volume Bomb .... ComSciT9(3-4) 149
Consumer - Fire Losses .... JFFCPF1(2) 181
Consumer Product Safety .... LabDat5(4) 15
Consumer Product Safety Commission .... JFFCPF1(4) 354
Continuous Spectrum .... PhysCE10(1) 116
Cool Flame ...... ComFla22(1) 131
Copper Oxide ..... PhysCE10(1) 99
Copper-Zirconium PhysCE10(5) 774
Correlating Parameter .... JFFLAO5(2) 151
Correlation ...... PhysCE10(3) 338
Corridor .... also see Halls. ... JFFCPF1(1) 32, JFFCPF1(2) 221
Cost Effectiveness .... FEngJ34(93)22
Cost-Effectiveness .... FirChf18(8) 58, FirChf18(9) 26, ... FirChf18(10) 42
Cost Effectiveness Symposium .... FPRev37(409) 463
Cotton .... JFFFRC1(3) 142, ... JFFLAO5(2) 107
Cotton Batting .... JFFCPF1(3) 240
Cyanogen-Fluorine Flame .... ComFla23(2) 227
Cylinder Jig .... FirEng127(2) 41
Cylindrical Furnace .... ComFla23(3) 283
D-C Discharge ... PhysCE10(4) 614
Data Sheet 644 ... NSNews109(6) 95
Day-Care Center ..... FirJrn68(6) 54
Decabromodiphenyl Oxide .... JFFCT1(1) 52
Decision Making ... FirCom41(10) 18
Decomposition Products .... JFFCT1(4) 250
Decomposition Temperature .... JFFLAO5(1) 76
Deflagration ..... ComFla22(1) 111, .. ComFla22(1) 119, ComFla22(2) 161
Deluge Sprinkler Systems Design .... FirTec10(4) 304
Dense Media ..... PhysCE10(1) 142
Denver Fire Department .... FirEng127(4) 52
Department of Transportation .... FirEng127(3) 57, FirEng127(8) 43
Department Store Fire .... FirCom41(1) 18, FirInt4(43) 74, ... FirJrn68(3) 42
Design Philosophy .. FPSTech(8) 16
Destruction Zone . PhysCE10(3) 437
Detonation ...... ComFla22(1) 111, . ComFla22(1) 119, ComFla22(2) 161, ... ComFla23(1) 37, PhysCE10(5) 710
Detonation Calculations .... ComFla22(2) 269
Detonation Front .... PhysCE10(1) 132, PhysCE10(6) 864

Detonation Front Perturbations .... PhysCE10(1) 102
Detonation Initiation .... PhysCE10(4) 561
Detonation Products .... PhysCE10(1) 119, PhysCE10(5) 737
Detonation Propagation .... PhysCE10(6) 912
Detonation Velocities .... PhysCE10(4) 598
Detonation Velocity .... PhysCE10(2) 270
Detonation Wave Front .... PhysCE10(5) 784
Detonation Wave Parameters .... PhysCE10(1) 110
Detonation Wave Structure .... PhysCE10(1) 110
Detonation Waves .... PhysCE10(3) 405, PhysCE10(5) 728
Detonations .... also see Explosions, ... ComSciT9(3-4) 119
Diatomic Molecules .... PhysCE10(3) 303, PhysCE10(4) 459
Diazo Salt Combustion .... PhysCE10(3) 449
Diethyl Phosphoramidates .... JFFFRC1(3) 142
Diffusion Flame ... ComFla22(1) 23, ... ComSciT9(3-4) 111
Diffusion Flame Length .... PhysCE10(6) 835
Diffusion Flame Lengths .... PhysCE10(4) 485
Diffusion Flame Structure .... PhysCE10(2) 151
Diffusion Flames .... ComFla22(1) 133, JFFLAO5(4) 255
Diffusion Jets .... PhysCE10(2) 220
Diffusion Method . PhysCE10(5) 723
Diffusive Turbulent Combustion .... PhysCE10(2) 220
Digital Transmission .... FEngJ34(95) 15
Dimethyl Phosphoramidates .... JFFFRC1(3) 142
DINA Propellant Combustion .... PhysCE10(4) 543
Disasters .... FEngJ34(95) 46
Discotheque Fire ...... FirJrn68(6) 5
Disney World ..... FirEng127(3) 48
Dispatching .... FirEng127(4) 68, ... FirEng127(10) 46
Dispersed Condensed Substances .... PhysCE10(1) 28
Dispersion Mechanism .... PhysCE10(1) 34
Distribution Plant Fire .... FirJrn68(1) 52
Dogs - Unfriendly at Fires .... FirEng127(12)22
Domestic Dwellings .... FPRev37(407) 394
Domestic Fires Seminar .... FPRev37(409) 464
Door Locks ...... FirEng127(11) 50
Drill Motor .... FirEng127(2) 41
Driver Training ..... FirCom41(8) 52
Drop Ignition Limits .... PhysCE10(4) 534
Drop Size .... PhysCE10(5) 710
Droplets .... ComFla23(1) 11
Dwelling .... FirJrn68(1) 22
Dwelling Fire .... FirJrn68(5) 5
Dwelling Fires .... also see Residential Fires, ... FirJrn68(6) 10
Dynamics .... ComFla23(1) 11

Early Warning ..... FirTec10(4) 287
Education .... FirEng127(4) 69 .... FirEng127(4) 69
Effluent .... FirTec10(2) 115
Electric Blasting .... NSNews109(6) 95
Electric Cables .... FirInt4(46) 41
Electric Conductivity .... ComFla23(1) 29
Electric Field ...... PhysCE10(1) 74

Electric Fields .... ComFla22(2) 267
Electric Gas Burner .... PhysCE10(2) 253
Electric Heat Tape .... FirJrn68(5) 11
Electrical Calibration .... ComFla23(3) 319
Electrical Conductivity Profile .... PhysCE10(6) 864
Electrical Field ... PhysCE10(5) 696
Electrical Fields .... ComFla22(1) 43
Electrical Ground ... FirCom41(4) 42
Electrical Installations .... FirJrn68(1) 71
Electrical Junction Effect .... PhysCE10(2) 265
Electrocardiogram Telemetry System .... FirEng127(11) 56
Electrode Erosion .... PhysCE10(2) 294
Electromagnetically Induced Motion .... ComFla22(2) 143, ... ComFla22(2) 263
Electron Distribution Function .... PhysCE10(5) 779
Electron Energy Exchanges .... ComFla22(1) 43
Electron Number Density .... ComFla23(1)
Electron Spin Resonance .... ComFla23(1) 47
Electronic Excitation of Nitrogen .... ComFla22(3) 337
Elevating Platform .... FirCom41(3) 28
Elevator - Department Store Fire .... FirInt4(43) 74
Elevator Fire ..... FirEng127(8) 170
Elevators .... FirJrn68(6) 79
Emergency Care ..... FirChf18(4) 41
Emergency Health Care .... FirCom41(7) 20
Emergency Lighting Feature .... FPRev37(401) 119
Emergency Medical Care .... FirChf18(4) 37, FirEng127(11) 24
Emergency Medical Service .... FirChf18(4) 34, FirCom41(8) 60, ... FirEng127(11) 38
Emergency Response .... FirCom41(5) 20
Emergency Service ... FirInt4(43) 85
Emission Spectrum .... PhysCE10(5) 762
Emmission Spectra .... ComFla23(2) 227
Energy Equation ... ComFla23(1) 17
Energy Feedback Analysis .... ComSciT9(3-4) 137
Energy Flux Levels .... FirTec10(3) 187
Energy Yield Kinetics .... PhysCE10(5) 629
Engine-Like Conditions .... ComFla22(1) 89
Equation of State ... ComFla22(1) 9
Escape Planning ..... FirJrn68(6) 10
Ethylene Copolymers .... JFFCPF1(3) 295
Excitation .... PhysCE10(3) 405
Excited States .... PhysCE10(4) 608
Exit Signs Visibility .... LabDat5(1) 14
Exothermic Reactions .... ComFla23(3) 319, PhysCE10(5) 629
Expanded Polystyrene .... JFFCT1(4) 236
Explosion .... ComFla23(1) 97, . PhysCE10(3) 437, PhysCE10(3) 440, ... PhysCE10(5) 774
Explosion Acceleration .... PhysCE10(6) 884
Explosion Hazards .. FPSTech(8) 16
Explosion Limit Temperature .... PhysCE10(6) 934
Explosion Loading .... PhysCE10(4) 603, PhysCE10(5) 782
Explosion Products .... PhysCE10(6) 791, PhysCE10(6) 877
Explosion Reliefs ... FPSTech(9) 23
Explosion Welded Junction Zone .... PhysCE10(6) 898

Explosion Welding .... PhysCE10(2) 284
Explosions .... also see Detonations, ... FirInt4(45) 25, PhysCE10(2) 292, ... PhysCE10(3) 452
Explosive .... LabDat5(3) 9, ... PhysCE10(1) 145
Explosive Actuators .... FPRev37(402) 182
Explosive Charge . PhysCE10(5) 737
Explosive Destruction of Tubes .... PhysCE10(1) 127
Explosive Hardening .... PhysCE10(1) 132
Explosive Loading .... PhysCE10(2) 277
Explosive Materials .... ComFla23(3) 329
Explosives .... ComFla22(1) 9, .. ComFla22(1) 53, ComFla22(1) 111, . ComFla22(1) 119, ComFla22(2) 161, ... ComFla23(1) 37
Expo-74 .... FirChf18(5) 30
Extinction .... ComFla22(1) 23, . ComFla22(1) 59, ComSciT9(1-2) 37, ... JFFLAO5(4) 255
Extinguishant ... ComSciT9(5-6) 255
Extinguishing Agents .... JFFLAO5(3) 223
Extinguishment ..... FirJrn68(4) 93, ... FirTec10(3) 197
Extraneous Electricity .... NSNews109(6) 95

Fabric .... FirInt4(43) 91
Fabric Fuels ..... ComSciT9(5-6) 255
Fabrics ... also see Flammable Fabric Textiles .... JFFLAO5(2) 107
Falling Drops .... PhysCE10(5) 772
False Fire Alarms .... FirTec10(3) 221
Fatality .... FirJrn68(1) 5
Federal Communications Commission .... FirEng127(8) 164
Federal Grant ..... FirEng127(7) 28
Ferrous Oxide ..... ComFla22(1) 77, ... PhysCE10(2) 197
FIFI - Fire Service Education .... FirCom41(1) 12
Fire Academy ..... FirEng127(4) 51
Fire Alarm Box ..... FirCom41(7) 31
Fire and Rescue System .... FirChf18(8) 58, FirChf18(9) 26, ... FirChf18(10) 42
Fire Apparatus Color .... FirCom41(8) 43
Fire Appliance Feature .... FPRev(399) 47
Fire Behavior ...... FirCom41(3) 12, ... JFFCPF1(1) 19
Fire Brigade .... FirChf18(9) 32
Fire Brigades .... FirInt4(44) 65
Fire Chiefs .... FirChf18(8) 64
Fire Column ..... ComSciT9(1-2) 41
Fire Combat .... FirCom41(8) 38
Fire Control .... FirCom41(12) 26
Fire Crews .... FirInt4(43) 69
Fire Damage ..... FPRev37(398) 12
Fire Damage in 1973 .... FPRev37(401) 115
Fire Danger Rating System .... FirTec10(4) 275
Fire Data System .... FirJrn68(6) 91
Fire Department .... FirChf18(3) 36, ... FirChf18(4) 34, FirChf18(4) 41, ... FirChf18(7) 21, FirCom41(1) 16, ... FirCom41(6) 28, FirEng127(4) 69
Fire Department Operations .... FirChf18(7) 16, FirChf18(8) 53
Fire Department Publicity .... FirChf18(9) 22
Fire Department Training .... FirChf18(9) 22
Fire Departments .... FirChf18(8) 50
Fire Detection .... FirEng127(8) 181, ... FirTec10(4) 287
Fire Detection Device .... FPRev37(408) 447
Fire Detector System .... FPRev37(406) 351
Fire Disasters ... FPRev37(406) 346

Fire Emergencies .... FEngJ34(94) 24
Fire Engineering ..... FirInt4(44) 29, ... FirInt4(45) 69
Fire Environment ... JFFCT1(3) 157
Fire Environments JFFLAO5(3) 203
Fire Equipment ... NSNews109(6) 79
Fire Exposure .... JFFCT1(1) 4
Fire Extinguisher .... FirJrn68(6) 58
Fire Extinguisher Guidelines .... NSNews109(6) 57
Fire Extinguishers .... NSNews109(6) 69
Fire Extinguishing Agent .... FirInt4(46) 50, FirTec10(4) 269
Fire Fatalities .... FirJrn68(1) 22
Fire Fighter .... FirCom41(1) 20
Fire Gas Hazard .... FirTec10(2) 115
Fire Hazard .... FEngJ34(95) 56, ... JFFLAO5(3) 179
Fire Hazards ..... FPRev37(400) 78, ... FPSTech(8) 16, JFFCPF1(2) 186
Fire Heat Source ..... FirTec10(1) 68
Fire Line .... FirEng127(4) 53
Fire Loss .... FirJrn68(1) 61
Fire Loss Figures FPRev(399) 63, ... FPRev37(405) 309
Fire Losses .... FirJrn68(5) 33, ... FirJrn68(6) 67, JFFCPF1(2) 181
Fire Origins .... FirJrn68(4) 19
Fire Prevention .... FEngJ34(93) 38, ... FEngJ34(93) 39, FEngJ34(93) 41, ... FirChf18(1) 41, FirCom41(4) 32, .. FirCom41(10) 24, Fir Eng127(9) 18, ... FirEng127(9) 22
Fire Prevention and Control Act of 1974 .... FirChf18(12) 23, ... FirCom41(12) 16
Fire Product .... FirTec10(2) 115
Fire Program ...... JFFCPF1(2) 115
Fire Protection .... FEngJ34(94) 22, ... FirChf18(5) 30, FirChf18(8) 48, ... FirEng127(4) 66, FirInt4(43) 18, ... FirInt4(46) 18, FirTec10(1) 5, ... FirTec10(2) 140, ... FPRev37(403) 221, ... FPRev37(407) 392, FPSTech(9) 4, ... JFFLAO5(3) 203
Fire Protection Facilities .... FirEng127(3) 48
Fire Protection in Europe .... FPRev37(403) 223
Fire Protection Standards .... FEngJ34(93) 47
Fire Research .... FirInt4(46) 61, ... FirJrn68(6) 23
Fire Resistance Rating .... LabDat5(2) 15
Fire-Resistive Material .... FirTec10(3) 201
Fire Retardant ...... JFFCT1(1) 52, .. JFFFRC1(2) 78, JFFFRC1(4) 218, ... JFFFRC1(4) 243
Fire Retardant Emulsion .... FirChf18(1) 36
Fire Retardant Impregnations .... JFFFRC1(2) 96
Fire Retardants .... JFFFRC1(1) 31
Fire Risk of Plastics .... FPRev37(398) 25
Fire Safety .... FirInt4(43) 36, ... FirJrn68(6) 33, FPRev37(407) 394
Fire Science Course .... FirChf18(12) 26, FirEng127(12) 40
Fire Science Training .... FirChf18(2) 24
Fire Service .... FEngJ34(93) 41, ... FirChf18(4) 37, FirCom41(1) 12, ... FirCom41(2) 26, FirCom41(8) 60, ... FirEng127(7) 38, ... FirEng127(10) 30, ... FirEng127(11) 38
Fire Service Education .... FirCom41(1) 12
Fire Service Instructors .... FirEng127(6) 58
Fire Service Management .... FirCom41(3) 20, FPRev37(403) 206
Fire Service Problems .... FirCom41(9) 28
Fire Service Technical College .... FPRev37(404) 250
Fire Severities ...... FirTec10(4) 315

Fire Spread .... FirTec10(1) 35, ... JFFLAO5(1)4, JFFLAO5(3) 167
Fire Station .... FirCom41(3) 26
Fire Station Site .... FirEng127(3) 45
Fire Strategy .... FEngJ34(93) 25
Fire Suppression ... JFFLAO5(1) 54
Fire Suppression System .... FirJrn68(5) 42
Fire Tactics Training .... FirCom41(9) 13
Fire Tests .... FirJrn68(2) 18, ... FirTec10(3) 211
Fire Training Center .... FirChf18(12) 30
Fire Warning Equipment .... FirJrn68(5) 28
Fireboat .... FirEng127(2) 29
Firefighter Casualties .... FirCom41(5) 14
Firefighter Fatalities .... FirCom41(4) 35
Firefighter Fitness .... FirCom41(1) 20
Firefighter Injuries .... NSNews109(6) 73
Firefighter - Overtime .... FirChf18(7) 24
Firefighter - Psychology .... FirCom41(4) 36
Firefighter Safety .... FirChf18(2) 26
Firefighter Stress .... FirCom41(7) 27
Firefighter - Visibility .... FirCom41(5) 22
Firefighters Certified .... FirEng127(8) 96
Firefighters - Coal Fabrics .... FirTec10(2) 153
Firefighters - Education .... FirChf18(12) 26, FirEng127(4) 69
Firefighters - Esteem .... FirCom41(11) 26
Firefighters - Plastics Hazards .... FirInt4(43) 55
Firefighters Self-Image .... FirCom41(11) 26
Firefighters - Training .... FirEng127(7) 38, FirEng127(8) 96
Firefighters - Women .... FirEng127(4) 59
Firefighting ..... FPRev 37(400) 92, ... FPRev37(401) 139
Firefighting Aspects .... FirCom41(4) 38
Firefighting Facilities .... FPRev37(407) 382
Firefighting Strategy .... FirEng127(12) 31
Firefighting Training .... FirChf18(5) 39
Fireground .... FirEng127(3) 40, ... FirEng127(10) 50
Fireground Command .... FirChf18(8) 64
Fireground Control .... FirEng127(4) 49
Fireground Procedures .... FirCom41(10) 18
Fireground Work .. FirEng127(1) 47

Fireplace Stoves ..... LabDat5(2) 10
Fireworks Incidents .... FirJrn68(6) 86
First Aid .... FirCom41(4) 30
Fitness .... FirCom41(1) 20
Flame Front ..... PhysCE10(6) 841
Flame Front Development .... PhysCE10(1) 83
Flame Front Formation .... PhysCE10(1) 83
Flame Gases ...... ComFla22(1) 43, ... ComFla23(1) 109
Flame Inhibition .... JFFFRC1(1) 4
Flame Length .... ComFla22(3) 313
Flame Model .... ComFla23(2)
Flame Perturbation .... ComFla23(1) 73
Flame Plasma .... PhysCE10(5) 779
Flame Propagation .... ComSciT9(5-6) 197

Flame Propagation Measurements ... ComSciT9(3-4) 137
Flame Retardancy .. JFFFRC1(1) 26, JFFFRC1(3) 125
Flame Retardant .. JFFFRC1(3) 152
Flame Retardant Fiber ... JFFCPF1(3) 265
Flame Retardant Filler ... JFFFRC1(1) 13
Flame Retardants ... ComSciT9(1-2) 13, JFFFRC1(2) 110, .. JFFFRC1(3) 142, JFFFRC1(4) 175
Flame Retarded Urethane Foam ... JFFFRC1(2) 61
Flame Retarding Plastics ... JFFFRC1(4) 185
Flame Spread .... ComSciT9(1-2) 71
Flame Spread Characteristics ... JFFCPF1(4) 367
Flame Spread Mechanisms ... ComFla22(3) 353
Flame Spread Velocities ... JFFLAO5(1) 85
Flame Spreading .. ComSciT9(1-2) 1, ComSciT9(1-2) 75, ComSciT9(3-4) 173
Flame Stoichiometry ... ComFla23(3) 399
Flames ... ComFla23(1) 83, .. PhysCE10(2) 256, PhysCE10(2) 291
Flames - Temperature Profiles ... ComFla23(1) 83
Flames - Velocity Profiles ... ComFla23(1) 83
Flammability ... FirInt4(43) 78, .. JFFCPF1(3) 225, JFFCPF1(3) 265, JFFLAO5(4) 289
Flammability Behavior ... JFFLAO5(4) 227
Flammability Limits ... ComFla22(1) 89
Flammability Specifications ... FirJrn68(2) 36
Flammability Tests ... FirInt4(43) 91
Flammable Fabric Ignition ... LabDat5(4) 17
Flammable Gases ..... LabDat5(3) 9
Flammable Liquids ... FirCom41(3) 8
Flight Velocity .... PhysCE10(6) 877
Flixborough Disaster ... FPRev37(405) 296
Flixborough Explosion ... FirInt4(45) 18
Floor ... FirEng127(9) 38
Floor-Covering Flammability ... JFFCPF1(1) 32, JFFCPF1(2) 221
Flooring Materials ... JFFCPF1(4) 305
Flotation Devices .... LabDat5(3) 17
Flow Meters ...... FirEng127(5) 44
Flow Velocity .... ComSciT9(1-2) 75
Flowfield .... ComSciT9(5-6) 209
Fluid Layer ...... PhysCE10(2) 260
Fluorocarbon Surfactants ... FPRev37(400) 92
Fluoroprotein Foam ... FirInt4(45) 57
Foam Characteristics ... FirEng(9) 48
Foam Tender .... FPRev37(406) 349
Foamed Plastic ...... FirJrn68(5) 51
Foamed Plastics Fire ... FirJrn68(6) 16
Foams .... also see Urethane Foams
Formaldahyde Oxidation ... ComFla22(2) 153
Fort Worth TX Fire Department Modernization . FirEng127(10) 46
Fracture Velocity in Solids ... PhysCE10(6) 891
Freight Train ..... FirEng127(10) 24
Fuel Air Mixtures ... PhysCE10(5) 691
Fuel Droplets .... ComFla22(3) 377
Fuel Jet Flame .... ComFla22(3) 283
Fuel-Lean Flame Gas ... ComFla22(3) 343
Fuel Storage .... FPRev37(403) 221
Fuel Surface .... ComSciT9(3-4) 173
Fumes ... JFFCT1(3) 177

Funding .... FirEng127(11) 38
Furnishings .... FirJrn68(2) 36,
.. JFFCPF1(2) 115, JFFCPF1(2) 186
Furniture .... JFFCPF1(2) 186

Garden Apartment ... FirChf18(2) 32
Garments .... Also see Clothing,
.... JFFCPF1(1) 19
Gas Boundary Layer Stability ....
.... PhysCE10(6) 797
Gas Burner Facilities ....
.... LabDat5(4) 10
Gas-Chromatographic Monitoring ...
.... JFFCT1(1) 78
Gas Explosion .... FirJrn68(6) 28
Gas Laser .... PhysCE10(6) 857
Gas Line Incidents ....
.... FirEng127(7) 38
Gas Mixture Burning Rate ....
.... PhysCE10(1) 45
Gas-Phase .... ComFla23(1) 47
Gas-Phase Oxidation Reactions .....
.... ComFla22(2) 209
Gas Sampling .... PhysCE10(4) 492
Gas Suspension ... PhysCE10(5) 676
Gas Turbine Combustors ....
.... ComFla22(2)
Gas Turbine Engines ....
.... ComSciT9(5-6) 261
Gas Turbine Powerplants ....
.... ComSciT9(3-4) 133
Gas Well Fire .... FirChf18(11) 27
Gaseous Mixtures at Elevated Pressures .... PhysCE10(1) 102
Gases .... ComFla22(1) 105,
.... ComSciT9(5-6) 247,
.... ComSciT9(5-6) 273
Gasification Rate ....
.... PhysCE10(3) 354
Gasless Combustion .. PhysCE10(1) 4
Gasless Reactions ....
.... ComFla22(3) 323
Gasless Systems Ignition ....
.... PhysCE10(4) 518
Gasoline .... FirCom41(9) 22,
.... FirJrn68(4) 10

Governments Dilemma ....
.... FEngJ34(93) 18
Grading Schedule ....
.... FirEng127(10) 30
Gravitational Influence ....
.... PhysCE10(1) 28
Group Fire .... FirJrn68(4) 13

H-N-O .... ComFla23(1) 37
Halls .... FirEng127(12) 36
Halogen .... JFFFRC1(1) 4
Halogen-Containing Compounds ....
.... JFFFRC1(4) 185
Halogenated Methanes ....
.... ComFla22(1) 133
Halon 1301 System ....
.... FirJrn68(6) 105
Halons .... JFFLAO5(4) 255
Hammer Rigidity . PhysCE10(2) 260
Hand Lines .... FirEng127(7) 32
Hangar Protection ... FirInt4(44) 36
Hangars ....
.... also see: Aircraft Hangars
Haunted House ...... FirJrn68(2) 14
Hazard .... FirJrn68(4) 100
Hazard Load Calculations ....
.... FirTec10(3) 181
Hazard Reduction .. FirCom41(5) 20
Hazardous Cargo ... FirCom41(8) 36
Hazardous Chemicals Blaze ....
.... FPRev37(398) 22
Hazardous Materials ....
... FirCom41(4) 11, FirEng127(4) 61,
.... FirEng127(8) 43
Heart Disease ..... FirEng127(10) 52
Heart Test .... FirCom41(8) 50
Heat Conducting Element ....
.... PhysCE10(5) 634
Heat-Evolution Kinetics ....
.... PhysCE10(4) 530
Heat Extraction Systems ....
.... FirInt4(46) 85
Heat-Loss Rates .. ComFla22(2) 197
Heat Losses ...... ComFla23(3) 319,
.... PhysCE10(4) 512
Heat Radiation ...... FirTec10(1) 54

Heat Transfer .... ComSciT9(1-2) 49
Heated Surfaces .. ComFla22(1) 105
Heating Temperature .... PhysCE10(5) 782
Heats of Reaction .... ComFla23(3) 357
Heavy Streams .... FirEng127(1) 45
Helicopter .... FirCom41(4) 68
Helicopter Response .... FirChf18(1) 44
Helicopters ...... FirEng127(8) 178
Heterogeneous Condensed Systems .. PhysCE10(2) 178
Heterogeneous Ignition .... PhysCE10(4) 498
Heterogeneous Ignition Characteristics .... PhysCE10(1) 52
Heterogeneous Ignition Process ..... PhysCE10(2) 191
Heterogeneous Reactions .... PhysCE10(4) 530
Heterogeneous System Combustion .. PhysCE10(2) 162
Heterogeneous Systems .... PhysCe10(4) 526
HI System .... FirEng127(8) 43
High Expansion Foam .... FirCom41(3) 15
High-Frequency Processes .... PhysCE10(3) 386
High-Pressure Installations .... FirInt4(45) 79
High School .... FirChf18(12) 26, FirEng127(12) 40
High School Students .... FirChf18(2) 24
High Velocity Particles .... ComSciT9(1-2) 55
Highrise Building .... FirCom41(7) 16, FirEng127(12) 18
Highrise Buildings .... FirCom41(3) 19, FirInt4(44) 49, FirJrn68(2) 46, FirJrn68(6) 79
Highrise Code .... FirChf18(3) 36
Highrise Fire ...... FirEng127(7) 18
Highrise Fires ...... FirChf18(3) 30, FirTec10(1) 35
Hollow Cylindrical Explosive .... PhysCE10(1) 119
Holography ...... PhysCE10(6) 939
Hose Lines - 5-Inch .... FirEng127(4) 52
Hose Loading ..... FirCom41(11) 30
Hose Stream ...... FirEng127(5) 32
Hospital Fire Statistics .... FEngJ34(95) 44
Hospital Patient Room .... FirTec10(4) 287
Hot Channel ..... PhysCE10(5) 684
Hot Spots .... ComFla23(3) 313
Hotel Fire .... FirInt4(43) 60, FirJrn68(2) 31, FPRev37(398) 8
Hotel Fire .... FirCom41(6) 40
Hotel Security NSNews109(6) 82
Human Activity Pattern .... JFFCPF1(1) 4
Human Behavior ..... FirChf18(3) 30
Human Contribution .... FirJrn68(4) 19
Hydrant Visibility .... FirEng127(4) 63
Hydraulic Calculations .... FEngJ34(94) 40
Hydrazine Azide .. PhysCE10(2) 270
Hydrazine Chloride Combustion .... PhysCE10(2) 185
Hydrocarbon Drop . ComFla22(3) 313
Hydrocarbon Fires ... FirInt4(45) 45
Hydrocarbon Flame Front .... PhysCE10(6) 841
Hydrocarbon Mixtures .... ComFla23(3) 347
Hydrocarbons ..... ComFla22(1) 35, ComFla23(2) 203
Hydrogen .... PhysCE10(6) 847
Hydrogen-Air Flames . ComFla23(2)
Hydrogen Combustion .... PhysCE10(1) 65
Hydrogen Density .... ComSciT9(3-4) 129

.... ComSciT9(3-4) 129
Hydrogen Diffusion Flame ....
.. PhysCE10(2) 240, PhysCE10(5) 717
Hydrogen Flame .... ComFla22(1) 71
Hydrogen-Fluorine-Helium Mixtures .
.... ComFla22(2) 237
Hydrogen Ignition ....
... PhysCE10(1) 65, PhysCE10(2) 230
Hydrogen Oxidation ....
.... PhysCE10(3) 372
Hydrogen-Oxygen . ComFla23(1) 47
Hydrogen-Oxygen Flames ....
.... ComFla22(2) 191
Hypergolic Ignition ....
.... ComFla22(1) 1

Identifying Victims ....
.... FirEng127(3) 40
IFE 1974 Examinations ....
.... FEngJ34(95) 27
IFE Annual Conference ....
.. FEngJ34(96) 17, FPRev37(408) 434
Igdanite Detonation Properties ......
.... PhysCE10(1) 144
Ignition ... also see Piloted Ignition; Spontaneous Ignition ....
.... ComFla22(1) 105,
.... ComSciT9(1-2) 55,
.... ComSciT9(3-4) 171,
.... ComSciT9(3-4) 173,
.... ComSciT9(5-6) 233,
.... PhysCE10(5) 684
Ignition Characteristics ....
.... ComFla22(3) 323
Ignition Delay .... JFFLAO5(2) 136
Ignition Energies ....
.... ComFla23(2) 203
Ignition Front .... ComFla22(3) 283
Ignition Limit ..... PhysCE10(1) 88,
.... PhysCE10(5) 676
Ignition Mechanism ....
.... PhysCE10(4) 526
Ignition Method .. PhysCE10(2) 245
Ignition Modes .... PhysCE10(1) 74
Ignition Reaction .. PhysCE10(1) 99
Ignition Studies .... JFFCPF1(2) 186
Ignition Waves ... ComFla22(2) 273
Illnesses .... FEngJ34(94) 32
Implosion .... PhysCE10(2) 277
Incentive Pay Plan ....
.... FirEng127(4) 69
Individual .... PhysCE10(1) 99
Induction Rates ...... FirInt4(45) 34
Industrial Environments ....
.... FPRev37(405) 307
Industrial Fire Protection ....
.... FirInt4(45) 79
Industrial Flooring ....
.... FPRev37(407) 392
Industrial Losses .... FEngJ34(93) 25
Industrial Society ....
.... FPRev37(406) 346
Inert Additives ... PhysCE10(1) 144
Information Systems ....
.... FirCom41(10) 18
Infrared Spectroscopy ....
.... PhysCE10(5) 656
Inhibited Explosion Limit ....
.... PhysCE10(6) 847
Inhibition .... ComFla22(2) 209,
.... ComFla22(3) 415
Inhibitor Consumption ....
.... PhysCE10(6) 847
Initiation Patterns ....
.... ComFla22(1)53
Injuries .... FEngJ34(94) 32

Injury Severity .... JFFCPF1(1) 4
Instrument .... PhysCE10(5) 762
Inte-bild Conference ....
.... FPRev37(398) 25
Interferometric Holography ....
.... PhysCE10(6) 923
Ionization .... ComFla23(1)
Ionization in Flames ....
.... PhysCE10(5) 705
Iron Additive to Hydrogen-Oxygen Flame .... ComFla22(2) 191
Iron Oxide .... PhysCE10(1) 99
Irradiation .... ComFla22(2) 223
Iso-Octane Sprays ....
.... ComSciT9(5-6) 247

Isobutene-Perchloric Acid Mixtures .... PhysCE10(1) 99

Jet Diffusion Flames .... ComSciT9(1-2) 25
Jet Plane Fire ...... FirCom41(9) 31
Jet-Stirred ...... ComSciT9(5-6) 221
Johns Hopkins Conference .... FirChf18(8) 64

Kerosene Sprays ... ComFla23(1) 11
Kinematics .... PhysCE10(5) 746
Kinetics .... ComFla22(2) 153, ComFla23(2) 233, ComSciT9(5-6) 221, PhysCE10(2) 245, PhysCE10(4) 459
Kinetics of Reactions in Flames .... ComFla23(1) 73
Kinetics of Thermodissociation .... PhysCE10(3) 303
Kumamoto .... FirCom41(1) 18, FirJrn68(3) 42

Labor Department Hearings .... FirChf18(7) 24
Lactose .... ComFla23(3) 363
Laminar Flame ... PhysCE10(5) 696
Laminar Flame Radiation .... PhysCE10(3) 383
Laminar Flame Region .... ComFla23(3) 337
Laminar Premixed Flames .... ComFla22(3) 365
Laminated Plastics ... FPSTech(8) 4
Large Fires .... FirTec10(2) 147
Large-Loss Fires .... FirJrn68(4) 77, FirJrn68(6) 50
Laser Anemometry . ComFla23(1) 57
Laser Instrument .. PhysCE10(6) 934
Laser Radiation .. PhysCE10(2) 256
Laser-Schlieren Method .... PhysCE10(5) 629
Latch Straps ..... FirEng127(11) 68
Layered Halon ...... FirTec10(1) 25
Lead Modifiers ... ComFla22(3) 289
Legislation .... FEngJ34(93) 18
Leisure Center .... FirInt4(44) 18
Life Fire Hazard .... JFFCT1(4) 191
Life Hazard .... JFFCT1(4) 191
Life Safety .... FirJrn68(2) 65
Life Support .... FirTec10(1) 15
Light Fixtures .... FirJrn68(3) 14
Light Frequency Shifting .... ComFla23(1) 57
Light Pulse Source PhysCE10(1) 116
Liquid Fuel Drops .... ComSciT9(5-6) 233
Liquid Fuel Fires .... ComFla23(3) 337, ComSciT9(1-2) 71
Liquid Fuel Spray .... ComSciT9(5-6) 197
Liquid-Solid Systems .... ComFla22(1) 1
Liquid Transformations .... PhysCE10(3) 392
Locked Doors ..... FirEng127(2) 41
LOI Test .... also see Oxygen Index Test, FirInt4(43) 78
Lounge Fire .... FirJrn68(1) 16
Low-Dispersed Fillers .... PhysCE10(1) 110
Low Frequency Vibrations .... PhysCE10(1) 38
Low-Temperature Oxidation .... ComFla23(3) 295
Low-Temperature Zone .... PhysCE10(6) 841
LP-Gas .... FirCom41(9) 22, FirJrn68(1) 52
LP-Gas Bleve .... FirCom41(8) 34
LP-Gas Tank Farm . FirEng127(6) 20
LP-Gas Tank Rupture .... FirCom41(5) 14
LP-Gas Tank Trucks .... FirJrn68(5) 18

Macrocylinders ... ComSciT9(1-2) 31
Magnesium Oxychloride .... FirTec10(3) 201, JFFFRC1(4) 243
Magnesium Particles .... ComFla22(3) 383

Magnesium Powders .... PhysCE10(4) 548, PhysCE10(5) 669
Magnetic Field ... PhysCE10(5) 784
Magnetic Properties .... PhysCE10(4) 594
Management .... FirCom41(4) 52
Management Development Program . ... FirEng127(12) 42
Management of Information .... FEngJ34(95) 16
Management Tool .. FirCom41(2) 30
Manhole Rescues .. FirEng127(2) 35
Mannequins .... JFFCPF1(1) 19
Marina Fire .... FirCom41(10) 22
Marine Fire Protection .... FirEng127(7) 28
Marine Gas Hazards .... FirCom41(12) 26
Mass Force Field .. PhysCE10(2) 162
Mass Regression .. ComSciT9(1-2) 31
Mass Spectrometry . ComFla23(1) 73
Master Plan .... FirChf18(8) 48
Materials First Ignited .... FirJrn68(3) 56
Mathematical Model . FirTec10(4) 304
Mathematical Models .... PhysCE10(1) 56
Mattress Flammability .... JFFCPF1(3) 240
Mechanical Heating .... PhysCE10(2) 260
Medical Aid .... FirInt4(43) 85
Medical Aid Vehicles .... FirEng127(3) 57
Medical Emergencies .... FirChf18(1) 44
Medical Facilities .... FirJrn68(6) 33
Medical Services .. FirEng127(8) 164
Medium Behavior . PhysCE10(3) 437
Medium Composition .... PhysCE10(4) 473
Men and Performance .... FirCom41(6) 42
Merchant Navy Training .... FPRev(399) 61
Merchant Vessels ..... FirInt4(43) 36
Merchantile Fire ... FirCom41(11) 31
Metal-Boron ..... PhysCE10(2) 201
Metal Cutting .... PhysCE10(6) 857
Metal Embossing . PhysCE10(6) 931
Metal Fires .... FirTec10(3) 197, ... FirTec10(4) 269, JFFLAO5(3) 223
Metal Interfaces .. PhysCE10(6) 904
Metal Parts Ignition .... PhysCE10(2) 212
Metal Plate Acceleration .... PhysCE10(2) 292
Metal Plates ...... PhysCE10(3) 409
Metallic Additives .... ComSciT9(1-2) 61
Metallic Particle .. PhysCE10(3) 363
Metallized Compositions .... PhysCE10(2) 169
Methane .... ComFla23(2) 233, .. JFFLAO5(2) 136, JFFLAO5(3) 190
Methane Conversion .... PhysCE10(3) 446
Methane Flame Extinguishment .... FirTec10(1) 25
Methane-Oxygen . PhysCE10(2) 235, .. PhysCE10(3) 446, PhysCE10(4) 612
Methylamine Perchlorate Combustion .... PhysCE10(5) 650
Metric Conversion .... LabDat5(2) 9
MHD Generator ... ComFla23(1) 29
Mild Steel .... PhysCE10(1) 132
Mini-Maxi Pumper .... FirChf18(10) 27, FirChf18(11) 29
Mixing Processes .... ComSciT9(3-4) 111
Mixtures .... PhysCE10(1) 99, . PhysCE10(2) 235, PhysCE10(3) 313, .. PhysCE10(4) 459, PhysCE10(4) 612
Mobile Casualty Center .... FPRev37(408) 449
Mobile Communications Systems .... FPRev37(405) 289
Mobile Home Fire .... FirJrn68(1) 5

Mobile Homes .... LabDat5(3) 4
Mobile Unit .... FirEng127(6) 26
Mobilizing by Computer .... FEngJ34(93) 35
Molecular Beam ... ComFla23(1) 73
Monatomic Inert Gas .... PhysCE10(3) 303
Monitor .... FirInt4(45) 87
Monnex .... FPRev37(400) 92
Monodispersed Particles .... PhysCE10(1) 88
Motel .... FirJrn68(4) 5
Motel Fire .... FirJrn68(2) 5
Multicomponent Diffusion .... PhysCE10(1) 45
Multicomponent Fuel Mixture .... PhysCE10(6) 826
Multiple Alarms ... FirEng127(4) 49
Multiple-Death ...... FirJrn68(3) 69
Mutual Aid .... FirCom41(6) 40, ... FirCom41(11) 31, FirEng127(2) 26
MVSS-02 .... JFFCPF1(3) 295

Na-x Fire Extinguishing Agent .... FirTec10(4) 269
NASA Breathing Apparatus .... FirEng127(1) 47, FirEng127(8) 68
National Bureau of Standards .... LabDat5(4) 15
National Electrical Code .... LabDat5(2) 4
Natural Gas .... FirJrn68(3) 77
Natural Gas Explosion .... FirCom41(3) 22
NBS Research ..... FirEng127(7) 38
Nickel Hardening . PhysCE10(3) 421
Nickel Softening .. PhysCE10(3) 421
Night Vision Systems .... FirEng127(8) 178
Nitric Oxide .... ComFla22(1) 71, . ComFla22(2) 259, ComFla22(3) 299, ... ComFla23(2) 277, ... ComSciT9(5-6) 209, ... PhysCE10(2) 230
Nitric Oxide Formation .... ComFla23(2) 249
Nitrocellulose Propellants .... ComFla22(3) 289
Nitroester Combustion Zones .... PhysCE10(5) 656
Nitrogen .... ComSciT9(5-6) 255
Nitrogen Atmosphere .... ComSciT9(1-2) 31
Nitrogen Dioxide Formation .... ComSciT9(5-6) 261
Nitroglycerine .... PhysCE10(3) 334
NO Formations ... ComSciT9(1-2) 17
Non-Ideal Plasma . PhysCE10(2) 289
Nonacoustic Pulsations .... PhysCE10(3) 334
Nonisothermic Thermographic Studies .... PhysCE10(4) 530
Nonstationary .... PhysCE10(3) 341
Normal Burning .. PhysCE10(6) 826
NOx Emissions ... ComSciT9(1-2) 61
NOx Formation ..... ComFla22(2), ... ComSciT9(5-6) 221
Nozzles ..... see: Automatic Nozzles
Numerical Methods .... ComFla22(2) 171
Nursing .... FirEng127(4) 55
Nursing Home Fire .... FirCom41(2) 24, FirEng127(4) 55, ... FirJrn68(3) 11

O+NO-N+O2 ..... ComSciT9(3-4) 79
Oblique Collisions PhysCE10(3) 409
Oblique Detonation .... PhysCE10(6) 877
Occupational Emotional Stress .... FirCom41(7) 27
Office Building ..... FirJrn68(1) 61, ... FirJrn68(2) 65
Ohio State University .... JFFCT1(2) 95
Oil Bulk Ore Carrier .... FirInt4(45) 25
Oil Burner .... ComSciT9(1-2) 61
Oil Burner Facilities .... LabDat5(4) 10
Oil Refinery ..... FPRev37(407) 382
Oil Risks .... FPRev37(406) 349

Oil-Soaked Lagging . FPSTech(9) 13
Oil-Tank Fires ...... FPSTech(8) 21
Oleum Leakage ..... FEngJ34(94) 47
Optical Density ... JFFLAO5(2) 151
Organic Compounds JFFLAO5(4) 321
Organic Fuel Nitrogen .... ComFla22(3) 299
Oscillating Characteristics .... PhysCE10(1) 137
OSHA Plan Records FirEng127(8) 53
OSHAct Regulations .... NSNews109(6) 69
Overtime Requirements .... FirChf18(7) 24
Oxidation Reactions .... ComFla23(1) 47
Oxidizing Gas Flow .... PhysCE10(5) 710
Oxygen Atom Formation .... ComFla23(2) 233
Oxygen Enriched Atmospheres .... JFFLAO5(1) 16
Oxygen Index ...... ComFla23(1) 1
Oxygen Index Test .... also see LOI Test, FPSTech(8) 4
Oxygen-Inert Atmospheres .... ComFla22(3) 383
Oxygen-Rich Atmosphere .... PhysCE10(2) 212

PETN .... PhysCE10(6) 874, ... PhysCE10(6) 912
Paint .... FirCom41(4) 34
Paper .... ComFla22(2) 223, . ComSciT9(1-2) 75, JFFLAO5(3) 167
Paramedic Service .... FirEng127(11) 34
Paramedics .... FirCom41(12) 20
Parking Structures ... FirInt4(43) 49
Partial Equilibrium Models .... ComFla22(3) 299
Particle Distribution .... PhysCE10(4) 554
Particle Size ...... PhysCE10(5) 669
Percus-Yevick Equation .... ComFla22(2) 269
Performance Appraisal Systems .... FirEng127(6) 28
PHA Mixture Models .... PhysCE10(1) 41
Phosphate .... JFFFRC1(4) 205
Phosphorus Compounds .... JFFFRC1(2) 110
Phosphorus-Containing Vinyl .... JFFFRC1(3) 125
Photo Team .... FirChf18(9) 22
Physiological Hazard .... JFFCT1(3) 157
Pill Ignition Test .. JFFLAO5(4) 268
Piloted Ignition ... JFFLAO5(2) 107
Pine Wood .... ComSciT9(1-2) 31
Pipeline Accident .... FirJrn68(3) 77
Plane Destructive Waves .... PhysCE10(1) 124
Plane Jet Breakup .. PhysCE10(5) 755
Plasma .... ComFla23(1) 29
Plastic Parts .... LabDat5(4) 4
Plasticity .... PhysCE10(4) 603
Plastics .... also see Foamed Plastics, ... FirInt4(43) 55, FirInt4(43) 78, ... FirJrn68(6) 23, JFFCPF1(2) 186
Plate .... PhysCE10(6) 877
Plates .... PhysCE10(6) 884
Plug-Flow Burner . ComFla23(2) 249
PNA PMMA Mixtures .... PhysCE10(3) 345
Pneumatic Puller FPRev37(402) 162
Point Source ..... ComFla23(1) 109, ... ComSciT9(3-4) 173
Point Source Explosions .... PhysCE10(6) 923
Pollution Control .... FPRev37(405) 307
Polyatomic Gases . PhysCE10(4) 459
Polycrystals ...... PhysCE10(3) 452
Polyester-Cellulosic Fiber Blends .... JFFLAO5(4) 227
Polyester Polyurethane .... FirCom41(9) 20
Polymer Surface . ComSciT9(1-2) 151
Polymer Systems .. JFFFRC1(3) 152

Polymeric Materials .... JFFCPF1(3) 225, JFFCT1(2) 124
Polymerization Front Propagation .... PhysCE10(1) 22
Polymerization Front Propagation Theory .... PhysCE10(5) 643
Polymers .... JFFLAO5(1) 16
Polymorphic Transition .... PhysCE10(6) 801
Polyurethane Foam .... JFFFRC1(4) 175
Polyurethane Foams JFFCT1(4) 259
Polyurethane Insulation .... FirEng127(3) 44
Polyvinylchloride .. JFFFRC1(2) 78
Population Inversion .... ComFla22(2) 237, PhysCE10(4) 608
Population Inversions .... PhysCE10(4) 473
Porous Bodies .... PhysCE10(5) 782
Porous Condensed Systems .... PhysCE10(6) 811
Porous Cylindrical Solids .... PhysCE10(4) 568
Potassium .... ComFla2(2) 191
Potassium Chlorate .... ComFla23(3) 357, ComFla23(3) 363
Powder Mixtures ... PhysCE10(1) 4
Powdered Materials .... PhysCE10(5) 746
Power .... PhysCE10(1) 116
Power Cross .... FirJrn68(2) 7
Power Stations .... FirInt4(46) 18
Pre-Fire Planning .... FirChf18(1) 34, FirEng127(4) 54
Precombustion .... FirTec10(2) 129
Prefabricated Fireplaces .... LabDat5(2) 10
Premixed Jets .... PhysCE10(2) 220
Preplanning .... FEngJ34(94) 24
Pressure Dependence .... PhysCE10(4) 548
Pressure Measurement .... PhysCE10(2) 265
Pressure Vessels .. NSNews109(6) 80
Probe Current .... PhysCE10(5) 779
Probe Measurements .... PhysCE10(5) 705
Process Plant Design .... FirInt4(45) 69
Product Composition .... PhysCE10(2) 201
Professional Engineering .... LabDat5(3) 6
Professional Qualifications Board .... FirCom41(2) 26
Propane .... ComFla23(3) 295
Propane Cloud .... FirCom41(2) 18
Propane Oxidation .... PhysCE10(6) 841
Propane-Oxygen Flame .... ComSciT9(3-4) 129
Propane Tank Blast .... FirEng127(7) 35
Propellant .... PhysCE10(1) 38, ... PhysCE10(5) 764
Propellant Burning Laws .... PhysCE10(2) 197
Propellant Erosion .... PhysCE10(3) 341
Propellants .... ComFla22(1) 59, .. PhysCE10(3) 338, PhysCE10(6) 811
Propylene Oxide . FPRev37(401) 130
Protective Clothing Feature .... FPRev37(408) 425
Psychology .... FirCom41(4) 36
Public Image .... FirCom41(11) 26
Public Safety .... FirChf18(3) 28, ... FirChf18(4) 46, FirChf18(5) 45
Pump Operators ... FirEng127(5) 44
Pump Operators Course .... FirEng127(10) 18
Pump - Remote Controlled .... FirEng127(11) 52
Pumper also see Articulated Pumper; .... Mini-Maxi Pumper; .... Radio-Controller Pumper, ... FirCom41(7) 26
Pupils .... FirEng127(9) 18
PYRO Propellant . ComFla22(2) 273
Pyrolysis .... ComSciT9(1-2) 31, ... JFFLAO5(2) 116

Pyrolysis Experiments .... JFFLAO5(1) 76
Pyrotechnic Compositions .... ComFla23(3) 357, ComFla23(3) 363
Qualifications Board .... FirEng127(3) 54
Quartz .... PhysCE10(3) 426
Quartz Glass ..... PhysCE10(4) 578
Quasistationary Approximation .... PhysCE10(4) 534
Quasistationary Concentration ......
Method .... PhysCE10(1) 94, ... PhysCE10(3) 376
Quench Distances . ComFla22(1) 131
Quenched Premixed Flames .... ComFla22(3) 415

Radiant Heat Pulse .... PhysCE10(5) 764
Radiant Heating .. ComSciT9(1-2) 41
Radiant Panel Test . JFFCPF1(4) 305
Radiated Heat .... PhysCE10(5) 717
Radiation Incident .... FPRev37(400) 88
Radiative Heat Transfer .... ComSciT9(5-6) 273
Radio .... FirCom41(7) 31
Radio Control .... FirEng127(11) 52
Radio-Controlled Pumper .... FirCom41(4) 50
Radio System .... FirEng127(10) 46
Radio Teleprinter .. FirEng127(4) 68
Radioactive Materials .... FirChf18(7) 16, FirChf18(8) 53
Rail Yard .... FirChf18(6) 32
Rate Constant Determinations .... ComFla23(1) 109
Rate Constants ... ComSciT9(3-4) 79
Rate Data .... ComFla23(2) 215
RDX - Thermal Decomposition .... ComFla22(1) 13, ComFla22(1) 19
RDX-Wax .... ComFla22(1) 119
Reactant Relationships .... PhysCE10(2) 201
Reacting Gas Mixture .... PhysCE10(1) (74)
Reaction Kinetics .. ComFla22(1) 23
Reaction Mechanism .... JFFLAO5(3) 190
Reactive Gas ..... PhysCE10(6) 936
Recirculated Products .... ComFla22(2) 281
Recirculation Region .... ComFla23(1) 57
Recombination Rate Constants .... PhysCE10(2) 291
Records Center Fire .... FirJrn68(3) 5, FirJrn68(4) 65
Recruiting .... FEngJ34(95) 20
Recruits Training ... FEngJ34(95) 20
Reducer Inhibition .... PhysCE10(2) 206
Refractive Indices .... ComSciT9(3-4) 159
Refractory Synthesis .... PhysCE10(3) 445
Refuse-Handling ..... FirJrn68(2) 82
Regulations .... FirInt4(46) 61
Relaxation Wave Velocity .... PhysCE10(2) 274
Release Rate Apparatus .... JFFCT1(2) 95
Release Rate Data ... FirTec10(3) 181
Remote Ignition of Explosives .... PhysCE10(1) 142
Repair Garages ...... FirJrn68(5) 18
Rescue Devices .. FPRev37(402) 162
Rescue Tenders .. FPRev37(404) 267
Rescue Work ...... FirEng127(4) 55
Residential Fire Safety .... FirJrn68(2) 18
Residential Fires ..... FirJrn68(3) 56
Residential Occupancies .... FirJrn68(1) 71
Response Time ...... FirChf18(2) 34
Rest Home Fire ...... FirJrn68(5) 22
Retirement Community .... FirChf18(12) 33
Revenue Sharing ..... FirChf18(8) 64
Reynolds Numbers PhysCE10(5) 784
Rhenium .... ComFla22(2) 191
Road Tanker .... FEngJ34(94) 47

Rocket Combustion .... ComFla22(2) 171
Rocket Motors ... ComSciT9(3-4) 95
Rocket Propellant Combustion .... ComSciT9(3-4) 149
Roof Tank Fires ..... FirJrn68(4) 93
Roof Trusses .... LabDat5(3) 4
ROTC Cadets .... FirChf18(9) 32
Round Tubes ..... PhysCE10(6) 939
Rung Testing Device .... FirChf18(10) 36

Safe Flame .... LabDat5(2) 10
Safe Streets Act ...... FirChf18(6) 37
Safety .... LabDat5(1) 14, ... LabDat5(4) 17
Safety Bill ...... FPRev37(401) 145
Safety Cans .... LabDat5(2) 20
Safety First .... FirCom41(4) 52
Safety Symbols . NSNews109(6) 104, ... NSNews109(6) 106
Salvage Operations .. FEngJ34(93) 22
Sampling .... ComFla23(1) 109
Sampling Probes ... ComFla23(1) 73
Sao Paulo Brazil .... FirEng127(7) 18, FirInt4(44) 24
Saw Blades .... FirCom41(4) 60
Saw Mill Fire .... FirChf18(3) 32
Scale Effects ..... PhysCE10(4) 603
Schlieren System .... JFFLAO5(1) 4
School Activities .... FirEng127(9) 18
School Fire .... FirJrn68(6) 50
Schools .... FirTec10(3) 221
SCORE .... FirChf18(6) 30
Sea Rescue .... FirChf18(3) 34
Search Areas ...... FirEng127(11) 68
Seattle Fire Department .... FirEng127(7) 28
Self-Contained Breathing Apparatus . ... FirCom41(4) 40
Self-Heating ..... ComFla23(3) 319, ... JFFLAO5(4) 321
Self-Heating Slab .. ComFla23(1) 17
Self-Locking Doors .... FirEng127(11) 68
Self-Propagating Eaves .... PhysCE10(3) 445
Self-Reversed Contours .... ComFla23(3) 305
Semiconfined Volume .... PhysCE10(1) 38, PhysCE10(2) 178, .. PhysCE10(3) 354, PhysCE10(6) 818
Service Station Explosion .... FirJrn68(4) 10
Shallow Explosives .... PhysCE10(3) 440
Ship Fire .... FirInt4(44) 91
Ship Fire Unit ...... FPRev(399) 61
Shock Compression .... PhysCE10(4) 568
Shock Loaded Bismuth .... PhysCE10(5) 752
Shock Loading ... PhysCE10(6) 904
Shock Wave ..... ComSciT9(5-6) 233
Shock Wave Decay PhysCE10(5) 732
Shock Wave Effects .... PhysCE10(3) 426
Shock Waves ...... ComFla22(1) 53, . ComFla23(2) 233, PhysCE10(3) 392, . PhysCE10(3) 421, PhysCE10(4) 561, . PhysCE10(4) 578, PhysCE10(4) 594, . PhysCE10(5) 629, PhysCE10(5) 746, . PhysCE10(6) 891, PhysCE10(6) 919, .. PhysCE10(6) 931, PhysCE10(6) 939
Shocked Gases ... ComFla22(3) 407
Shopping Complexes .... FPRev37(400) 78
Signs .... NSNews109(6) 102
Silicon Dioxide ... PhysCE10(3) 426, ... PhysCE10(4) 578
Simulation Methods .... ComFla23(3) 373
Single-Component System .... PhysCE10(4) 459
Single-Family Residences .... FirJrn68(5) 42
SLRP Analysis ...... FirJrn68(5) 51
Small-Scale Furnace ... LabDat5(1) 5
Smoke .... FirJrn68(1) 9, ... JFFCT1(3) 177
Smoke Barriers ... FirEng127(12) 36

Smoke Control ...... FirInt4(44) 49, ... FirTec10(1) 35
Smoke Damage .... FirEng127(6) 52
Smoke Density Chamber .... FirTec10(3) 187, JFFLAO5(2) 151
Smoke Detection .... FirJrn68(6) 69
Smoke Detectors ..... FirJrn68(6) 79
Smoke Development FirTec10(3)187
Smoke Evolution . JFFLAO5(2) 125
Smoke Extraction Systems .... FirInt4(46) 85
Smoke-Producing Characteristics ... . JFFLAO5(1) 64
Smoke Retardant . JFFFRC1(3) 152
Smoke Shutter ...... FirInt4(46) 73
Smoke Suppressant JFFFRC1(2) 78
Smoke Test Methods .... FirTec10(4) 282
Smokeproof Towers .. FirJrn68(2) 46
Smouldering Plastics .... JFFCT1(4) 250
Sodium Chloride .. PhysCE10(2) 274
Soil Cavities ..... PhysCE10(6) 907
Solid Particles ..... PhysCE10(1) 56
Solid Particles in Flames .... ComFla23(1)
Solid Propellant .... ComFla23(3) 381, ... ComSciT9(5-6) 195, ... PhysCE10(4) 554
Solid Propellant Burning .... PhysCE10(6) 818
Solid Propellants .... ComSciT9(1-2) 37, ... ComSciT9(5-6) 183
Solids .... PhysCE10(3) 440
Solvent Factory Fire . ... FPRev37(408) 442
Soot Formation .. PhysCE10(5) 767
Soot Particles .. ComSciT9(3-4) 159, ... PhysCE10(2) 256
Sound .... ComSciT9(3-4) 95
Sound and Flow Interaction in Rocket Motors .... ComSciT9(3-4) 95
Sound-Deadening Board .... FirJrn68(4) 100
South America Burning .... FirJrn68(4) 23
Spandrel Spaces .... FirTec10(2) 110
Spark .... PhysCE10(6) 912
Spark Ignition Kernels .... ComFla22(2) 143, ComFla22(2) 263
Specific Surface .... PhysCE10(1) 41
Spectral Lines .... ComFla23(3) 305
Spectroscopic Study .... PhysCE10(1) 15
Spherical Combustion Propagation Process .... PhysCE10(5) 691
Spin Detonation Core .... PhysCE10(3) 386
Spontaneous Ignition .... ComFla22(1) 35, ComFla22(2) 223, ... ComFla23(3) 347
Spray Booths .... FirJrn68(3) 14
Spray Combustion .... ComSciT9(3-4) 165
Sprinkler Heads . FPRev37(402) 182
Sprinkler Installations .... FEngJ34(94) 40
Sprinklers .... FirJrn68(1) 61, ... FirJrn68(2) 70
Stability Theory .. PhysCE10(6) 818
Stairs .... FirEng127(12) 36
Stairways .... FirJrn68(1) 9
Standard FF 4-2 ... JFFCPF1(3) 240
Standards-Making .. FirCom41(4) 47
Star of Life .... FirEng127(3) 57
Static Systems ..... ComFla22(1) 35
Stationary Combustion .... PhysCE10(4) 608
Steel Tubes ...... PhysCE10(4) 603
Steelwork .... FPSTech(9) 4
Stirred-Flow Reactor .... ComFla23(3) 295
Stirred Reactor ... ComFla22(2) 197, ... ComFla23(3) 319
Stochastic Model . ComFla23(2) 249
Stoves .... FirJrn68(3) 87
Straw Burning .... FPRev37(400) 81
Strong .... PhysCE10(6) 891
Structural Change .... PhysCE10(3) 452

Structural Characteristics .... FirJrn68(1) 22
Structural Fires ..... JFFCT1(4) 191
Students Against Fires .... FirChf18(6) 30
Studying .... PhysCE10(5) 762
Styrene Polymers .. JFFFRC1(1) 26
Subsequent ...... PhysCE10(3) 421
Substances .... PhysCE10(6) 934
Summerland Enquiry .... FPRev37(404) 249
Summerland Fire .... FEngJ34(96) 8
Super-Rate Burning .... ComFla22(3) 289
Supercompressed . PhysCE10(3) 405
Superdome .... FirEng127(4) 66
Supersonic Flow .. PhysCE10(4) 473, .. PhysCE10(5) 723, PhysCE10(6) 936
Supersonic Gas Flows .... PhysCE10(1) 56
Supersonic Reacting Flow .... PhysCE10(4) 492
Supply Hose ...... FirEng127(7) 32
Supply Lines ...... FirEng127(4) 52
Surface Cleanliness .... PhysCE10(2) 284
Surface Effects ... PhysCE10(3) 409
Surface Formation PhysCE10(3) 354
Surface Structure . PhysCE10(3) 345
Surface Temperature Criterion .... ComSciT9(3-4) 171
Surfboards .... FirChf18(3) 34
Suspended .... PhysCE10(1) 88
Swirling Flows ... ComFla23(2) 143
Symbols .... NSNews109(6) 102
Synthetic Foam Compound .... FirInt4(45) 34
Synthetic Polymers .. JFFCT1(3) 141
Systems .... PhysCE10(2) 201

T-Burners .... ComSciT9(3-4) 95
Tactics .... FirCom41(2) 28
Tank Car Explosion .... FirCom41(10) 21
Tank Truck Fire .... FirCom41(4) 70
Tanker .... FirChf18(11) 39
Tanker Trailers .. FPRev37(401) 130
Tantalum-Oxygen Interaction .... PhysCE10(2) 245
Tavern Fire .... FirJrn68(5) 38
Teletypewriter ..... FirEng127(2) 42
Temperature Curves .... FirTec10(4) 315
Temperature Dependence .... ComFla22(3) 295
Temperature Measurements .... PhysCE10(6) 904
Temperature Profiles .... ComFla23(1) 83
Temperature Sensitivity .... ComSciT9(5-6) 183
Textile Materials ... JFFCPF1(2) 115

Textiles .... also see Fabrics, ... JFFCPF1(3) 225
Thermal Analysis . ComFla23(3) 363
Thermal Decomposition .... ComFla22(1) 13, ComFla22(1) 19, ... JFFCT1(4) 259, PhysCE10(3) 338
Thermal Decomposition Products .... JFFCT1(4) 236
Thermal Degradation .... ComFla22(2) 223, PhysCE10(6) 801
Thermal Diffusion ComFla23(3) 399
Thermal Dissociation .... PhysCE10(4) 459
Thermal Excitation Efficiency .... PhysCE10(4) 473
Thermal Explosion .... PhysCE10(3) 376
Thermal Instability .... ComFla23(3) 329
Thermal Insulation .... JFFLAO5(4) 321
Thermal Oxidative Degradation .... JFFLAO5(4) 243
Thermal Radiation Hazards .... FirTec10(2) 147
Thermal Theory .. PhysCE10(4) 498
Thermal Wave .... PhysCE10(5) 752

Thermochemical Cycle .... PhysCE10(6) 898
Thermochemical Method .... ComFla22(2) 197
Thermodynamic Functions .... PhysCE10(6) 791
Thermophysical Properties .... PhysCE10(2) 289
Thermoplastics .... JFFFRC1(1) 13, ... JFFLAO5(2) 125
Thin Plate .... PhysCE10(3) 401
Thin-Walled Tubes .... PhysCE10(2) 277
Third-Order Reactions of Atomic Lead .... ComFla22(3) 295
Tire Warehouse Fire .... FirJrn68(2) 70
Titanium .... ComFla23(1) 129
Tolylene Diisocyanate .... JFFCT1(4) 259
Tornado .... FirEng127(11) 30
Tornado Rescue Work .... FirEng127(2) 26
Total Flooding ..... FirJrn68(6) 105
Toxicities .... JFFCT1(2) 104
Toxicity .... JFFCT1(4) 236, ... JFFCT1(4) 250
Toxicological Parameters .... JFFCT1(1) 4
Toxicology .... JFFCT1(2) 124, ... JFFCT1(4) 268, JFFRC1(4) 205
Trailer .... FirEng127(6) 26
Training .... FirEng127(11) 38
Training Center .... FirEng127(8) 96
Training Program .. FirEng127(3) 41
Training Reorganization Plan .... FirChf18(7) 21
Transition Metals ... PhysCE10(1) 4
Transitional Processes .... PhysCE10(3) 354
Transportation Accidents .... FirCom41(4) 11
Trauma .... FirCom41(10) 16
Triazine .... ComFla22(1) 13, ... ComFla22(1) 19
Trotil .... PhysCE10(4) 561
Truck-Bays .... FirEng127(3) 45
Tube Wall Motion PhysCE10(5) 737
Tunnel .... FirEng127(10) 24
Tunnel Rescues .... FirEng127(2) 35
Turbulent Characteristics .... PhysCE10(5) 723
Turbulent Field ... PhysCE10(2) 240
Turbulent Flame ... ComFla22(1) 99
Turbulent Flames .... ComSciT9(3-4) 177
Turbulent Flow ... PhysCE10(6) 933
Turbulent Fluctuations .... ComSciT9(1-2) 17
Turbulent Mixing .... ComFla22(2), .. ComFla23(2) 249, ComFla23(3) 283
TV Fire .... FirEng127(6) 52
TV Fires .... FirEng127(9) 33, ... FirEng127(10) 40, FirJrn68(4) 5

UFIRS .... FirCom41(2) 30
UHF Bands ...... FirEng127(8) 164
UL s Follow-Up Service .... LabDat5(1) 8
UL Testing Program ... LabDat5(4) 4
Unconfined Explosions .... PhysCE10(6) 919
United States .... FirJrn68(4) 77
Unsteady Combustion .... ComFla22(2) 259
Urethane Foams ... JFFFRC1(1) 31, ... JFFFRC1(2) 61
USSR-Power Stations .... FirInt4(46) 18

Vapor-Air Mixtures .... PhysCE10(6) 934
Vapor Phase Diffusive Burning Rate . ... PhysCE10(3) 363
Vapors .... LabDat5(3) 9
Vehicle Standards ... FirCom41(1) 20
Velocity Gradient . ComFla22(2) 281
Velocity Measurements .... ComFla23(1) 57
Velocity Profiles ... ComFla23(1) 83
Ventilation Systems .... FEngJ34(95) 56

Vibrational Combustion .... PhysCE10(5) 772
Visibility of Fire .... FirCom41(5) 22
Volunteer Administrative Officers ... . FirChf18(10) 31
Volunteer Fire Company .... FirChf18(9) 20
Volunteer Fire Department .... FirChf18(6) 35, FirChf18(12) 33, ... FirCom41(4) 50
Wake - Electron Concentration variations .... PhysCE10(1) 137
Wall-Ceiling .... FirJrn68(5) 51
Warehouse Fire .... FirEng127(1) 45, ... FirEng127(3) 44, FirEng127(6) 20
Warning Systems ..... LabDat5(2) 6
Water .... FirChf18(11) 24, ... FirEng127(9) 38
Water - Floor Load .... FirEng127(9) 38
Water Supplies ... FirEng127(10) 30
Weak Discontinuity Propagation Velocity .... PhysCE10(6) 933
Wedge .... PhysCE10(6) 936
Wheat .... FirEng127(8) 170
Wildfire Fighting .... FirEng127(9) 42
Wildfires .... FirEng127(8) 178
Women .... FEngJ34(93) 15, ... FirChf18(9) 20, FirEng127(10) 50
Women Firefighters .... FirEng127(4) 59
Women Volunteers . FirEng127(4) 59

Wood Charring Rate JFFFRC1(2)96
Wood Fires ...... ComSciT9(1-2) 13
Wood Stoves Hazards .... FirJrn68(3) 87
Woods - Thermal Degradation .... JFFLAO5(4) 243

FIRE TECHNOLOGY EDUCATION IN SWEDEN

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INTRODUCTION

Sweden covers 0.3% of world land area and is approximately the same size as California or twice the size of the United Kingdom. She is the fourth largest country in Europe after Russia, France, and Spain, and is about the same latitude as Alaska. Malmo, in the south, is on a level with Glasgow. Stockholm is beyond the northern tip of Scotland, while Kiruna, in the north, is above the Arctic Circle. Sweden enjoys a temperate climate, thanks to the Gulf Stream.

There are two forest districts in the country. Forests cover most of the northern part of Sweden. There is also a smaller forest area in the southern part.

In 1969 the total population in the country was 8,013,700. Some 50% of the population live in four areas in the southern part of the country. Very few people live in the northern regions.

Sweden is a constitutional monarchy with a parliamentary government system. Political power is concentrated in the Cabinet and the Parliament and the role of the monarch is mainly representative and symbolic. There are five political parties which are active both in national and local politics. The differences of opinion on practical policy between these parties, the Communists excepted, are not particularly great.

The public sector of the Swedish economy accounted for about 30% of the Gross National Product in 1969. The central and local governments accounted for more than 50% of gross domestic investments and for 25% of total consumption.

DEFENSE

Sweden has not been at war since 1814. The cornerstone of Swedish foreign policy, supported by all political parties, is that Sweden should not belong to any military alliance. Sweden's firm resolve to maintain this policy is backed by a strong military organization. In 1970 the total budget expenditure on defense was U.S.$1,247,000,000. Swedish defense is based on a system of compulsory military service for men between the ages of 18 and 47. Sweden has an advanced

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domestic weapons industry. Supersonic jet fighters, tanks, naval ships, and electronic supplies, including computers, are manufactured in the country.

CIVIL DEFENSE

The aim of Swedish civil defense is to protect and save lives. This activity is headed by the Civil Defense Board. In order to protect the population from heavy losses from air attacks, preparations have been made to evacuate four million civilians from urban areas. For people who have to remain in such areas, shelters have been built to protect three and one half millions. To permit the local civil defense forces to operate effectively after an air attack, their staff has been trained in fire fighting, clearance work, and medical care. Specially trained and equipped mobile rescue forces are available to reinforce the local civil defense when necessary. About 300,000 men and women are engaged in civil defense work. There is a main Civil Defense College located some 30 miles from Stockholm and training centers throughout the country.

SOCIAL WELFARE

Total welfare expenditure in Sweden amounts to about 17% of the Net National Income. Internationally this is rather high, but by no means an exceptionally high percentage. The large expenditure for social welfare purposes is not only due to high social aims, but also to the large proportion of older people who require increased expenditure, particularly for pensions and health.

INDUSTRY

Sweden's industry has for centuries been based on the abundant indigenous resources of timber and iron ore. No significant deposits of coal and oil have ever been discovered and hydroelectric power is the main domestic source of energy.

The most important sector of Swedish industry is engineering. Swedish industry is to be found scattered practically throughout the country, with the exception of the inland areas of Norrland. The forest industry is mainly located in the coastal areas of Norrland. Steel and metal industries are to be found both along the coasts and inland. The engineering industry is found in Central and Southern Sweden, while the chemical industry is based mainly in the southern part of the country and the armaments industry in the southern part of Central Sweden and in the west. The motor industry is found both on the west coast and in the Stockholm region.

LOCAL ADMINISTRATION

The central administrative boards are concentrated almost entirely in the capital city, Stockholm. Government agencies, however, are to be found throughout the country. Sweden is divided into 24 counties, each with its own government. Each county is divided into a number of municipalities which, by 1974, will have been reduced to about 280. They are governed by elected councils.

FIRE DAMAGE AND THE NATIONAL ECONOMY

In Sweden 125-150 people lose their lives every year as a result of fires and the number is constantly increasing. The insurance companies pay out around U.S.$50,000,000 each year in claims for damage directly caused by fire. Somewhere in the region of 4,000 dwellings are either completely or partly destroyed every year. The community is also hard hit by the costs incurred by fire damage for which no compensation is forthcoming, either because the property in question was under-insured or because it was not insured at all. State-owned buildings are as a rule not insured and, therefore, do not appear in statistics on fire damage. In addition to the direct costs, there are also indirect losses due to total breakdown of operations or temporary interruptions, loss of work, and so on. Moreover, the transport sector is more and more frequently suffering fires which cause serious loss of human lives, equipment, and goods. The accumulated costs of fire damage is estimated to be something approaching U.S.$100,000,000 per annum.

The costs of measures for fire control in buildings has been assessed as representing some 2% of building investments or around U.S.$40,000,000 per annum. The fire service, financed both by the State and by the local authorities, costs almost U.S.$60,000,000. In addition to this there is the amount invested by trade and industry in industrial fire control, permanent fire extinguishing equipment, etc. If we add to this the fire insurance companies' administrational costs, the sum incurred by fire damage, fire insurance, prevention, and extinguishing of fires has risen to around U.S.$300,000,000.

TECHNICAL PROGRESS AND FIRE CONTROL

Changeover to automated methods and assembly-line manufacture is a feature of development in industry. Rationalizations result in fewer, but larger and more vulnerable buildings; i.e., large warehouses, data processing centers, manufacturing plants, etc. Major damages are responsible for the greater part of the costs incurred by fire damage in Sweden, as indeed is also the case in other industrialized countries. One percent of all the fires in Sweden is responsible for more than half the total cost of damages. From the international standpoint, the risk of loss in percentages of the market must be accorded an economic significance which is not apparent in present statistics.

In the transport sector a transition to larger units is taking place; larger vehicles, terminals, etc. Also the speeds of different forms of transport are gradually increasing. Larger and increasingly complex vessels are being introduced in shipping. Indeed, the technical developments in the field of transport and distribution call for greater attention from the aspect of fire control.

Development trends in the building field involve a transition to the use of less reliable structures from the point of view of fire engineering coupled with the advent of denser building development. Large, wide-spanned buildings without partition walls, multi-basement story buildings and denser developments of small timber houses are examples of building design which creates a need for qualified fire engineering research. Statically indeterminate construction in buildings of conventional type and new, advanced designs in the form of shell and suspended roofs are other examples. New, compound problems such as fire damage—toxic effect—corrosive effect come to the fore as new materials are adopted for use.

FIRE RESEARCH

Fire Research has been somewhat neglected in Sweden. Efforts in this field have been sporadic and the coverage poor. Important contributions have, however, been made in fire research in connection with building technology, and here Sweden has played a part which has attracted attention internationally. The resources available for fire engineering tests of large building units such as walls and floor slabs are, however, perhaps poorer in Sweden than in any developed country. The Research Institute of National Defense is in the process of building up a large fire research department and a new body, the Swedish Fire Research and Development Council, is now to be established in order to achieve better coordination of work in fire research.

FOREST FIRE CONTROL AND THE FOREST FIRE-SPOTTING SERVICE

In view of the fact that 55% of Sweden's land area is covered with forest, forest fires should be a major problem. This is not the case. The annual loss due to forest fires amounts to less than U.S.$400,000. The main reason for this is an extensive fire control organization of long standing with the local fire brigades as a basis and a thorough forest fire-spotting service which is now operated with the assistance of the flying clubs in the forested counties.

ORGANIZATION OF FIRE SERVICES

The legislation concerned with fire means that the responsibility for extinguishing fires and for a major part of the preventive aspects of the fire service rests with the local authorities. The law also accords the owner or the user of a building a certain measure of responsibility for the prevention of fire. Building legislation is uniform throughout the country and controls the requirements regarding the fire-retardant aspects of buildings. The local building committee is the body responsible for decisions regarding fire-control measures in building construction, always, however, in consultation with the head of the fire brigade. Surveys of fire damage and any special inspections are carried out by the officers of the fire brigade under the provisions of the fire legislation.

At the local level the fire authority is responsible for the fire service. The fire chief is answerable to this authority, but also has, according to the law, considerable authority to act independently. Most municipalities have a fire brigade. If, however, a fire brigade is lacking, the local authority in question will have assured itself of satisfactory facilities for fire extinguishment by means of agreements. The fire brigades have both full-time and part-time staff. As a rule, a brigade will have a small, full-time force on duty which is assisted by a part-time emergency force when the need arises.

Each County Government Board has a Fire Marshal in its employ for the purpose of ensuring that the municipalities in the county have satisfactory fire fighting organizations. It is probable that this arrangement will soon be replaced by another system. The Government in Stockholm has an official organ, the Inspector General of Fire Services, who acts as consultant to the Government and to the local fire services. This organ has been of great importance to the Swedish fire service. It is, however, primarily an administrative body and its contribution in the form of development work is nowadays relatively modest.

Parallel to the trend in trade and industry and in the building field described above, local authorities are showing greater interest in rationalization in the municipal fire service. Personnel costs are rising steadily as a result of the general increase in prosperity and efforts are, therefore, being made to limit staff and to compensate for this by an increase in the technical resources. As municipal units merge, the number of fire brigades becomes less and at the same time the size of the individual fire brigades decreases. On the other hand, the greater size of the areas to be covered, together with their more and more differentiated business life and a rising number of objects with a large fire risk potential, increase the need for an effective municipal system of fire control.

The local authorities' own federation, the Swedish Union of Local Authorities, started a special fire service section some years ago, but this has been mainly occupied with rationalization projects which have often led to substantial reductions in the staff of fire brigades. This has produced a controversial situation where we have, on the one hand, the above agency and, on the other, the Inspector General of Fire Services, and, above all, the officers of the local fire brigades. It is true that some of the criticism directed towards the Union's fire service section may have been misguided, but there is no doubt that the staff of this agency have in a considerable number of cases not succeeded in achieving a satisfactory balance between economy and safety in the field of fire control. This situation is one of the most serious problems faced by the Swedish Fire Service today.

As most of the responsibility for fire fighting service plus a major part of measures for fire prevention rests with the local authorities, the costs involved are being covered by the local taxes. The larger municipal units which will be in existence after 1974 will provide a better basis for municipal fire services than the considerably smaller municipalities found today. However, the author of this paper considers an organization like the county fire brigades in Britain, the Tokyo Metropolitan Fire Board, and the County of Los Angeles Fire Department superior to a municipally based organization.

The Swedish fire brigades also play an important part in general rescue work. This aspect of their activities may be described as voluntary as there is at the moment no law governing the rescue service apart from certain special types of accidents such as atomic disasters, sea rescues, etc. A proposal was, however, put forward by a Royal Commission in April 1971 to the effect that the fire brigades should be made responsible by law for the greater part of the rescue work in cases of accident. This extension of the Fire Service's sphere of responsibility will be accompanied by an increase in the resources available to the Inspector General of Fire Services and it has been suggested that the National Fire Technical College should also operate training schemes in rescue techniques. This latter proposal is mainly interesting since it will mean that the College will also be responsible for basic practical training.

FIRE-FIGHTING FORCES AND FIRE STATIONS

The Swedish fire brigades are small if compared with some to be found abroad. The same applies with regard to the initial size of the forces sent to the scene of a fire. The Stockholm Fire Brigade numbers only about 500 men for a city with a population of 740,000 and this includes both technical maintenance staff and ambulance men. An ordinary call to a fire in a private home involves a force of about ten. The Swedish fire brigades do, on the other hand, have fairly good staff resources for fire prevention. Even towns with populations of no more than 10,000 have a professional fire chief, usually one with a station officer diploma. Communities with populations of more then 15,000 have without exception a fire chief with a degree in fire engineering.

The staff of a fire brigade may be either full-time or part-time. Normally, both types are found. Officers, specialists, and duty officers then constitute the full-time staff, while the part-time staff forms the second line force. Training at the national Fire Technical College is required for all categories except ordinary part-time firemen.

The Swedish fire brigades cover larger fire fighting areas than is usually the case in other countries. The number of stations is, therefore, fairly small. Stockholm has, thus, no more than nine fire stations and Uppsala, with a population of 110,000, has only one. Fire stations in Sweden are, however, considerably larger than the normal size of stations in many other countries. A small station will have 6-8 fire engines, while a larger station may have more than 20. The trend, however, is now to have more fire stations of smaller size; the problems encountered with traffic jams contribute to an increase in this tendency. The birth of new suburbs around the towns also leads to a need for more, though smaller, stations.

FIRE FIGHTING EQUIPMENT

Each fire brigade is in principle free to purchase the fire fighting equipment it considers appropriate. The equipment to be found in the fire brigades, therefore, varies widely, although certain main types do occur. Hoses and hose accessories are standardized, while vehicles and personal equipment varies from brigade to brigade. The fire engine chassis are as a rule of Swedish, American, or German manufacture, while the bodywork is, with few exceptions, of Swedish origin. Pumps and all lightweight ladder equipment are Swedish-made, while the turntable ladders may be either German or Swedish. In recent years, standard vehicles of German manufacture have been introduced in Sweden, although in small numbers. Breathing equipment was previously German, but Swedish-made equipment is now predominant. Compressed air apparatus is the main type used. Product development of fire-fighting material in Sweden has largely become possible, thanks to the support received from the Swedish Civil Defense Board.

FIRE SERVICE TRAINING

The Government authorities realized at an early stage the importance of giving fire officers a satisfactory training. The National Fire Technical College was founded in 1941, thus replacing the training programs previously operated by the Swedish Fire Protection Association. The present fire legislation strictly limits the scope for becoming a fire officer without having attended this college in order to maintain a high level of competence. Thus, in practice, nothing can replace the diploma obtained from the National Fire Technical College however long a person's practical service or however qualified his other training may be. Sweden is, thus, one of the very few countries in the world where the competence of fire officers is bound up with a formal course of training in approximately the same way as is the case for doctors and dentists, etc. There is, of course, no doubt that examples of outstanding ability are to be found among persons of long practical experience and natural talent and inclination for self-tuition. We feel, nevertheless, that a sufficiently high average standard can be maintained only by a direct link between competence and formal training. For this reason the Government takes responsibility for the entire theoretical training of the staff of the local fire brigades. The training is free of charge and all, with the exception of the future chief officers, receive a salary and daily expenses during the period they spend at the college.

Four main categories of pupil can be distinguished as regards the nature of the training received; part-time fire officers of various ranks, full-time chief fire officers, other full-time fire officers, and full-time firemen. Chimney sweeps as well as fire fighting staff are also trained at the National Fire Technical College, first by attending an eight-week course and then, after a certain period of practical work, a course lasting a further ten weeks. In this case, also, competence is dependent on this formal training.

It should be noted that all fire officers, with the exception of chief fire officers, are recruited from the ranks of the firemen. Thus, they have an opportunity of promotion. The official qualification in which the training culminates does not, however, limit the holder to a particular fire brigade. When a fireman has completed training for a certain officer's rank, he is qualified to hold that rank in any fire brigade in the country. A certain amount of transfer of fire officers also takes place between the different brigades, although primarily in the case of smaller brigades. The larger brigades recruit as a rule internally. The chief officers, on the other hand, often move from one fire brigade to another. Naturally, such exchange of staff also promotes the exchange of ideas, know-how, and experience. On the other hand, it occasionally gives rise to problems in trying to maintain a state of continuity when changes take place too often.

TRAINING OF PART-TIME FIRE OFFICERS

Although more and more fire brigades in smaller communities will be getting full-time fire chiefs—as a rule, station officers—part-time fire officers will continue to exist in Sweden, at least for the foreseeable future. These may be said to correspond to the volunteer fire chiefs found in other countries. The Swedish part-time fire officers are, however, reimbursed for the hours which they spend on duty.

Training of these officer categories consists of a combined practical and theoretical course lasting two weeks, plus an additional one-week course in fire prevention. The training of fire chiefs and their deputies includes a further eight-week theoretical course. All these courses are preceded by a correspondence course for preparatory purposes.

The eight-week training course for part-time fire chiefs comprises 320 lessons, the main subject studied being theory of fire suppression, fire prevention, and building science.

TRAINING OF PROFESSIONAL CHIEF FIRE OFFICERS

The training system for chief fire officers which has been in use in Sweden since 1941 is, as far as we know, without parallel in any other country. Swedish legislation invests the fire officers, and in particular the fire chiefs, with very considerable powers. As a result of this and also, in view of the highly qualified tasks which the chief officers are called upon to carry out, this officer category must undergo a highly qualified course of training. It has not been possible to recruit future chief fire officers from the ranks of the firemen since the basic knowledge of the latter is not sufficient for a highly qualified technical course of training. This does not mean that practical experience is not highly valued. Nevertheless, it cannot replace training at university level. It is, of course, also true of the reverse and the training system in use in Sweden represents a compromise in which practical training has been partly forced to give way to theory. Experience increases as time goes on and the excellent basic knowledge provides the best conceivable scope for development for the individual person. The training system for chief fire officers, culminating in a formal examination, is thus the only means of obtaining appointments as fire chiefs, deputy fire chiefs, and assistant fire chiefs in Sweden.

Future chief fire officers are recruited from technical colleges after having obtained a diploma in engineering. This diploma corresponds to a little less than a Bachelor's degree in the U.S. After being accepted by the National Fire Technical College, students first undergo four months of practical fireman training. This training takes place with the City of Gothenburg Fire Brigade, but completely in accordance with the training program of the college. The training is kept under supervision by the college and any student who proves unsuitable is withdrawn from the course. During these four months the students also take part in the extinguishing of a very large number of fires.

After the basic fireman training, the theoretical instruction begins at the National Fire Technical College in Solna just outside Stockholm. This comprises a total of some 2,200 lessons, lectures, and laboratory tests spread over a period of three terms.

Subjects devoted the most attention are the theory of fire extinguishing with 465 lessons, fire prevention with 315, building science with 250, and personnel management with 150. Other subjects are mathematics, physics, chemistry, electrical engineering, telecommunications, mechanical engineering, motor mechanics, civics, and industrial safety and accident prevention. Special emphasis is laid on various types of municipal activity such as urban planning, formation of real estate, water supply and sewage systems, and construction of roads and streets. Seminars and study visits are also arranged in various subjects, talks by guest speakers, and physical training programs.

Space is too limited here to be able to go into the curricula in detail. To give a few brief examples, however, the study of mathematics includes mathematical statistics and nomography, the theory of fire extinguishing includes the study of the rudiments of fire extinguishing techniques, extinguishing equipment, protective equipment, methods of fire extinguishing, investigation of the causes of fire, fire-fighting in wartime, and the organization of the fire service in time of war. The subject of fire prevention covers the study of the causes of fire complete with statistics, fire prevention in buildings, fire prevention in heating and ventilation systems, fire prevention in public buildings, fire insurance, fire prevention in transport and communications, inflammable and explosive materials, surveying of fire damage and structural details, including scrutiny of plans. Finally, the study of mechanical engineering includes internal combustion engines, steam power and refrigerating techniques, atomic energy, and pumping systems.

The training given at the National Fire Technical College comes under four main headings; general technology, fire technology, administration, and personnel management. The training given in the first two fields is of high quality, but that given in administration is not so advanced. The situation with regard to personnel management is regrettable. In comparison with many other countries this training is below standard and it is probable that a commission will be appointed in the near future to undertake the task of suggesting improvements.

The instruction is organized as follows:

The course begins with the study of basic subjects such as mathematics, physics, chemistry, etc., plus the basic principles of applied fire engineering subjects, primarily the theory of fire suppression. At a later stage the study of the applied technical subjects begins, plus the more qualified fire engineering subjects such as fire prevention. The training concludes with a concentrated course with individual instruction in personnel management and leadership. Immediately prior to the examination the students are required to submit a group thesis. Written tests take place after completing the study of each major block of subjects, and only after passing all tests can a student obtain his degree. He is thereafter formally qualified to hold all types of higher posts in the local fire brigades. Naturally, he usually has to begin with a post as deputy chief of a smaller brigade or as assistant fire chief—third rank in a large brigade. Some students obtain posts with insurance companies, the Swedish Fire Protection Association, Government authorities, or private industry on graduation.

The Swedish system has both advantages and disadvantages when compared with systems in other countries. One of the disadvantages is without doubt the fact that our chief officer students do not from the very beginning have the years of practice required for the lower ranks of fire officers in Sweden and for all fire officers in most other countries. Furthermore, our college exercises control only over the actual training. The other two, equally important, components which together with the training course determine the ability of the individual student—that is, experience and talent for the work—are largely outside the college's range of influence. On the other hand, our chief officer students receive a general and applied training in fire engineering on a high level with stiff requirements and strict control over results. On leaving the National Fire Technical College the students thus have a high efficiency potential for their future work. The advantages of the system also include the fact that the Government by providing centralized training guarantees the competence of the fire chiefs as far as this quality is dependent upon the actual training.

THE NATIONAL FIRE TECHNICAL COLLEGE—RESOURCES AND CAPACITY

The college has its main training activity based in Solna, but also operates regional courses in the provinces. One to two station officer courses, two to three sub-officer courses, and five to seven fireman courses are held in Solna each year and a two-year chief officer training course is commenced every other year. In addition, one to two courses for part-time chief officers are held each year. The above courses each have places for 30 students, with the exception of the chief officer course which takes 20 to 24. A large number of special courses are also arranged in conjunction with other institutions. Courses in protection against radioactive fall-out are thus arranged in collaboration with the Swedish Nuclear Research Station and courses in fire-fighting on board ship in collaboration with the Navy.

The regional courses train an annual total of 500 to 600 part-time fire officers and approximately the same number are trained for fighting forest fires. This gives a grand total of between 1,500 and 1,800 students per year. However, only 500 to 600 of these receive their training in Solna. Most other training takes place with the larger fire brigades in accordance with the College training program. All training is financed by the Government.

The staff of the National Fire Technical College based in Solna is small. A director, two full-time teachers and about 100 visiting lecturers are responsible for all the instruction given there. The regional training program, on the other hand, employs around 200 visiting teachers and instructors. The college in Solna, however, houses the administrative premises, classrooms, laboratories, special premises for motor engineering, fire-fighting equipment, telecommunications, building science, dayrooms for teachers and students, etc. Here also is the internationally famous hall for tactical practice. It contains extensive audiovisual equipment which also permits the simulation of the effects of fire and smoke.

VOLUNTARY EFFORTS IN THE FIELD OF FIRE CONTROL

The old volunteer spirit from the time when fire control was a national movement in miniature has largely disappeared. An organized public service has arrived to take its place. A considerable contribution is, however, still made by organizations not financed through public funds. A substantial, and in some respects increasing, need for such assistance does, in fact, exist. The Swedish Fire Protection Association does very important work, mainly in the fields of mass instruction, propaganda, and technical service.

PROBE MEASUREMENTS IN LAMINAR COMBUSTION SYSTEMS#

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INTRODUCTION

One of the most fruitful methods of studying combustion processes has been the use of measuring probes. In this discussion we will consider the applications, problems, and limitations of such studies. The introduction of any probe, even an optical probe* always produces some disturbance and it is a quantitative question whether the required information is compromised beyond the point of usefulness.

The variables which are required to characterize a combustion system are velocity, temperature, and composition as a function of position and time. If the system is steady state and possesses some symmetry, e.g., bunsen flames or flat flames, the required number of variables can be greatly reduced. For example, one dimensional premixed or diffusion flames can be realized in the laboratory with this geometry and known initial flows, the system can be completely determined by measuring s variables where s is the number of species. This assumes conservation of mass and an equation of state. In principle the requirement could be reduced to s-n by applying conservation constraints to each atomic species individually, where n is the number of atomic species involved in the incoming molecules. This is not usually done because diffusion is so important in combustion that elaborate calculations are required. Instead the conservation laws can be used to check the quality of the data (Ref. 1, p. 88). Because this is an over-determined system, it is often possible to derive a variable which is difficult to measure directly from the other variables. For example, if absolute composition is known, local density can be calculated. Temperature can be calculated from density and the molecular weight using the equation of state. Velocity can be calculated from the inlet mass flow and local density. Similarly, missing concentrations can be deduced. (See Table 1.)

#Presented by Project SQUID Workshop on Combustion Measurements in Jet Propulsion Systems, Purdue University, May 1975.

*Optical beams of sufficient intensity can induce reaction, inhibit reaction, liberate heat and even levitate particles.

TABLE 1

Each line of the table gives the symbol for the variables which must be measured directly by some technique. The others are then obtained by calculation.

Flame system	Independent variable	Dependent variable: Distance z	Time t	Velocity v	Area ratio A	Density ρ	Temp. T	Concentration X_i, N_i
Flat [10]	z		Calc.	Calc.	A	Calc.	T	X_i; $i = 1, 2, \ldots, s - 1$
Flat	z		Calc.	v	Calc.	Calc.	T	X_i; $i = 1, 2, \ldots, s - 1$
Flat	z		Calc.	Calc.	A	Calc.	Calc.	N_i; $i = 1, 2, \ldots, s$
Spherical [11]	z		Calc.	Calc.	Calc.	Calc.	T	X_i; $i = 1, 2, \ldots, s - 1$
Conical [12]	z		Calc.	v	A	Calc.	Calc.	X_i; $i = 1, 2, \ldots, s - 1$
Expanding flame kernels	t	Calc.		Calc.	Calc.	Calc.	T	X_i; $i = 1, 2, \ldots, s - 1$
Theory	T	$\frac{dT}{dz}$ dz	Calc.	Calc.	Const.	Calc.		X_i; $i = 1, 2, \ldots, s - 1$

From R. M. Fristrom and A. A. Westenberg, *Flame Structure* p. 24 McGraw-Hill (1965).
Used with permission of McGraw-Hill Book Company.

In more complex geometry such as an axially symmetric diffusion flame, a two dimensional manifold of variables must be measured and, in the general case, a three dimensional manifold. If it is desired to derive rate of reaction or heat release information from the data, it is necessary to know not only the local intensive variables temperature, velocity, and composition, but also their first and second derivatives and the appropriate diffusion coefficients, thermal conductivities and coefficients of thermal diffusion. Determining rate of species production and heat release is difficult in most laboratory systems and virtually impossible in most practical systems. Therefore, the experimentalist must usually settle for more modest goals than complete analysis. Much useful information can be obtained from such measurements and we will now discuss some techniques which can be used for such measurements.

VELOCITY PROBES

Local velocity must be known to derive rate processes. Several probing techniques have been used: Pitot probes, particle visualization, etc.[1,2,3]

Pitot Tube

The pitot tube method of measuring velocity is standard in aerodynamics.[4] The principle is simple: if a tube connected to a pressure-measuring device is directed against a fluid flow, it will register a pressure which is proportional to the square root of the velocity. In flames these pressures are low, but measurable (Figure 1). These measurements are difficult to interpret because the probe must be small compared with the flame front thickness and boundary layer corrections become important. The measured pressure depends not only on velocity, but also on the Reynolds number, which is, in turn, a complex function of temperature and probe diameter.[4]

Flow Visualization with Particles

Another method of studying combustion aerodynamics is flow visualization with suspended microscopic dust particles. This is a standard aerodynamic technique.[1,2,7]

To be suitable for tracer studies a particle must be small, non-volatile, and non-reactive. Particle introduction disturbs a flame, the degree depends on the type, size, and number of particles. Particles can be visualized photographically using a timed, repetitive illumination. From such a picture, velocity can be obtained by direct measurement (Figure 2).

Common sources of error are accelerational lag, thermomechanical effect, and the requirement that the particle be very small compared with the flame thickness.

If a precision of 3% is acceptable, then particle-tracer techniques can be used for quantitative studies.[1]

With the advent of lasers, another particle method called laser doppler velocimetry has been developed. It is based on the principle that the light scattered from particles will be shifted in frequency by the doppler effect. By using a suitable

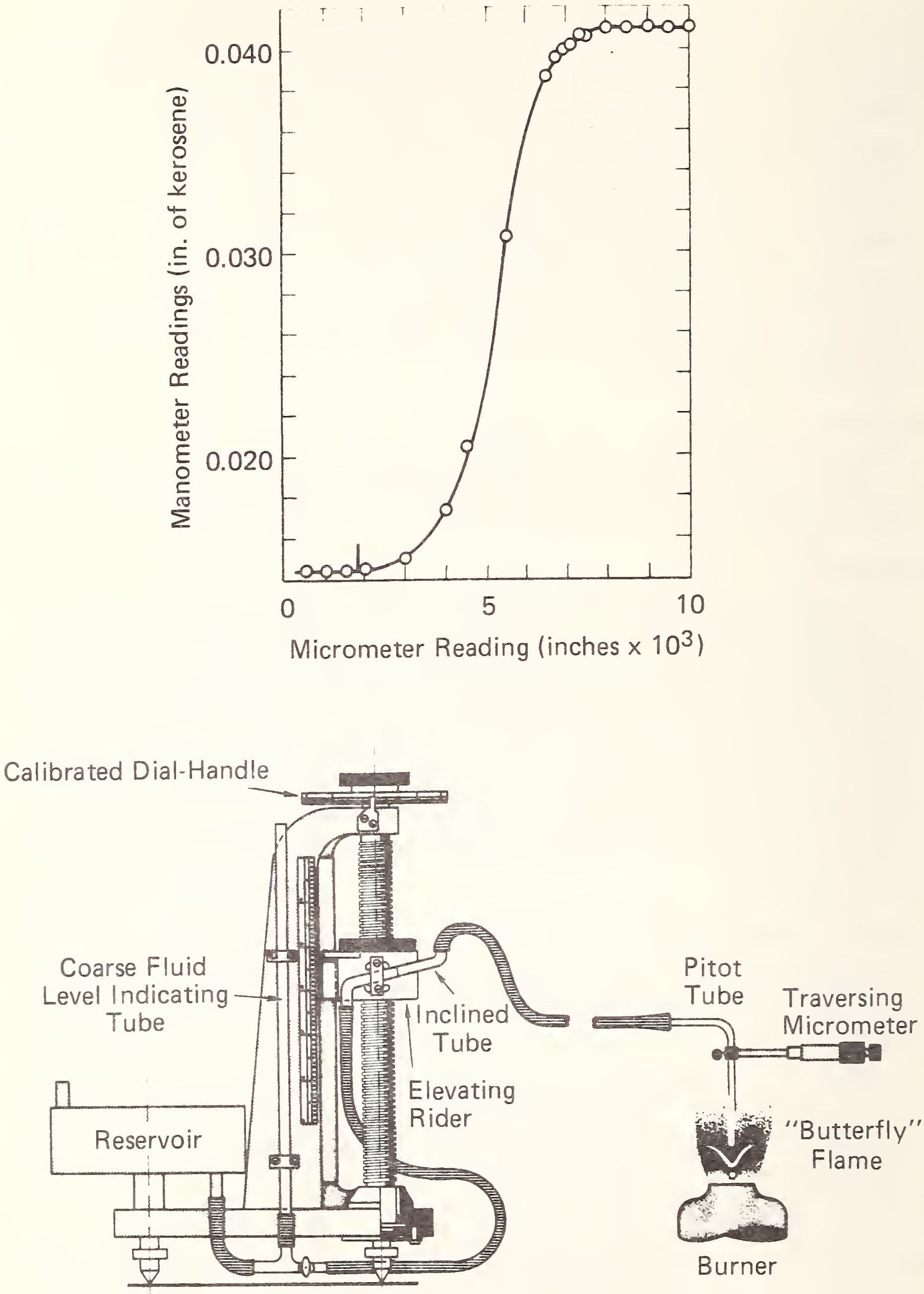


FIGURE 1 Apparatus for Pitot tube measurements in flames with typical profile. (Source derived from: J. C. Quinn, *Harvard University Combustion Aerodynamics Laboratory Report #5,* May 1953)

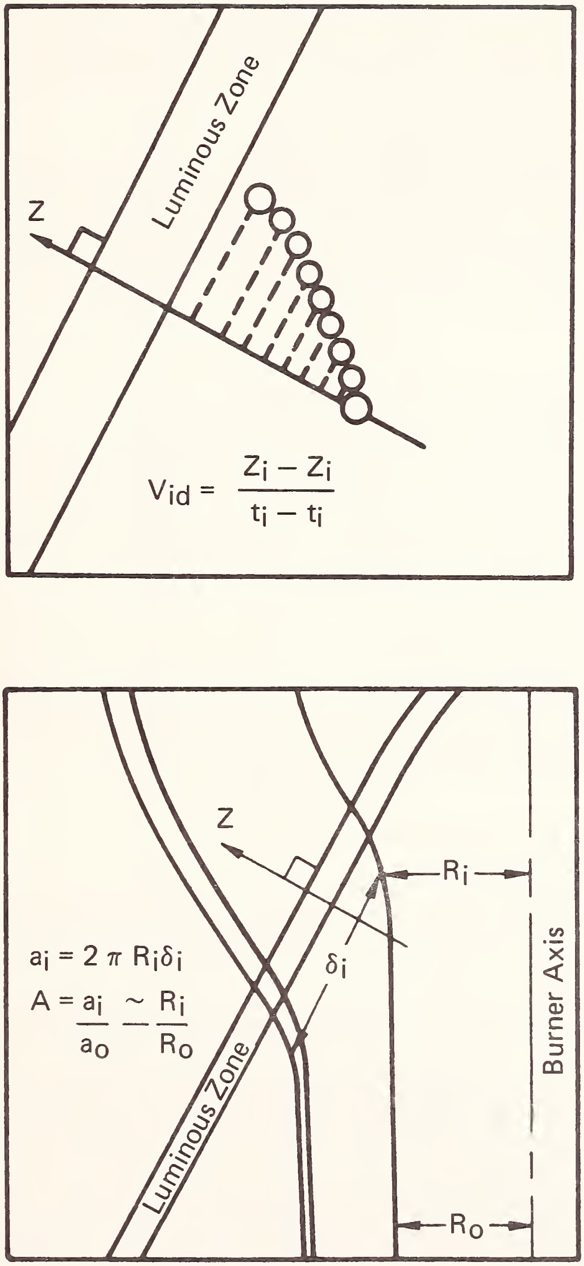


FIGURE 2 Measurement of velocity and area ratio in flames using particle track techniques.[7]

detector and mixer for the scattered and unscattered beam, a beat signal can be obtained which is proportional to the velocity of the particles. This very powerful technique is discussed in another presentation at this symposium.[3]

Other Methods of Measuring Gas Velocity

Many methods of measuring velocity are not applicable to combustion studies, because of the high temperatures or high spatial resolution required. The hot wire methods used to study boundary layers and turbulence can give serious errors because of the temperature gradients. An interesting variant is the pulsed hot wire of Westenberg and Walker[5] which uses the heated wake of a pulsed hot wire as a tracer.

Avoidance of Aerodynamic Measurements

Aerodynamic measurements are among the most difficult and least precise of combustion measurements. Therefore, it is desirable to avoid them or minimize the dependence on aerodynamic parameters. In flames, velocity profiles can be calculated from area ratio measurements and density determinations can be obtained from thermocouple or pneumatic probe traverses.

PROBE THERMOMETRY

Probes provide the most direct method of determining local temperature. Probe diameter should be small compared with the product and be rugged enough to stand the high-temperature corrosive flame environment. Thermocouples have found the widest usage in combustion studies.

Thermocouple Measurements

Thermocouple measurements make use of the thermoelectrical property of metals. This potential is reproducible and is a function of the materials chosen for wires. It is independent of the method of making the junction (wires may be welded, soldered, or simply twisted together) so long as good electrical contact is maintained, and *provided there is no appreciable temperature gradient across the joint.* A large number of thermocouple pairs have been studied[1,6,7] but only a few are suitable for flame use, notably the Pt, Pt-10% Rh and Ir, Ir-40% Rh couples.

The advantages of thermocouple measurements are: (a) they can be made with high precision; (b) they are small (<0.001 cm) and (c) they can withstand high temperature. (See Table 2.)

The principal source of error is radiation loss. Corrections can be made so that temperatures reliable to 10 and 20°K, positioned with a resolution of 50 microns, can be obtained.[1,7,8] This error can be eliminated by using the "null method" in which the thermocouple is heated electrically to balance the radiation loss. Temperature derivatives are primarily limited by the size of the wire used and the disturbances of the vibration and catalysis. Temperature differences as small as 0.1° C can be reliably measured, with positional uncertainty of 10^{-3}cm. Such

TABLE 2

Limits of some high temperature thermocouples

Couple or Material	Upper Temp.	Prob. Error	Max. Output	Comments
	°C	°C	Milli Volts	
W/Ta	3,000	±50	23	Inert or Reducing Atmosphere only
W/W-50Mo	3,000	50	8	
W/W-25Mo	3,200	50	5.4	"
Ta/Mo	2,600	50	19.5	"
W/Mo	2,600	50	8.0	"
W/Re	3,200	50	3.4	"
Ir-20Re/Re-30Ir	2,600	40	11	Air Compatible
Ir/Re-30Ir	2,400	35	15	"
W/Ir	2,400	20	41	Inert or Reducing Atmosphere only
Mo-Ir	2,400	35	33	
W/Pt	2,000	35	30	"
W/Rh-40Ir	2,100	35	27	"
Rh/Rh-8Re	2,000	--	7.4	Air Compatible
Pt-20Rh/Pt-40Rh	1,900	10	5	"
Pt-6Rh/Pt/30Rh	1,850	10	13.5	"
Rh/Pt-8Re	1,850	--	18	"
Pt/Pt-10Rh	1,800	3	19	"
Pt/Rh	1,800	15	30	"
Ir/Ir-40Rh	---	15	--	"

Attributed to: V. Sanders, "Review of High-Temperature Immersion Thermal Sensing Devices for In-Flight Engine Control" *Rev. Sci. Inst. 29* 917 (1958).

measurements are satisfactory for determination of derivatives, since the errors cancel.

Thermocouple thermometry is described in the literature and are discussed in many courses on electrical measurements. The techniques of fabrication of small noble metal couples and coating them with silica are described in the literature.[1,7]

A thermometer immersed in a gas stream will record a temperature differing from the true stream temperature due to kinetic energy transfer by stagnation in high velocity streams, conduction and radiation losses, and vibrational effects. These problems can be classified into two groups: the effects of the probe on the flame, and direct errors.

The central problem is the probe effects on the combustion system. This can be reduced by reducing size. This approach is limited by practical problems of fabrication or the heat transfer difficulties. Disturbances can be classified as aerodynamic, thermal, and chemical, and are discussed in some detail with respect to sampling probes.[1,7] The significant differences between the actions of probe thermometers and sampling probes can be summarized as follows.

The principal chemical disturbance of probes is the promotion of catalytic reactions on the thermometer surface which gives spuriously high temperatures and hysteresis. This is serious with metal surfaces, but it can usually be reduced by coating with non-catalytic materials, such as silica.[1,7,8]

The principal aerodynamic effect is the velocity deficient wake behind the thermometer which to a first approximation can be visualized as a local propagation of the flame front in this region. (See Table 3.)

Errors due to stagnation kinetic energy are negligible for combustion systems where the velocities lie below Mach 0.1. Conduction losses are small in most cases since the support wires can usually be aligned along isothermals.

Radiation is a major source of error. It is proportional to the fourth power of the temperature to the emissivity and inversely proportional to diameter (Eq. 1). These parameters are often not well known. One correction is based on the Nusselt-Reynolds Number correlation for cylinders.

$$\Delta T_{\text{rad}} = \frac{1.25\,\epsilon\sigma T^4}{\lambda} d^{3/4} \frac{\eta^{1/4}}{\rho v} \tag{1}$$

Based on his measurements for quartz-coated wires, Kaskan[8] suggests an ϵ of 0.22.

In this equation ϵ is the emissivity of the wire; σ is the Stephan-Bolzmann constant; λ is the thermal conductivity of the gas; d is the wire diameter; and η is the viscosity of the gas. In these cases the effective constant for a given thermometer can be determined by putting it in a gas stream at a known temperature and measuring the resulting temperature.

Pneumatic Probe Measurements of Temperature

If the pressure drop across an orifice is sufficiently high (pressure ratio >2.5) a sonic surface forms in the throat and flow depends only on the upstream pressure, temperature, molecular weight, and specific heat, with a minor Reynolds number correction for the effects of boundary layer. If two orifices are in series, the ratio of the pressure to the upstream pressure is given by Eq. 2.[1,7,9]

$$T_1 = T_2\,(P_1/P_2)^2\,K\,(\text{Reynolds Number}). \tag{2}$$

This provides a desirable method of temperature measurement since it provides a connection between composition and temperature studies. Calibration is required for quantitative work. It is not always necessary to calibrate at high temperature environment since Reynolds corrections can be evaluated by changing density through molecular weight. This is important since it is difficult to provide calibration temperatures above 1500° K. The orifices must operate in the continuum flow regime and the radical concentrations should not be high since they recombine before entering the second orifice, changing the molecular weight and

TABLE 3

Comparison of methods to determine temperature profiles in flame fronts

Technique	Upper Temp. Limit (°K)	Spatial Resolution (cm)	Precision (K or T/T)	Displacement (cm)	Corrections	Effect in Flames	Cost of Apparatus
Thermocouples	3000	10 dia. (10^{-2})	1	5 dia. (5×10^{-3})	Radiation	Aerodynamic Wake & Catalysis	Moderate, low
Resistance Thermometer	3000	10^{-1}	1	10^{-2}	Radiation	"	Moderate
Aerodynamic Measurements	3500	10^{-3}	3%	slight	Acceleration, lag & thermo-mechanical effects	Quenching	Moderate
Optical Pyrometry	None	5×10^{-1}	5	None	Non-equilibrium Radiation	Additives	Moderate
Spectroscopic Line Intensity	None	5×10^{-1}	5	None	"	None	High
Pneumatic Probe	2500	10 dia. 10^{-2}	2%	5 dia. 5×10^{-3}	Orifice Coefficients	Wake & Catalysis	Low
X-ray Absorption	None	5×10^{-1}	3%	None	Mol. Weight	None	High
Interferometer	None	5×10^{-2}	1%	None	Mol. Weight	None	High
Inclined Slit	None	5×10^{-2}	1%	None	Mol. Weight	None	Low

From R. Fristrom, "Experimental Techniques for the Study of Flame Structure," *Bumblebee Report No. 300, Applied Physics Laboratory*, The Johns Hopkins University, 187 (1963) ratio of specific heats. It is convenient to make the first orifice a quartz probe of the type used in composition sampling studies; the second orifice is not critical.

It is desirable to minimize the volume between the orifices to minimize equilibration time. Pressures can be measured by diaphragm gauges or mercury manometers. McLeod gauges are not satisfactory because flames contain condensible gases (Figure 3).

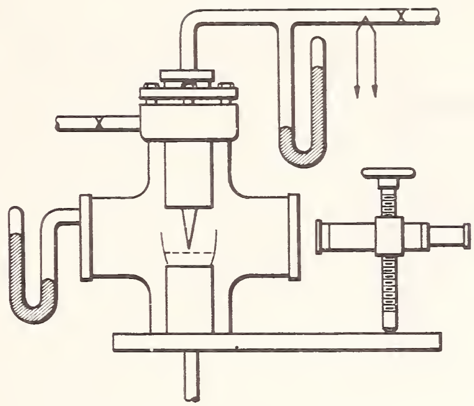
CONCENTRATION PROBES

The composition of combustion gases can be determined by probe sampling and subsequent analysis. Sampling probes can be divided into two categories: (1) Isokinetic probes, which remove a sample at stream velocity; and (2) Sonic probes, which remove the sample at sonic velocity. In the absence of reaction, isokinetic probes collect flux, while sonic sampling collects local concentration. If the sample contains reacting gases, the reliability of the sample depends on the rapidity of quenching. In isokinetic sampling, quenching times are controlled by the ratio between stream velocity, thermal conductivity, and reaction rate, which depend upon the probe diameter, reaction rate, effective thermal conductivity, and the rate at which subsonic gas stream can be accelerated without disturbing the sampled region. For flames the required heat transfer rates are large so that isokinetic sampling is used principally for slowly reacting systems, such as stack gases, or very large systems, such as engines or furnaces. The principal advantage of isokinetic sampling is that it samples flux, and the disturbance of two phase flow is minimized. Thus, if one is interested in particulates, this type of sampling is desirable.

By contrast, sonic sampling radically disturbs the system in the region of extraction, but offers the possibility of quenching rapid reactions. Quenching time varies with orifice diameter. Quenching is accomplished by adiabatic decompression, which simultaneously lowers pressure and temperature of the sample. In most such systems the probe walls need not be cooled because of the short residence time in the hot region of the probe.

Samples can be taken in batches with sample bottles or introduced directly into the analytical instrument through a continuous flow arrangement (Figure 4). Batch sampling allows analysis at leisure, but it is difficult to obtain reliable analyses of absorbant species such as water. This can be minimized by use of Teflon or polyethylene-lined sample bottles.

Where absorption is a problem a continuous flow system is best. Absorbing surfaces must ultimately come to equilibrium with the sample and the material reaching the analytical instrument becomes identical with that entering the probe. With Teflon lines only a few seconds are required to reach equilibrium with a typical water ladened sample, while under comparable conditions glass and metal systems require many minutes. One further precaution is necessary. The system must be continuum flow throughout (i.e., tube diameters large compared with the mean free path), and the pump must be isolated by a choking orifice or by a capillary of sufficient length so that back diffusion from the pump is negligible. This is necessary to avoid molecular separation which occurs at low pressures. This



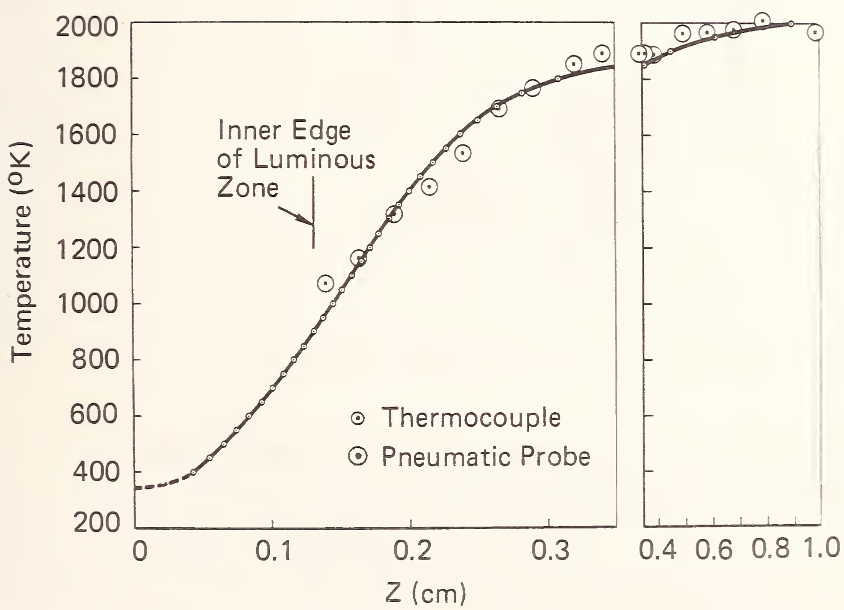


FIGURE 3 Temperature profiles using pneumatic probe compared with thermocouple derived profile. 0.1 atm. $CH_4$0.08 - O_2 - 0.92 flame.

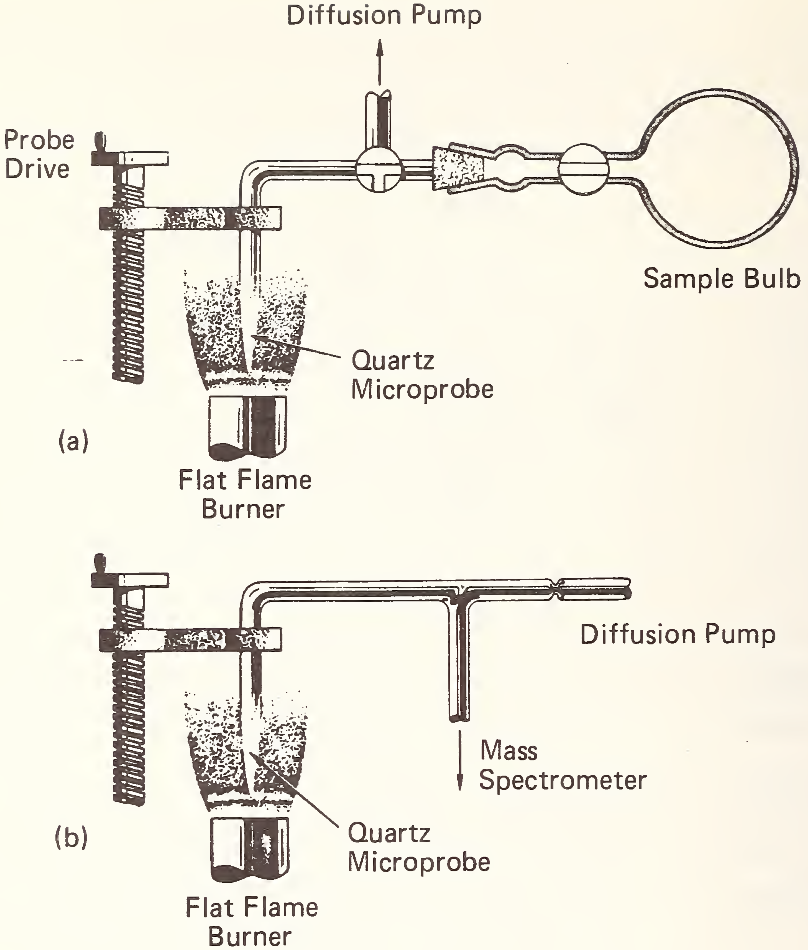


FIGURE 4 Batch and continuous flow sampling of flames.[7]

would bias the sample and analysis. A typical flow sampling system used in connection with a mass spectrometer is shown in Figure 4.

The central problem in sampling combustion systems is to obtain a representative sample and to interpret it either qualitatively or quantitatively in terms of the desired information. The withdrawal of a sample should either produce a quantitatively negligible disturbance of the system or produce one which can be corrected. Quenching occurs through pressure and temperature drop due to expansion of the sample. The slowing of reaction is cumulative, and it can be seen intuitively that if the rate of pressure and temperature drop due to adiabatic expansion is rapid compared with the reaction rates, the sample composition will be quenched or "frozen." Bimolecular reactions as short as a few tens of microseconds should be frozen by probes. Water cooled probes at stream velocity can be unsatisfactory because of longer quench times and because flames are disturbed by bulky cooled surfaces. On the other hand, in engines where the scale is larger, such probes are very useful.[10] A recent bibliography of the field exists.[11]

Species in Combustion Systems

Combustion is usually associated with high temperatures and steep temperature and concentration gradients. In such systems one finds not only reactants and products, but also intermediate and excited species such as vibrationally excited molecules, free radicals and atoms, and ionized species (Table 4). *Stable Species* are those species which have lifetimes that are long compared with the sampling processes. The limiting time may range from a few milliseconds for fast flow sampling systems to hours or days for batch sampling. Most species with paired electron spins are stable, but a few such molecules (e.g., O_3, H_2O_2, B_2H_6) are so reactive that they must be treated as transient species. Conversely, several radical species with unpaired spins are stable, notably oxygen and the oxides of nitrogen and chlorine, which can be treated experimentally as stable species.

Radicals and Atoms are important in combustion (Figure 5) since the fuel and oxidizer do not react directly, but are catalyzed through low activation energy paths involving radicals. A radical is a molecule (atoms are also considered molecules in this context) which has one or more unpaired electrons. It is not charged. In combustion, common examples are: H·, O·, OH·, and CH_3·.

Because of their reactivity, particularly with walls, radicals are difficult to sample, but this can be accomplished in many cases.[23,25,26]

Ions are charged species which occur in low but non-equilibrium concentrations in combustion. As a result of chemi-ionization processes, in hydrocarbon flames the initial reaction is $O + CH \rightarrow CHO^+ + e^-$. Following this, other molecular ions are rapidly formed by ion-molecule reactions so that a great complexity of molecular ions are found in flames.[12,13] Relatively few molecules have stable levels for extra electrons; therefore, most of the observed ions are positive. Flames are neutral overall, and the major negatively charged species in flames is the electron.

TABLE 4

Typical species distribution in a premixed laminar flame

	Typical Maximum Concentration (mole fraction)	Examples
Stable Species	$10^{-1} - 10^{0}$	CH_4, O_2, H_2O
Atoms and Free Radicals	$10^{-1} - 10^{-2}$	H·, O:, OH·
Ions	$10^{-7} - 10^{-12}$	CHO^+, H_3O^+
Vibrational-Electronic	10^{-5}	HF*

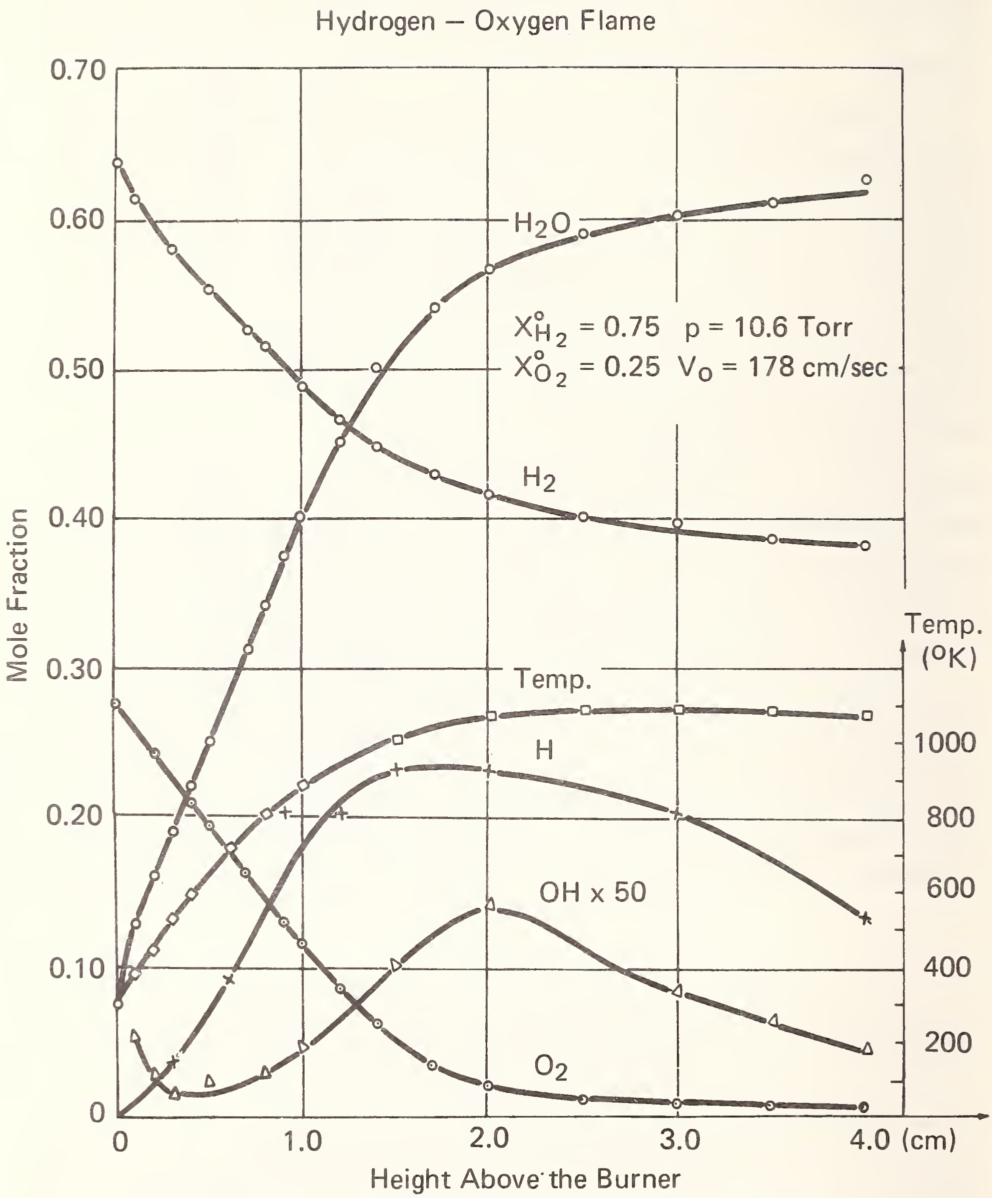


FIGURE 5 Composition profile of a low pressure hydrogen rich oxygen flame.[43]

Special extraction techniques are required, but since single charged particles can be detected, it is possible to measure the very low concentration of molecular ions in flames with satisfactory precision.

Data Interpretation

One is interested both in qualitative information, i.e., what species are present, and in quantitative analysis. Further, since combustion systems can have strong gradients, one is often interested in associating the analysis with a spatial position. Thus, the usual fruit of such studies is not a simple analysis, but a profile (Figure 5).

Often one wishes to deduce fluxes and rates of chemical reactions. This complex problem is discussed elsewhere.[1] Combustion systems contain steep gradients where substantial differences can occur between local concentration and local flux of a species (Figure 6). Concentration is the amount of a species in a unit volume which is an inherently positive scalar quantity. Flux is the amount of material passing a unit area in a unit time which is a vector quantity and may be positive or negative. In the absence of concentration and temperature gradients, these variables are numerically identical when expressed in dimensionless units (e.g., mole fraction and fractional molar flux).

In the simplest one-dimensional combustion system the reaction rate of a species is the spatial derivative of the flux vector (Figure 6, Eq. 3).

$$R = \mathrm{d}F/\mathrm{d}z = d(Xv + D\mathrm{d}X/\mathrm{d}z)/\mathrm{d}z. \qquad (3)^*$$

To obtain rate data it is necessary to associate a composition with a position and temperature and velocity as well as the first and second derivatives of the composition. In combustion systems, where at atmospheric pressure the temperatures may range from 300° to 2000° K and composition of a species passes from essentially zero to a maximum in a fraction of a millimeter, this is difficult and often not possible.

Analytical Methods for Stable Species

Once a stable sample has been taken any convenient analytical technique can be used. The method of choice depends on the availability of equipment and the complexity of the sample. The two most common methods have been mass spectrometry and gas chromatography, but spectroscopic methods such as IR and UV have also been used. These methods are discussed in standard texts.

Where the sample contains fewer than twelve species the method of choice is mass spectrometry because of its generality, sensitivity, and rapidity. With more complex mixtures, such as fuel rich combustion or polymer combustion, gas chromatography has the advantage of allowing the separation and analysis of complex mixtures. The combination of the two provides a very powerful tool for

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*In this equation R is rate, moles/cm^3/sec; F is flux, moles/cm^2/sec; X is concentration, moles/cm^3; v is velocity cm/sec; z is distance (cm); D is the diffusion coefficient, cm^2/sec.

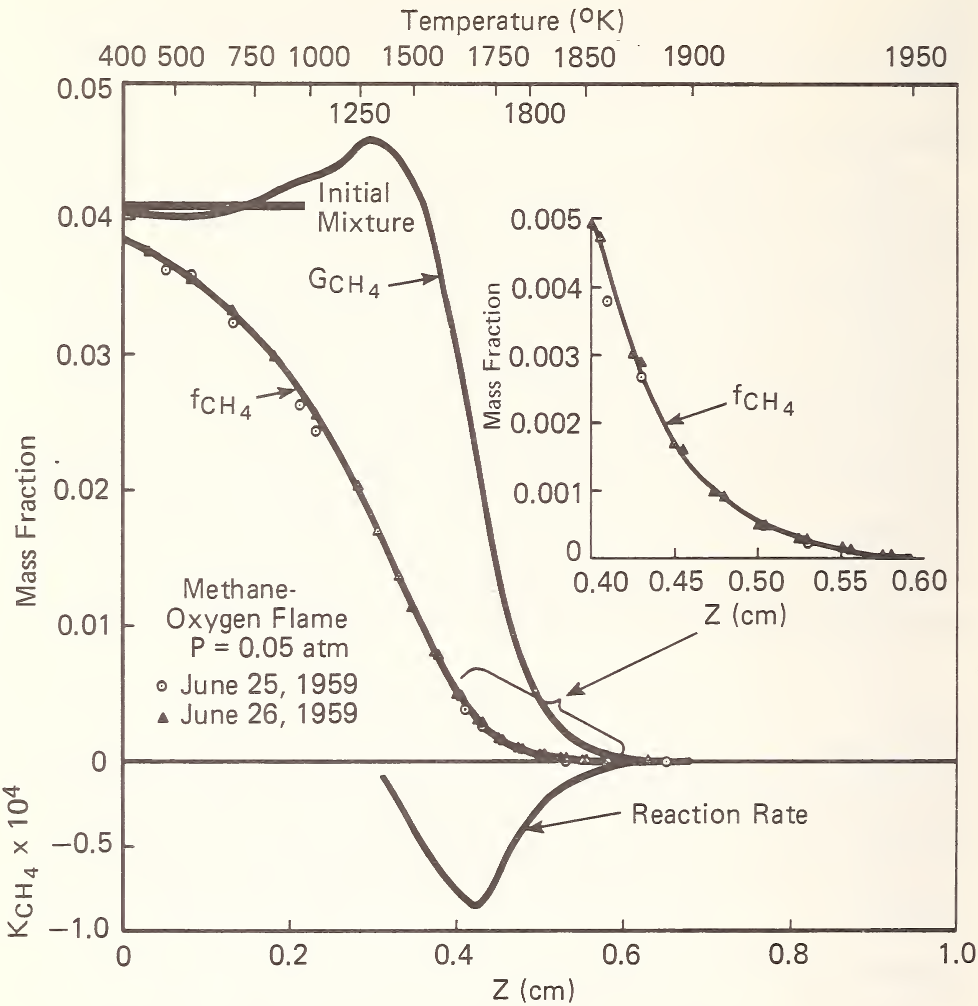


FIGURE 6 Concentration, flux and rate for CH_4 in a 0.05 atm. CH_4 - 0.08; O_2 - 0.92 flame.

combustion studies. Spectroscopic methods are convenient for following certain species, such as CO which is difficult to determine in mass spectrometry or gas chromatography.

Unstable Species

Unstable species can be divided into two general categories: free radicals (i.e., unpaired electron species) and ions (i.e., charged species). Different experimental techniques are required for the two types. Unstable species are important in flame processes, but have not been studied as completely as stable species because of the difficulties involved. They are usually present only in low concentrations ($10^{-2} - 10^{-8}$ mole fraction), and are too reactive for conventional sampling and analytical techniques.

Atoms and Free Radicals

Free radical species play an important role in flame chemistry and these odd electron molecules enter into most flame reactions. Most radicals are so reactive that they require special precautions for sampling and analysis. This problem is not unique to flame studies.

a. Calorimetric Methods

One classic method of determining atom concentrations is by calorimetry. Calorimetry has a number of advantages: (1) the equipment is moderate in cost; (2) the method can be absolute; and (3) good spatial resolution can be attained using thermocouples or other probes. There are certain serious disadvantages: (1) the method is not selective; (2) the efficiencies of coatings both catalytic and non-catalytic are not completely satisfactory; and (3) calculation of the effective sampling region for such a probe is difficult.

In spite of these difficulties, these techniques in the form of a double thermocouple have been used to study O atom concentrations[14] and H atoms[15] and the method has been used by Rossner[16] (Figure 7) in supersonic streams. This technique is satisfactory for simple chemistry.

b. Emission Spectroscopy

Sugden and his co-workers have studied flame radicals using the emission from traces of alkali metal salts as probes.[17,18] They have shown that the intensity of emission of the resonance lines which are proportional to the concentration of

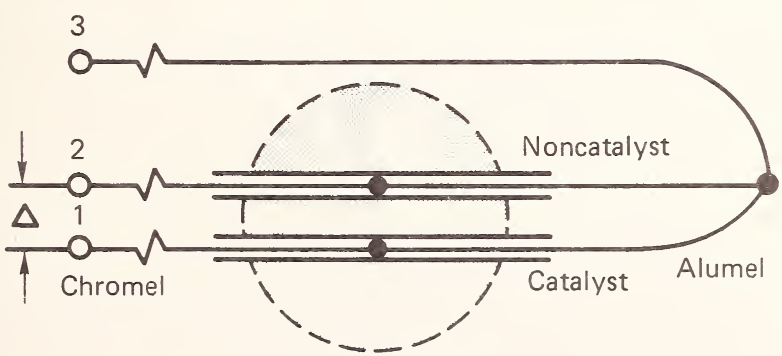


FIGURE 7 Diagram of catalytic probe for determining atom concentrations.

free alkali metals can be related to the concentrations of the radicals H and OH because of hydrides and hydroxides existing in equilibrium with the radicals. This technique is useful in regions where the metal-radical reactions are rapid compared with the change in atom or radical concentrations.

Another useful emission for radical studies is the "Oxygen afterglow" associated with the reaction $O + NO \rightarrow NO_2$. This emission is proportional to the oxygen atom (and NO) concentration and, since NO is regenerated rapidly, it can be considered to be constant. This can provide a convenient measure of relative oxygen atom concentration.[19]

c. *Exchange Methods*

A number of elementary reactions are well enough known that they can be used to estimate radical concentrations from isotopic exchange rates. The most commonly used materials are deuterated compounds. H and O concentrations can be inferred from the rates of reaction[1,20] of D_2O and N_2O. It should be noted that a correction should be made for the effect of deuterium substitution on the rate itself, since the rate may be as much as 40% slower than the corresponding H reaction.

$$H + D_2O \rightarrow HD + OD, \tag{4}$$

$$N_2O + O \rightarrow 2NO. \tag{5}$$

Since the concentrations of the deuterated compounds must be determined by sampling and analysis (usually by mass spectrometry), some precautions must be observed in avoiding wall exchange after sampling.

d. *Scavenger Probe Sampling*

Radical concentrations can be determined by combining microprobe sampling with chemical scavenging. This assumes that, after sampling by a microprobe, radical concentrations are "frozen" sufficiently long for mixing with a reactant, a species which quantitatively produces an analyzable product. Two examples are the determination of oxygen atoms by the reaction $O + NO_2 \rightarrow NO + O_2$ and methyl by the reaction $CH_3 + I_2 \rightarrow CH_3I + I$.

The apparatus consists of a cooled quartz microprobe with provision for scavenger injection (Figure 8).

e. *ESR Studies*

Due to Zeeman transitions in a magnetic field, many common radicals such as H, O, N, OH, halogen atoms, etc., can be detected with commercial spectrometers. This can be used for the measurement of absolute concentrations when calibrated against stable paramagnetic gases.

Electron spin resonance (ESR) has been utilized by allowing a flame to burn inside the resonant cavity of the spectrometer.[1] There are formidable problems of interpretation in this type of experiment. By combining probe sampling with ESR

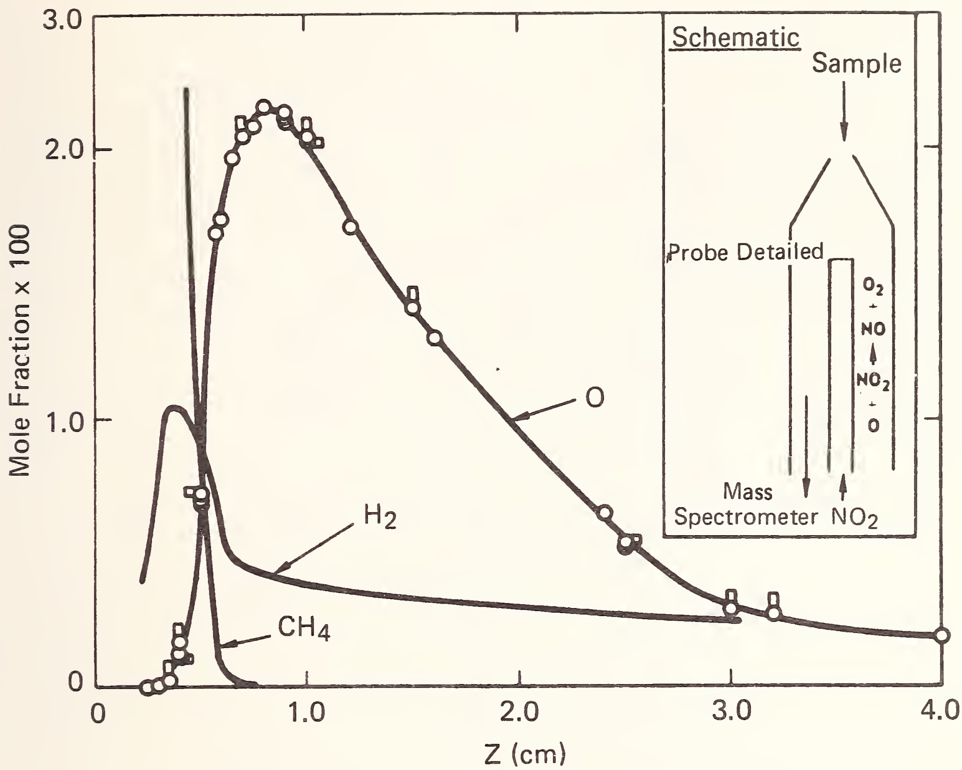
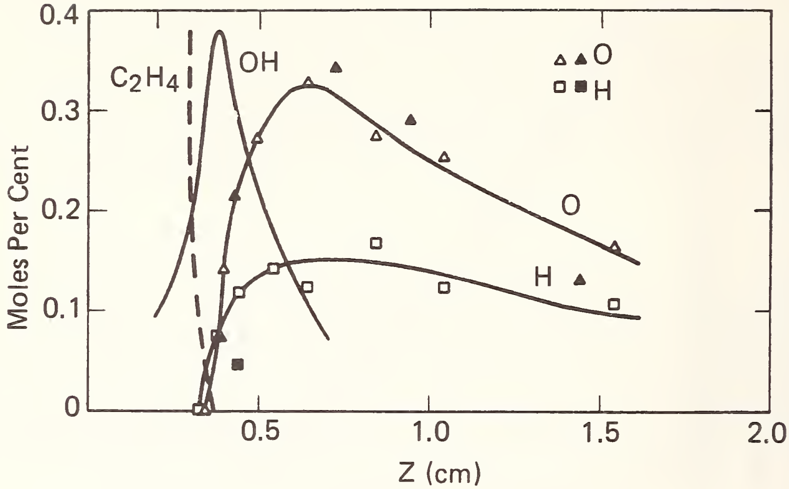


FIGURE 8 Oxygen atom concentration in a methane-oxygen flame determined by scavenger probe techniques. (Fristrom, R. M., "Scavenger Probe Sampling: A Method for Studying Gaseous Free Radicals," *Science,* Vol. 140, pp. 297-300 (19 April 1963). Copyright 1963 by the American Association for the Advancement of Science.)

spectroscopy absolute atom concentration profiles were measured in flames with the apparatus shown in Figure 9. Gas samples withdrawn from the flame zone were pumped directly through the ESR detecting cavity[21] (Figure 9).

f. Molecular Beam Mass Spectrometry

For species which have a high surface reactivity, collisionless flow inlet systems provide the only satisfactory inlet. Molecular beam inlet mass spectrometry was pioneered by Foner to establish the existence and identity of free radicals in flames and other reactive systems.[22] Two types of molecular flow inlet systems exist, the effusive and the supersonic. Effusive molecular beams are of low intensity and sample the boundary layer of a system. If wall processes are under study, are unimportant, or can be corrected for, this provides a satisfactory sampling system; otherwise, continuum sampling should be used. Continuum flow beams are intense, but there are a number of problems. They are supersonic, the velocity distribution is narrow, and local temperature is low (Figure 10). Vibrationally and



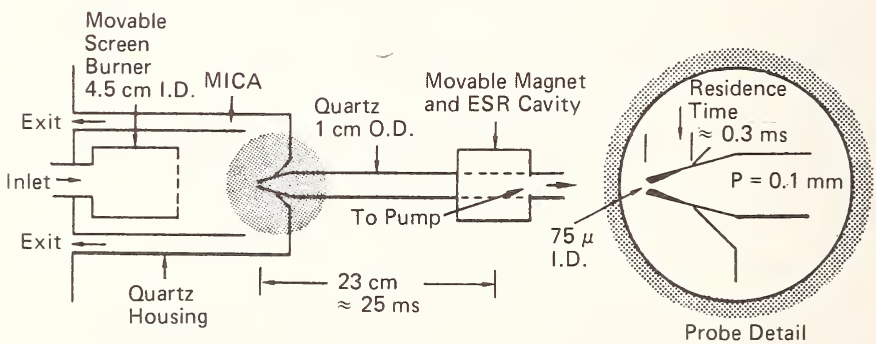
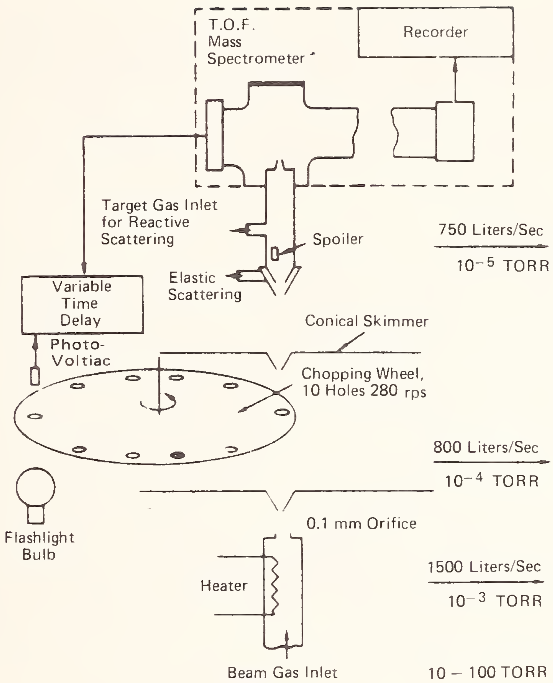


FIGURE 9 H and O atom profiles of ethylene-oxygen flames by probe sampling and ESR detection.[21]



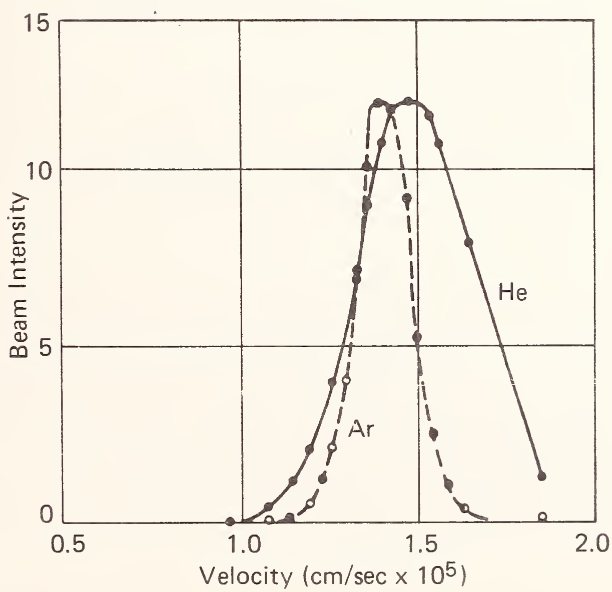


FIGURE 10 Velocity distribution of molecules in a supersonic molecular beam.[42]

electronically excited states are frozen with the problems associated with cracking pattern changes.

Several problems are associated with molecular beam mass spectrometry of flames: (1) mass separation by inlet flow; (2) change of cracking pattern with temperature due to changes in vibrational distributions; and (3) polymer formation.[23]

For stable species, microprobe sampling coupled with conventional analysis is usually quantitative except for strongly absorbed species. Molecular beam sampling is necessary for satisfactory sampling of such species. Free expansion produces separation due to Mach number focusing.[23] Interference of stable species with radicals can be reduced by lowering the electron beam energy below the threshold of ionization for stable species or by using magnetic separations. For trace molecular species the problem is more difficult. Calibration for expansion may be possible by combining information from a non-reactive trace molecule comparison with a knowledge of vibrational levels of the sample. Again if the species is a radical, problems can be reduced by lowering electron beam energy.

One of the major problems with molecular beam inlet mass spectrometry is that to form a satisfactory molecular beam with molecules which have made no wall collisions one must form a supersonic beam and skim out the center core. This can only be done by using a very wide angle sampling cone ($>120°$). Such a blunt probe has a strong perturbing effect on flames (Figure 14). The compromise which has usually been employed is about a 40° cone.[24,25] This does not visually disturb most flames and does allow beam formation. Such a beam, however, contains many molecules which have made wall collisions because of unfavorable aerodynamic configuration.[26] This does not invalidate the analysis since the system is calibrated, however, radicals which do not survive wall collisions may be lost. This problem requires further study.

A mass spectrometer is not a primary analytical instrument, and for precise work, standard samples must be used. Stable standards can be prepared, but calibration can be a problem with strongly absorbed species such as water and acids. The case of radical species is different and more difficult. These species cannot be prepared as standard samples because of their reactivity. Three techniques have been used. (1) Atoms can be prepared from their diatomic parent by an electric discharge. Using a knowledge of the total pressure and the cracking pattern of the parent species one can deduce the calibration factor of the radical species provided concentrations as high as a few percent can be obtained. (2) A radical or atom can be titrated or scavenged in a flow system and its concentration compared with that of a stable, known species. (3) One can look at an equilibrium system in which other species of the equilibrium are known and deduce the sensitivity of the radical by difference.[24] Since ion charges are known, ion sensitivities can be determined directly provided the collection efficiency of the inlet system can be determined.

Charged Species

The spatial distribution of charged species can be measured by: (1) the Langmuir probe, which measures d-c resistance; (2) the r-f probe which measures energy dissipation in the microwave region; (3) the photographic technique; and (4) the ion sampling mass spectrometer. The first two techniques measure electron concentrations; the first and third can measure either electrons or positive ions, but do not distinguish between positive ions. The fourth technique allows the direct measurement of individual positive ion concentrations. We will discuss the Langmuir probe and ion spectrometry. Discussions of the other two methods can be found elsewhere.[1,7]

a. The Langmuir Probe

The Langmuir probe was one of the earliest methods for studying ion concentrations in flames. It is possible to measure ion or electron concentration and effective electron temperature.[27] It consists of large area and small area electrodes (Figure 11). At a given voltage, current is limited by ions (or electrons) arrival at the small electrode. The current is proportional to electrode area. If the small electrode is positive, current is proportional to the electron concentration; if the small electrode is negative, current is proportional to the positive ion current. The area ratio between small and large electrodes must be very large to make the limiting electrode positive, because of the high mobility of the electron. Complications stem from the electrode size which affects the gradient and the plasma potential which develops around an electrode immersed in a plasma. The technique has been criticized because of the disturbance to the system being studied; but with reasonable care useful results can be obtained in systems with spatial resolution which could be obtained by no other technique (Figure 11). The techniques are similar to polarography in electrolytes.

The energy from electric fields higher than a few megacycles is absorbed only by free electrons because ionic particles are too massive to respond. This method for studying electron concentrations has the advantage of not disturbing the system. The disadvantages are low spatial resolution and difficulties in determining exact path lengths and absorption coefficients.

b. Ion Mass Spectrometry

The best technique for identifying ions is direct mass spectrometry. Reliable identifications can be made and quantitative studies of ion concentration profiles are possible.[12,13]

The apparatus (Figure 12) is similar to the conventional mass spectrometry, but no electron gun is used. A sampling orifice and a set of focusing electrodes are required. Considerable care must be devoted to the design of the sampling inlet and pumping system. It is necessary to maintain low pressure inside the spectrometer (mean free path large compared with the apparatus) to avoid spurious ions.

APPLICATIONS

Probe sampling has been applied to a large number of combustion problems.

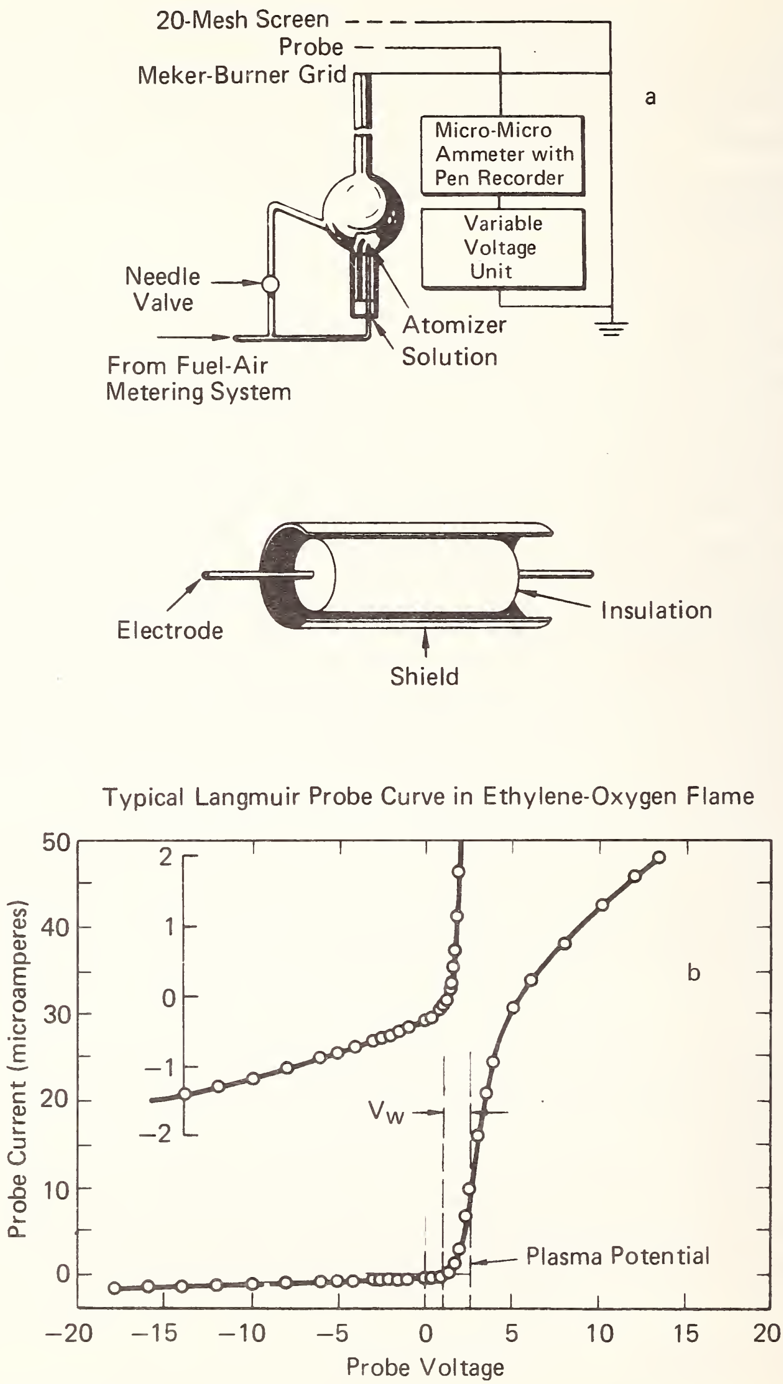


FIGURE 11 The Langmuir probe technique for studying ions and electrons in flames. [Attributed to: H. Calcote, "Ion and Electron Profiles in Flames," *Ninth Symposium (International) on Combustion,* Williams & Wilkins Co. 622 (1963).]

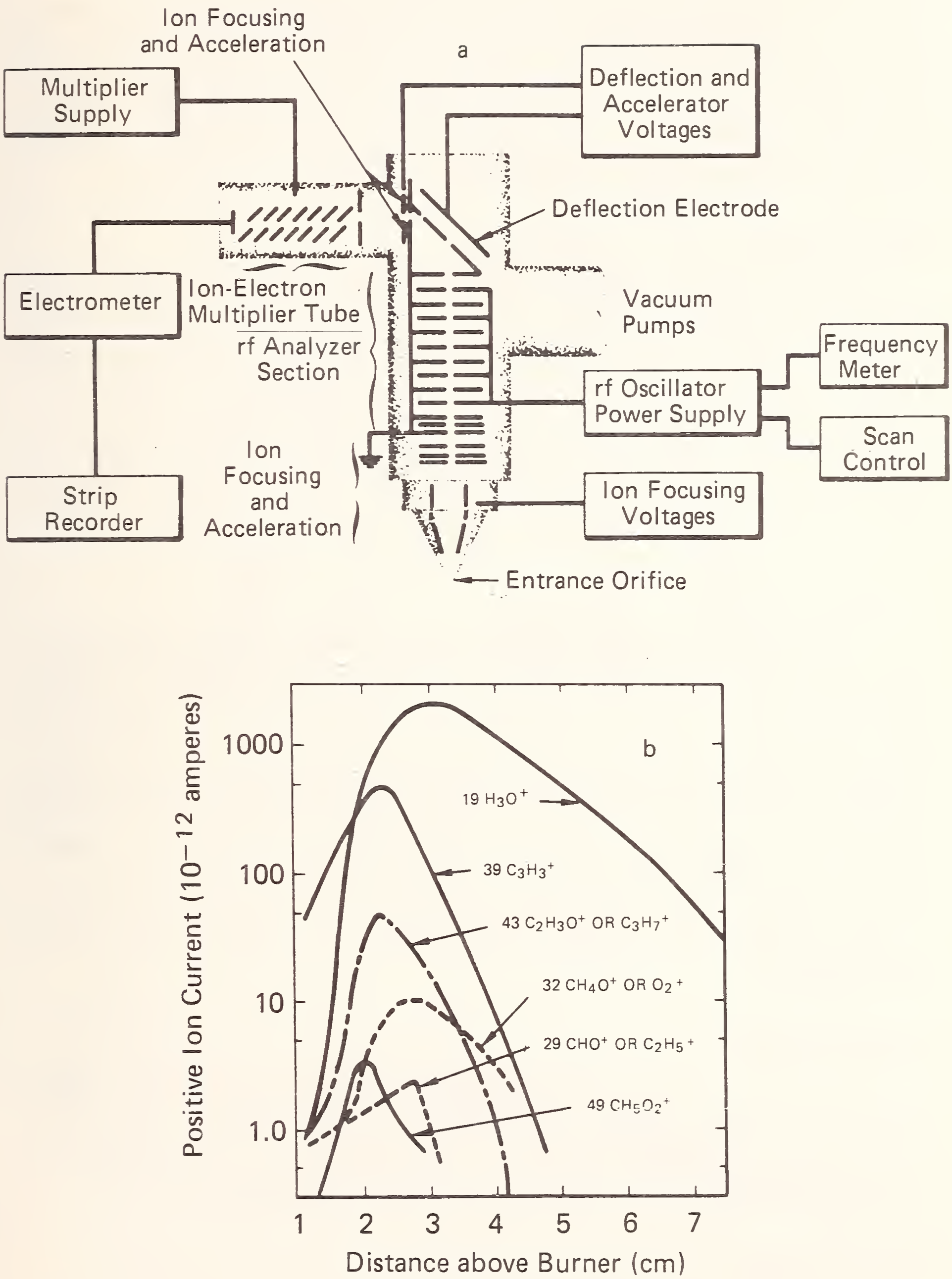


FIGURE 12 Determination of ion concentrations by mass spectrometry. [Attributed to: H. Calcote, "Ion and Electron Profiles in Flames," *Ninth Symposium (International) on Combustion*, Williams & Wilkins Co. 622 (1963).]

We will present several typical examples. Many more examples can be found in the extensive combustion literature. Useful sources are the biannual International Combustion Symposium Volumes, some fifteen of which have appeared in print.[28] The first ten volumes are indexed in Volume 10. Other sources are AGARD publications, NACA reports, *Combustion and Flame, Fuel, Fire Research Abstracts and Reviews,* and other combustion journals.

Flame Sampling

Probing has been done extensively in the study of laminar flames and the techniques are discussed in detail in Fristrom and Westenberg.[1] There is a recent bibliography of the field[11] and there are several monographs.[20,29] A typical example of such a study is given in Figure 5. Diffusion flames present a two or more dimensional problem unless a symmetric system is analyzed. One such analysis is combustion along the stagnation axis of a porous cylinder as in the example[30] of Figure 13. Two dimensional diffusion flames have been studied qualitatively, but we are unaware of any quantitative analyses.

Combustor Sampling

During the development of jet and rocket propulsion following World War II many combustion studies were made using probes. These techniques are documented in Tine's survey,[10] the references previously cited, and a multitude of government reports such as the Ramjet Technology Handbook;[31] the Princeton Series;[2] AGARD Publications,[32] etc., many of which are still available. Two examples are illustrated in Figure 14 using water cooled sonic probe and water cooled isokinetic probes.[33] Large water cooled probes are satisfactory for many combustor problems because the rapid flow and high heat release make the disturbance offered by the probe negligible. Problems connected with time variation in such samples will be discussed by Billiger in the following paper in this symposium.[34]

Furnace Sampling

In the study of furnaces and low intensity combustors sampling has also been done with probes of the water cooled variety both with isokinetic sampling and sonic sampling. A discussion of furnace problems has been given by Thring.[35] An example of multi-inlet probe used in furnace studies is given in Figure 15.

Rocket Sampling

High pressure sampling presents many problems of stress and high heat flux, but even in the case of a rocket chamber it has been possible to sample using a supersonic inlet mass spectrometer[36] (Figure 16).

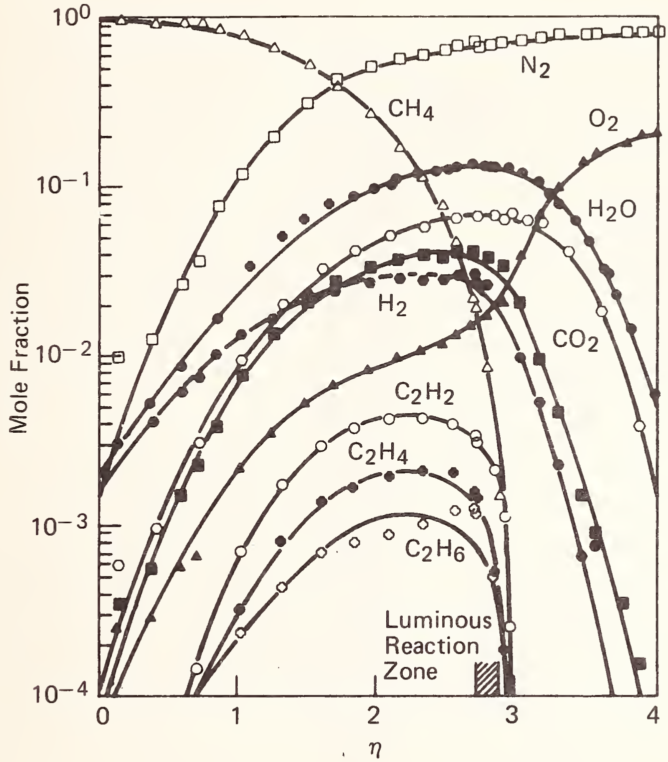


FIGURE 13 Composition profile along the stagnation axis of a cylindrical diffusion flame.[42]

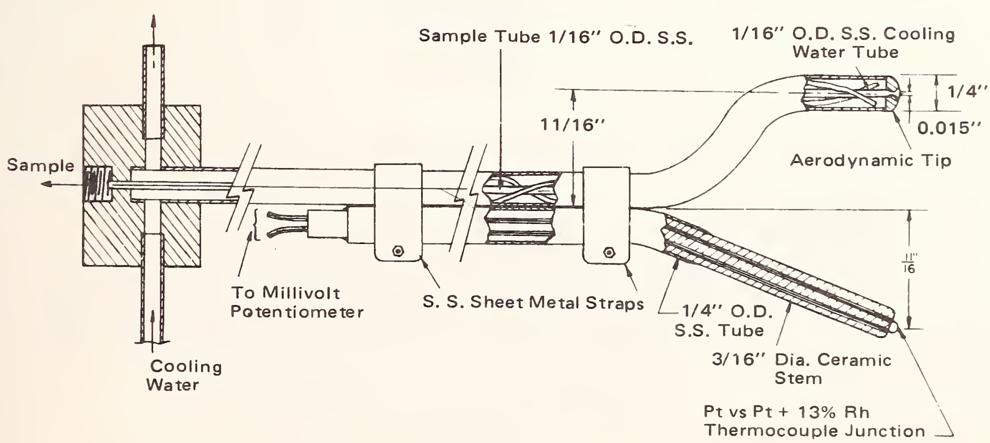


FIGURE 14 Probes for studying combustor performance.[33]

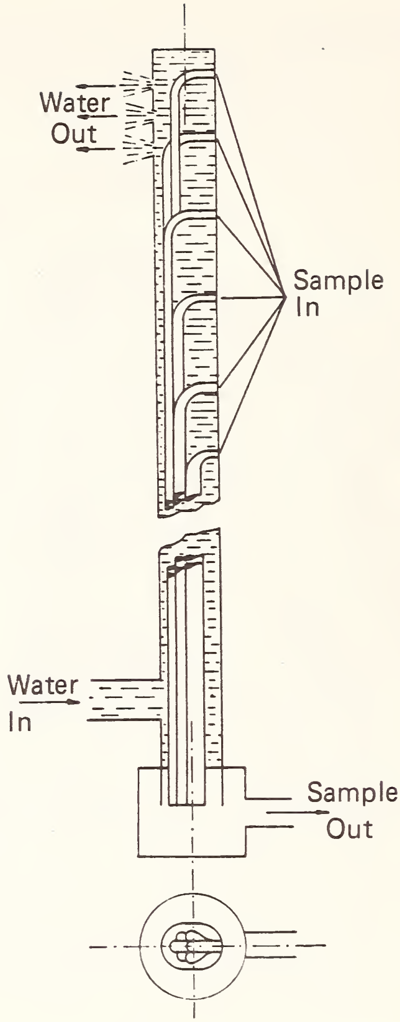


FIGURE 15 Multiple inlet water cooled probe for furnace studies.[35]

Supersonic Sampling

Sampling from a supersonic stream offers special problems, because probes usually produce a bow shock which can alter the sample. Special probes which swallow the shock have been used and samples analyzed using gas chromatography.[37]

Repetitive Phenomena

If a repetitive phenomena is reproducible it is possible to follow both the time

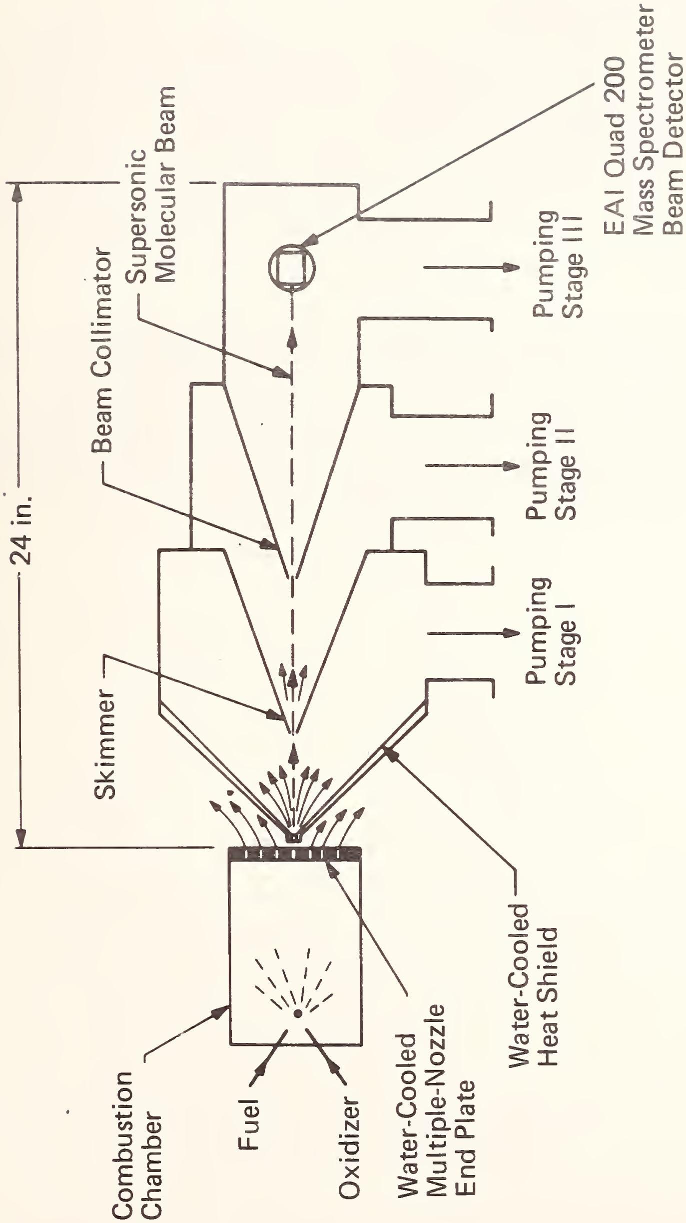


FIGURE 16 Molecular beam inlet sampling system for liquid fuel rocket.[36]

and space variation of the phenomena by positioning the probe and varying the phase time of analysis. This has been done in engines[38] (Figure 16) and in the study of spark ignition[39] (Figure 17).

Condensed Phase Sampling

Since many combustion processes involve condensed phase fuels, probing may be a useful technique for studying such combustion processes. Several studies have addressed this problem, one quenching the solid reaction by blowing out the flame with inert gas and analyzing the solid by microtone sampling and Neutron activation analysis[40] (Figure 18). The other used a low pressure liquid nitrogen probe on a moving wire—analysis was by weight and wet chemistry[41,42] (Figure 19).

SUMMARY

Probe sampling has been a versatile, useful tool in combustion problems. It is a well established technique with an extensive literature. In the future, probing techniques particularly molecular beam inlet systems should continue to be a valuable tool in combustion studies because of simplicity and relatively low cost. They should be particularly useful when combined with optical methods which can establish areas of applicability of probes.

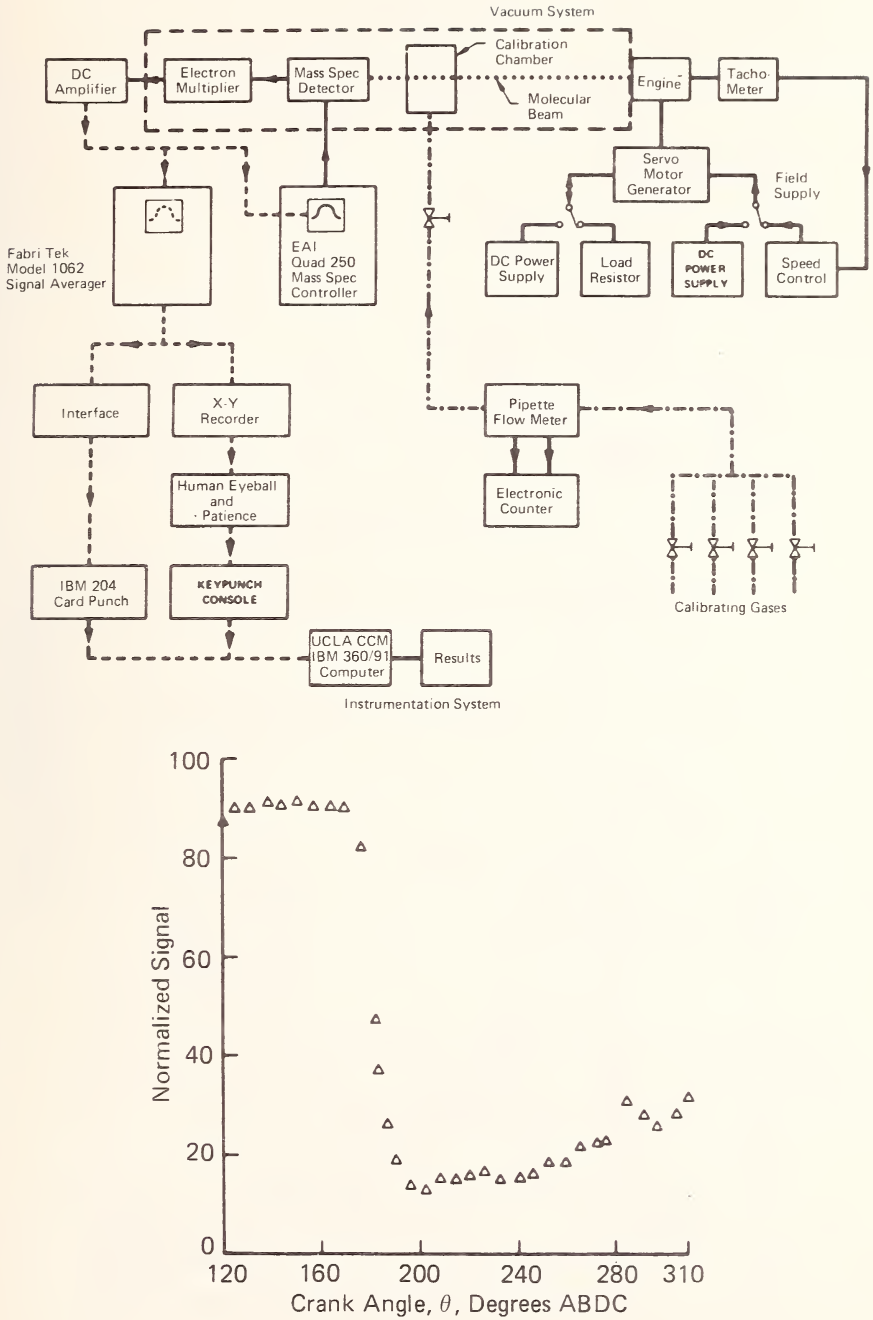


FIGURE 17a Supersonic molecular beam inlet system for studying internal combustion engines (a) apparatus schematic (b) relative concentration of propane as a function of crank angle.[38]

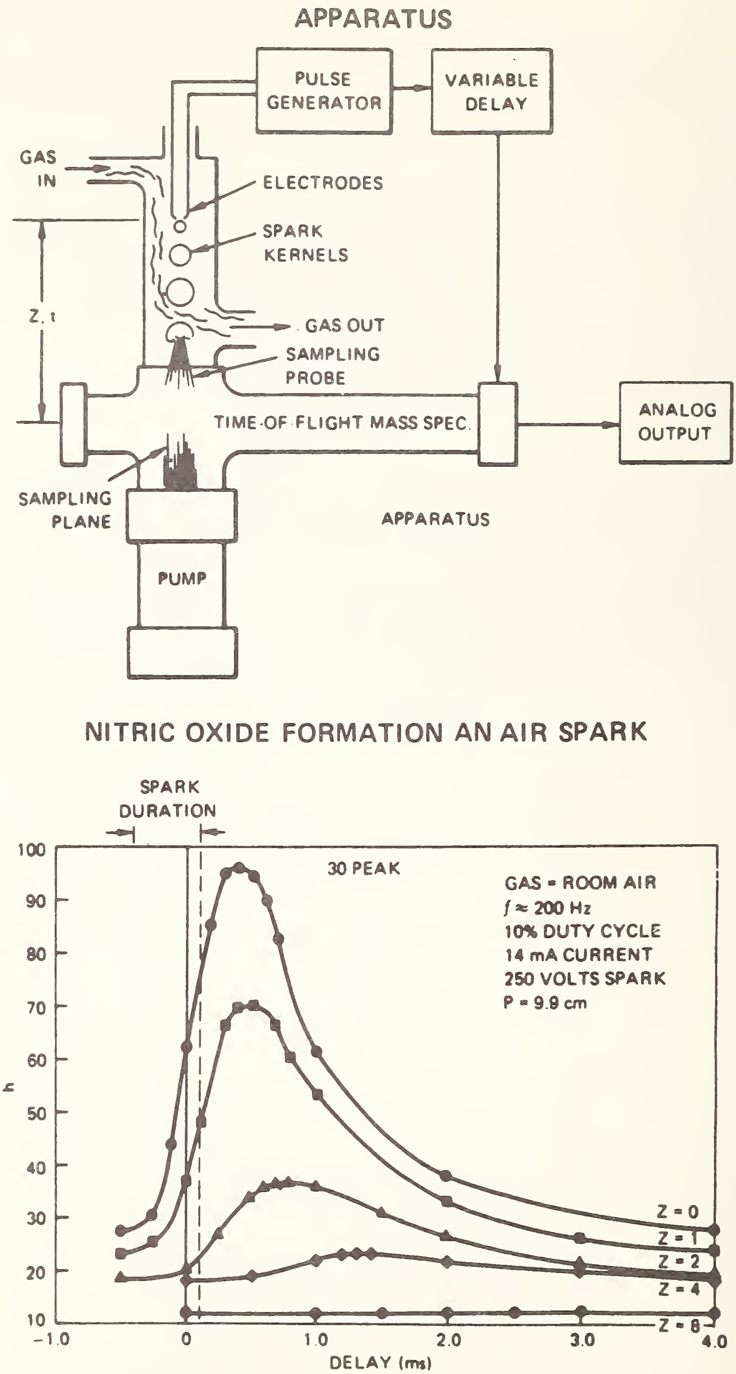


FIGURE 17b Spark ignition studies.[42]

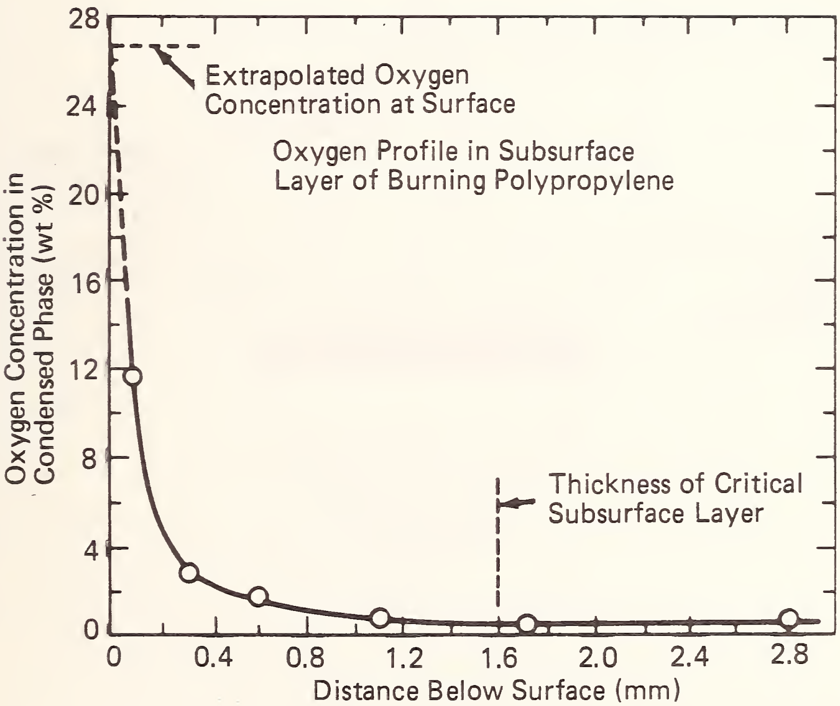


FIGURE 18 Microstructure of a polypropylene rod surface burning in the candle mode.[40]

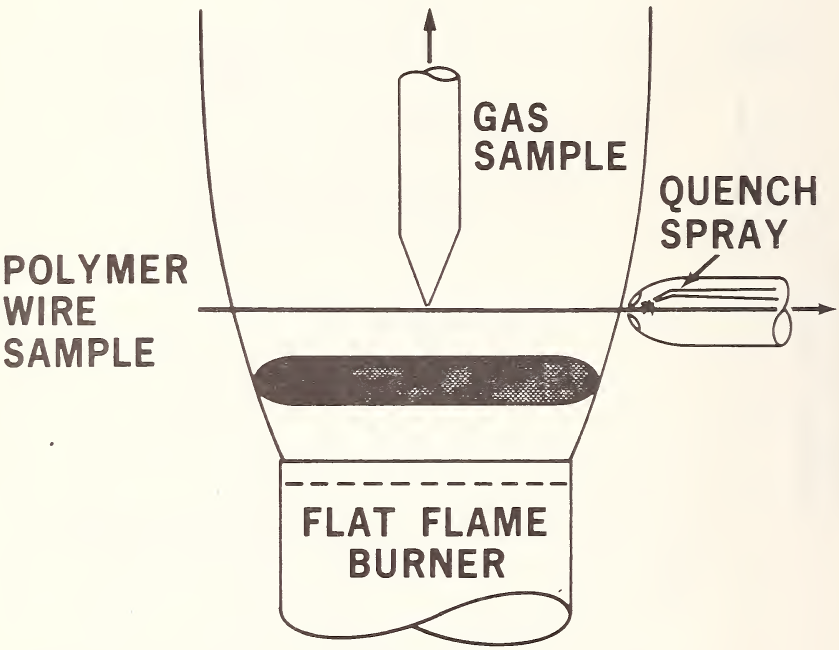


FIGURE 19 Apparatus for the study of the ignition of polymers.[42]

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ABSTRACTS AND REVIEWS

A. Prevention of Fires, Safety Measures, and Retardants

Barstad, J., Boler, J. B., Hjorteland, O., and Solum, E. "Variations in Hydrocarbon Gas Concentration During Supertanker Cleaning Operations," *Nature 241* (5386), 196-197 (1973)

Subjects: Gas explosion; Hydrocarbon-air concentration; Supertanker cleaning hazard; Explosion limit hydrocarbon-air mixtures

Safety in Mines Abstracts 22 No. 246
Safety in Mines Research Establishment

Following recent serious explosions aboard very large crude carriers (VLCC), interest was initially focused on the problems of cleaning and gas freeing of cargo tanks, especially with rotating jet systems and the electrostatic hazards were reported. A trial of the forced ventilation of cargo tanks before and during cleaning gave good results and was adopted by one company, but then, in December 1969, three tankers had explosions during cleaning - two of these tankers had used the too-lean method, the other had used no ventilation before or after cleaning. The authors since 1970 have investigated various aspects of explosion hazards and discuss some of the results obtained by exact measurements of gas concentrations aboard a VLCC, noting changes in the composition of the hydrocarbon gas mixture. The changes also resulted in variations in the values of the lower and upper explosion limits of the mixture in air.

Brannigan, F. L. (Montgomery College, Rockville, Maryland) "A Field Study of Non Fire-Resistive Multiple Dwelling Fires," *National Bureau of Standards Special Publication 411*, 178 (August 1973)

Subjects: Fires; Building codes; Fire walls; Building design

Author's Abstract

A field study was made of structural and building design factors contributing to the spread of fire in more than 40 non-fire-resistive, multiple occupancy dwellings, typically "Garden Apartments". Most deficiencies could be corrected by preserving the integrity of a gypsum board sheath serving as a fire barrier. Examples are given of penetrations and openings in fire barriers which permitted substantial fire spread.

Bridge, N. W. and Young, R. A. (Joint Fire Research Organization, Borehamwood, Herts, England) "Experimental Appraisal of an American Sprinkler System for the Protection of Goods in High Racked Storages," *Fire Research Note No. 1003, Joint Fire Research Organization* (February 1974)

Subjects: Sprinklers; High racked storages; NFPA 231C; Tests; Pallet storage

Authors' Summary

Six large-scale fire experiments are described, involving goods stored in a six-level rack, to simulate industrial conditions. For two tests, fourth level central and face sprinklers and sixth level central sprinklers were used. For four tests, a thick plywood barrier was put just above the fourth level and the fourth level central sprinklers were not used. The arrangements were derived from the NFPA Standard 231C - 1972 for Rack Storage of Materials.

In four tests the fire was lit in the first level. In two tests involving some polyurethane foam it was lit in the second level, (with the first level empty) simulating a system repeating every three levels. The rack is considered as the lowest portion of a much higher rack and so the effects of ceiling sprinklers are not discussed.

It is concluded that the barrier is an effective aid to stopping upward spread, but the arrangement of sprinklers is not capable of extinguishing the fire quickly at the lower levels. Without the shelf, the fire spread to the top of the rack, except with the half load of goods on each pallet, which would rarely occur in practice.

Buchbinder, B. and Vickers, A. (National Bureau of Standards, Washington, D.C.) "A Comparison Between Potential Hazard Reduction from Fabric Flammability Standards, Ignition Source Improvement and Public Education," *National Bureau of Standards Special Publication 411,* 1 (August 1973)

Subjects: Fabric fires; Flammability; Ignition sources; Education; Standards

Authors' Abstract

Mandatory standards have been and are being promulgated for flammable fabric item types (e.g., children's sleepwear, mattresses, upholstered furniture) to reduce the fire hazard inherent in the use of common ignition sources (e.g., matches, cigarettes, kitchen ranges). Trade-offs should be made between potential hazard reduction from fabric item standards and from design changes or improved quality control in ignition source fabrication. Public education is a third approach to the reduction of certain hazards.

Burgess, D., Murphy, J. N., Zabetakis, M. G., and Perlee, H. E. (Bureau of Mines, Pittsburgh, Pennsylvania) "Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 289 (1975)

Subjects: Flammable mixtures; Fuel spills; Dispersion of Spills; Leaks of Fuel; Ignition hazard

Authors' Abstract

The investigators of an unconfined gas explosion typically derive some measure of the air blast, leading to the assignment of a "TNT equivalent." This number is invariably small, ranging from 0 to 10% of the yield that one would have predicted from the heat of combustion of the fuel. The probable reason for this low value, as this paper seeks to show, is that only a small fraction of an atmospherically dispersed gas mixture can be within a flammable range of concentrations.

This paper draws on measurements of the atmospheric dispersion of natural gas to test the applicability of the bivariant Gaussian distribution equation with standard deviations, σ_y and σ_z, derived from the air pollution literature. Three observations are discussed in relation to the dispersion of flammable gases: (1) The concentrations of interest (flammable limits) are much higher than most critical pollutant concentrations; (2) concentration peaks may well be an order-of-magnitude higher than time-averaged concentrations, which are derived from a statistical treatment; (3) most flammable vapors are heavier than air and form ground-hugging layers that extend the distances of ignition hazard.

Calculations are presented of the volumes of vapor–air mixture within surfaces of equal concentration. From these figures, it is evident that most of the flammable vapor is quickly dispersed to concentrations below the lower limit of flammability.

Doyle, W. H. (Society of Fire Protection Engineers, Boston, Massachusetts) "Minimizing Serious Fires and Explosions in the Distilling Process," *Society of Fire Protection Engineers Technology Report No. 2,* Society of Fire Protection Engineers, Boston, Massachusetts

Subjects: Fire; Explosions; Distillation; Flammables; Industrial Hazards; Chemical plants

Author's Abstract

Distillation, while not normally a hazardous operation, does require precautions because of the heating, vaporizing, and condensing of large volumes of flammables. The suggestions made to reduce the potential for catastrophic fires and explosions are based on studies of industrial fires and explosions involving such equipment. The hazard of explosive vapors outside of the distillation equipment as the result of mechanical failure is covered. The problem of the distillation of reactive chemicals such as (1) compounds subject to peroxide formation. (2) nitrated compounds. (3) compounds containing double or triple bonds, and (4) those subject to rapid polymerization is discussed.

Edmonds-Brown, H. "Safety Aspects of Electrical Engineering Practice in the Petroleum Industry." *Mining Technology 55*, (629), 88-91 (1973)

Subjects: Fire safety; Petroleum industry safety; Gas detection: Electrical apparatus dangers

Safety in Mines Abstracts 22 No. 240
Safety in Mines Research Establishment

The author discusses the risk of fire or explosion due to the presence of flammable gas or vapor/air mixtures likely to arise in the petroleum industry. Factors considered are the vapor conditions of petroleum liquids at various temperatures, the effect of mixtures of products, potentially hazardous situations, gas detection, classification of hazardous areas, and electrical apparatus in classified areas.

Gandee, G. W. and Clodfelter, R. G. (Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio) "Evaluation of the Effectiveness of Anti-Mist Fuel Additives in the Prevention of Vapor Phase Fire and Explosions," *Project Report, December 1972 - March 1973, Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-73-111* (January 1974)

Subjects: Gunfire; Aviation fuel, JP-4, JP-8; Flammability limits; Fuel systems vulnerability, Aviation safety

Authors' Abstract

A series of vertical gunfire tests was conducted at Wright-Patterson AFB in order to assess the effectiveness of fuel additives in reduction of the fire and explosion hazards that can be associated with kerosene (JP8) fuel under gunfire conditions. This program considered commercial additives which have been developed for the fire-safe fuel efforts of the FAA, the Army, and the British Government. The additives were intended to prevent fuel mist or spray during a crash situation. This effort considered the effectiveness of these additives at a concentration of approximately 0.3% wt. in the prevention of explosions of fuel mist or spray as a 50 caliber armor piercing incendiary (API) ordnance round passes through the liquid-vapor interface. Results indicated that additives could be effective. Two of the four materials evaluated, CONOCO AM-1 and Imperial Chemical Industries, Ltd. FM-4 reduced average pulse pressure rise to less than 10 psi as compared to 40 psi rise with neat JP-8. Additives were not effective when evaluated in JP-4 fuel.

Handa, T., Suzuki, H., Takahashi, A., Ikeda, Y., and Saito, M. (Science University of Tokyo) "Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part II. Checks on Factors Concerning the Surface Flame Spread Rate and Smoke Evolution of Organic Building Materials by Small Inclined Type Test Furnace." *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 44 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Furnace tests; Building materials; Fire hazard; Fire modelling

Authors' Conclusions

The flame-spread rate of the macroscopic upward flame is dependent on the gas flow rate, and when the gas flow is assumed to be laminar, the flame-spread rate is nearly proportional to $\cos^2 \theta$, where θ is the inclination angle of the furnace.

The flame spread pre-heats the not-yet-ignited portions by thermal diffusion through thermal conduction toward the interior of the wood sample and by convection heat transfer along the spreading direction. This brings about the shift in ignition point and is decided by heat balance between the heat-evolution rate and thermal diffusion rate, that is to say, by the balance of flame energy accumulation together with the combustion along the z-direction and the heat dissipation in the x-direction. Moreover, the smoke evolution rate corresponds to the flame-spread rate, and the relation between the flame-spread rate and the heat-evolution rate and the smoke evolution rate, shows the oscillating phenomena accompanying heat accumulation or dissipation in the directions including the z-direction.

Harmathy, T. Z. (National Research Council Canada, Ottawa, Canada) "Design Approach to Fire Safety in Buildings," Progressive Architecture, April 1974, 82-87, Reinhold Publishing Company: *Technical Paper No. 419, Division of Building Research, National Research Council of Canada*

Subjects: Fire safety; Building design; Building fires; Fire severity; Fire load; Equal area compartment fires

Abstracted by G. Fristrom

The author observes that commonly used fire safety measures in building codes are inadequate and can lead to both overprotected and underprotected situations. If the building designer had a better understanding of the characteristics of compartment fires, he would be in a better position to design for minimal damages and for special detecting and suppression equipment.

Safety depends on circumstances, but general rules will aid the designer. The paper outlines the concepts of fire load and the characteristics of compartment fires. It gives fire severity parameters. The concept of equal areas in fire situations is explained and applied. The article provides an excellent introductory survey of fire safety concepts.

Harmathy, T. Z. (National Research Council, Ottawa, Canada) "Designers Option: Fire Resistance or Ventilation," *Technical Paper No. 436, Division of Building Research, National Research Council of Canada* (1974)

Subjects: Compartment fires; Fire resistance; Ventilation; Fire load

Author's Summary

The inadequacy of the conventional philosophy underlying fire safety provisions is discussed. The characteristics of compartment fires are outlined and three "fire severity parameters" introduced. These parameters are shown to depend primarily on the fire load and compartment ventilation. A new "defensive design approach" is suggested which, if followed from the early stages of architectural design, will result in a higher degree of fire safety and often also in considerable savings in building costs.

Harmathy, T. Z. (National Research Council, Ottawa, Canada) "Flame Deflectors," *Building Research Note No. 96, Division of Building Research, National Research Council of Canada* (October 1974)

Subjects: Fire spread; Flame deflectors; Building fires

Abstract by R. M. Fristrom

The use of flame deflectors to prevent the spread of fires in buildings from one floor to another is discussed. Several designs are proposed and an estimate of the additional building cost is made. Possible designs for self activating deflectors are also given.

Harrison, G. A. (National Bureau of Standards, Washington, D.C.) "The High Rise Fire Problem," *CRC Critical Reviews in Environmental Control 4* (4) 483 (1974)

Subjects: High rise fires; Fires, high rise; Building fires

Author's Conclusions

The results of this high-rise fire problem study lead to the following conclusions:

1. Many and varying definitions of a high-rise building exist, which suggests that some confusion or lack of uniformity of thought still exists among building officials. None of the definitions recognizes the change in life-safety risk as the building height increases considerably, e.g., 10 stories vs 80 stories.
2. Historically, the life losses associated with high-rise buildings have been very low in the United States. Where large life losses have occurred in high-rise buildings, well-established traditional fire protection engineering principles were found to have been violated. Where sprinklers were installed, life losses in high-rises were virtually nonexistent.
3. High-rise buildings in the United States have performed well under serious fire conditions. American building codes have sufficient structural requirements to retard the spread of flames. However, the phenomenon of flame spread via the exterior windows is not being addressed by the codes.
4. The fire experience since 1960 shows that fuel loading is changing, both in the nature of the fuel and in quantity. Plastics are being used in increasing amounts for construction materials and furnishings in high-rises. The fire experience record shows that greater heat, smoke, and toxic-gas production potential exists with certain types of plastics than with traditional materials, and that selected plastics have contributed to large fires in fire-resistant high-rises. These plastics were in the form of furnishings and construction materials. The use of plastics has changed the fuel loading, smoke, and toxic-gas production situations from what they were a decade ago.

5. With the advent of central air-conditioning, central-core design concepts, and general loosening up of the compartmentation concept by allowing a multitude of holes to be punched through fire-rated barriers for ducts, pipes, cables, etc., increased avenues are available for the passage of heat and smoke. Current code requirements do not fully address the smoke movement problem within high-rises, as documented by fire experience records. The predominant movement of smoke within a high-rise is via egress routes, although an unprotected pipe chase allowed smoke to claim 21 fatalities in one high-rise fire case.

6. Fire experience reports document the continued attempts of building occupants to utilize elevators during fire emergencies. As designed, elevators do not serve as safe means of egress in the event of a fire, and numerous persons have perished as a result of insufficient elevator designs.

7. A research gap exists with respect to human behavior as it is affected by stress conditions created by fires.

8. High-rise buildings pose special problems to fire department operations. These include difficulties in getting to the fire within a building, ventilation restrictions in trying to move smoke, and shielding effects that make voice communication difficult between the fire fighter and the command post.

Hayashi, T. and Tarumi, H. "Interruption of Explosions by Flame Arresters: First Report on the Quenching Ability of Sintered Metals," *Report of the Research Institute of Industrial Safety, (Japan), 21* (1) 19 p. (November 1972) (in Japanese)

Subjects: Explosion interruption; Flame arresters; Quenching ability of sintered metals; Sintered metals as flame quenchers

Safety in Mines Abstracts 22 No. 248
Safety in Mines Research Establishment

The sintered metals tested were commercial filters, discs 2 mm thick, with a diameter of 40 mm. Bronze and stainless steel discs were tested. The disc under test was fitted tightly into a flange and bolted between the end flanges of steel pipe enclosures. One enclosure was the explosion chamber, the other the protected chamber. For the first series of tests the effect of the dimensions of the explosion chamber on the quenching of the flame was studied; the hydrogen content was kept at 30% by volume in air. It was found that, with a constant diameter, increasing the length of the chamber resulted in more dangerous explosions. With L/D constant, the larger the diameter of the pipe, the more easily the explosions were transmitted into the protected chamber. In the other series of experiments the hydrogen content was varied between 10 and 60% by volume, while the enclosure was kept constant at one inch diameter pipe. For bronze discs of 120 μm filtration diameter the minimum limiting safe pressure was at the stoichiometric concentration, for 100 μm disks at a slightly lower concentration. For discs of smaller filtration diameters and for stainless steel discs the most dangerous mixture was at a hydrogen content of nearly 20%.

Holmes, C. A. (Forest Products Laboratory, Madison, Wisconsin) "Flammability of Selected Wood Products Under Motor Vehicle Safety Standards," *Journal of Fire and Flammability 4,* 156-164 (1973)

Subjects: Fire test, motor vehicle safety standard No. 302; Wood flammability

Author's Abstract

ABSTRACT: Motor Vehicle Safety Standard No. 302 specifies the burn-resistance requirement and the test procedure for materials used in the occupant compartments of motor vehicles. In this study, the fire performance of some selected wood and wood-based products, including ½-inch lumber, veneers, plywood, hardboard, corrugated fiberboard, and kraft paper, were determined under this standard. Only the 0.012-inch-thick kraft paper burned at a rate in excess of the 4 inches per minute limitation of the standard. The other materials had zero or very low burn rates. Enamel and clear lacquer did not add any flammability by this test method to ⅛-inch birch plywood or hardboard. This study strongly indicated that wood and wood-fiber products in general will have burn rates less than the 4 inches per minute limitation of Standard No. 302.

Krucke, W. "Uses and Evaluation of Non-Flammable Elastomeric Materials," *Colloquim: Space Technology - A Model for Safety Techniques and Accident Prevention,* Institut fur Unfallforschung, Cologne 398-402 (April 1972)

Subject: Non-flammable elastomeric materials

Safety in Mines Abstracts 22 No. 389
Safety in Mines Research Establishment

The development and application of non-flammable fluoroelastomeric compositions started with the need for materials which would be self-extinguishing in 100% oxygen at 16 psi pressure. Several related fluorocarbon elastomeric compositions were used in the Apollo Program to make formed components such as hose, shoe soles, and circuit breaker cases. Coating solution made from one of these compositions found wide use in the Apollo Program as a non-flammable coating for fabrics and plastic substrates. More recently, the coating solution is being evaluated and tested as a coating in aircraft applications. Commercial civilian uses have appeared in electronic equipment, business machines, and fire fighting equipment.

Lie, T. T. and Harmathy, T. Z. (National Research Council Canada, Ottawa, Canada) "Fire Endurance of Concrete-Protected Steel Columns," Journal of the American Concrete Institute No. 1, Proceedings V. 71, 29-32 (January 1974): *Research Paper No. 597, Division of Building Research, National Research Council of Canada*

Subjects: Columns, supports; Concretes; Fire resistance; Fire tests; Steels; Structural design

Author's Abstract

An empirical formula is developed for the prediction of the fire endurance of concrete-protected steel columns. Fire endurance is interpreted as the time during a standard fire test required for the temperature of the steel core to reach 1000F (538 C). In the light of numerous fire test results, the accuracy of the formula appears to be satisfactory. A numerical example is included to show the application of the formula.

Lyle, A. R. and Strawson, H. "Electrostatic Hazards in Tank Filling Operations," *Fire Prevention Science and Technology* (4), 8-12 (1973)

Subjects: Electrostatic hazards; Fuel tank filling hazard

Safety in Mines Abstracts 22 No. 443
Safety in Mines Research Establishment

The article demonstrates how the generation and accumulation of electrostatic charges can lead to real hazards when hydrocarbon products are handled, unless adequate precautions are taken. The precautions may include: the avoidance of flammable air-fuel mixtures, earthing of all conductors, limiting flow rates to minimize pipe charging and increasing the conductivity of the product by means of an additive.

Lynch, J. R. "Respirator Requirements and Practices," Coal Mine Health Seminar. Joint Staff Conference of the Bureau of Mines and the National Institute for Occupational Safety and Health, September 1972, *U.S. Bureau of Mines Information Circular 8568* (1972)

Subject: Respirators, law requirements, need, development

Safety in Mines Abstracts 22 No. 264
Safety in Mines Research Establishment

The purpose of this paper is to discuss the requirements of law with respect to non-emergency respirator use, the need for respirators in various situations that occur in coal mining and the results of a study of the use or non-use of respirators, together with some comments on the attitudes toward respirators and the reasons why they are or are not used. Based on this information, the solutions for some of these problems will be offered. These include the development of respirators which will meet the needs and requirements of law and the development of programs, standards, and regulations which will provide for and require their use.

Mallet, M. "Fireproofing of Cellular Polyurethane Materials," *Revue Generale des Caoutchoucs et Plastiques 48* (7-8), 793-797 (1971) (in French)

Subjects: Fire retardant synthetics; Flammability testing; Combustion phenomenon

Safety in Mines Abstracts 22 No. 390
Safety in Mines Research Establishment

The phenomenon of combustion, the various methods of making flame retardant synthetic materials and methods of testing flammability are reviewed. The methods adopted to protect cellular polyurethanes are discussed. An actual test of the behavior of a cladded urethane panel in fire is described. It is concluded that although much progress remains to be made, current techniques, if properly applied, are sufficient to meet the necessary requirements in most cases.

Manheim, J. R. (Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio) "Vulnerability Assessment of JP-4 and JP-8 Under Vertical Gunfire Impact Conditions," Final Report, February 1970 - March 1971, *Air Force Aero Propulsion Laboratory Report No. AFAPL-TR-73-76* (December 1973)

Subjects: Gunfire; Aviation fuels; Flammability limits; Fuel systems vulnerability; Aircraft safety

Author's Abstract

This report presents results of tests conducted to determine effects of a fifty-caliber incendiary projectile penetrating vertically from the bottom into a partially-filled fuel tank. Fuel types investigated in this program are JP-4 (high volatility fuel) and JP-8 (low volatility fuel). This test program was carried out in two phases: (1) "non-equilibrium" tests conducted with a cylindrical tank to determine effects of fuel temperature, initial ullage pressure, tank volume, fuel depth, venting, etc. and (2) equilibrium tests conducted with various rectangular tank configurations to determine effects of initial fuel-air mass ratio of the ullage fuel-air mixtures on ignition and reaction over-pressures. Results of "non-equilibrium" tests showed that both JP-4 and JP-8 can be ignited over the temperature range of 10 to 130°F. Results also showed that reaction over-pressures resulting from JP-4 tests were generally higher than those from JP-8 tests. Increasing fuel depth and venting area tend to decrease reaction over-pressures. Results of tests conducted with equilibrium fuel-air mixtures indicated that mixtures with initial fuel-air mass ratios as low as .002 could be ignited. No ignition was observed in fuel-air mixtures with initial fuel-air mass ratios greater than 0.11.

O'Neill, J. H., Sommers, D. E., and Nicholas, E. B. (National Aviation Facilities Experimental Center, Atlantic City, New Jersey) "Aerospace Vehicle Hazard Protection Test Program: Detectors; Materials; Fuel Vulnerability," Final Report, October 1970 - September 1972, under Contract No. USAF F33615-71-M-5002 for U.S. Air Force Systems Command (February 1974); *Air Force Aero Propulsion Laboratory Report No. AFAP-TR-73-87*

Subjects: Aerospace vehicle fires; Fires in aerospace vehicles; Detectors; Flammability of materials; Fuel vulnerability

Authors' Abstract

Fire tests were conducted in a turbojet powerplant installation to determine the effectiveness of an Edison and a Honeywell Ultra-violet Fire Detection System. The four sensor units for each system were installed on the forward bulkhead of the engine nacelle's accessory and compressor compartment (Zone II) and provided surveillance aft to the firewall. Fires having fuel-flow rates of 0.04 and 0.13 gallons per minute were initiated about 12 inches forward of the firewall at several locations around the periphery of the engine.

Both systems provided adequate detection of the 0.13 gallon per minute fires, but generally there was limited detection of the small 0.04 gallon per minute fires, depending on the fire location. Both systems provided rapid response time to fires, within the range of 0.2 to 1.0 seconds after the fuel-to-fire was released. In this test installation the peripheral disposition of the sensor units on the forward bulkhead provided overlapping coverage by most units.

A study of flammability and smoke generation characteristics was performed on different types of litter pads and pillows. These items were subjected to the following tests; Horizontal Test Method No. 5906, Vertical Test Method No. 5903, Radiant Panel Test Method, ASTM E-162, and Smoke Measurement Test Method, ASTM STP No. 442.

Fire resistance tests in a standard 2,000°F flame-test environment were conducted on two flexible self-sealing low pressure Aeroquip hoses and an aluminized asbestos-faced flexible fiberglass cloth. One hose was coated with an AVCO Corp. intumescent paint identified as Flexible Flame Arrest; the other was uncoated. The hoses were tested while temperature-controlled oil was pumped through the hose.

An investigation of the vulnerability of JP-4 and JP-8 fuel, contained in a fuel tank, to ignition by incendiary gunfire was made. Tests were conducted utilizing a horizontal, liquid phase test article, either JP-4 or JP-8 fuel and varying the following parameters; (1) standoff distance between the fuel cavity and the test article skin, (2) volume of the standoff cavity, (3) ventilation rate in the standoff space, and (4) airflow over the test article surface. A series of tests was also conducted with an elevated fuel tank. This test configuration permitted fuel to vapor penetration by the incendiary projectile. These tests were conducted with either JP-4 or JP-8 fuel and simulated airflows of 0, 90, 150, and 390 knots over the test article.

Osipov, S. N., Gorb, V. Yu., and Bovsunovskaya, A. Ya. "Calculating the Admission of Nitrogen to Prevent Explosions When Underground Fires Are Being Sealed Off," *Ugol' Ukr. 16* (12), 44-46 (December 1972) (in Russian)

Subjects: Explosion prevention, by nitrogen atmospheres; Mine fire prevention

Safety in Mines Abstracts 22 No. 349
Safety In Mines Research Establishment

Osipov, S. N. and Orlov, N. V. "The Use of Nitrogen for Extinguishing an Underground Fire," Ugol' 45 (8) 60-62 (August 1970) (in Russian) *Safety in Mines Research Establishment Translation 5966*

Subjects: Fire, underground; Fire extinguishment by nitrogen; Nitrogen as fire extinguishing agent

Safety in Mines Abstracts 22 No. 545
Safety in Mines Research Establishment

In recent times nitrogen has been used to seal off fire zones in gassy mines, but a method of determining the amount of nitrogen required has not yet been worked out. Investigations were carried out during 1968 - 1969 to study the movement of nitrogen in sealed-off workings and to discover methods of suplying nitrogen which would ensure rapid filling of the fire zone. The results are described and a method of making the necessary calculations is presented.

Pelouch, J. J., Jr. and Hacker, P. T. (Aerospace Safety Research and Data Institute, Lewis Research Center, Cleveland, Ohio) "Bibliography on Aircraft Fire Hazards and Safety," Volume II - Safety, Part 1, Preliminary Form, 392 pages, *National Aeronautics and Space Administration NASA TMX 71553*

Subjects: Aircraft fire safety; Fire safety of aircraft

Pitt, A.I. (Joint Fire Research Organization, Borehamwood, Herts, England) "Investigation of Safe Operation of a Radiant Portable LPG Heater," *Fire Research Note No. 1014, Joint Fire Research Organization* (June 1974)

Subjects: Space heater; LPG; Tests; BS2773, 1945

Author's Summary

A portable butane-fired radiant heater of high output was tested in accordance with BS 2773 and BS 1945. The heater failed to comply with a number of clauses, but was not in fact stated to comply. However, recent trends in domestic heating comfort requirements indicate that a re-appraisal of current limitations of heat output could be justified.

Powell, J. H. (Safety in Mines Research Establishment, Sheffield, England) "Deficiencies in Safety Schemes which Rely on Stochastically Failing Protective Equipment," *Journal Institute Maths Applics 14* 41-56 (1974)

Subjects: Safety scheme deficiencies; Protective equipment failure

Author's Abstract

Probability theory is used to assess the deficiencies of safety schemes which rely on devices which can fail either in an undetected manner only, or in both undetected and detected ways. Three quantities are used to express the deficiencies of these schemes; the mean period during which devices are ineffective, the proportion of time for which they are ineffective and the distribution of the durations of their ineffective periods. Analytical expressions are derived for these quantities for a scheme in which only undetected failures occur and devices are replaced at regular intervals. Monte Carlo simulation techniques are used to estimate the measures of deficiency for situations in which both types of failure are possible. Consideration is given to the "cost-benefit" aspects of safety schemes in simple circumstances in which the rate of occurrence of the hazards involved, and the penalty to be paid in the event of a catastrophe, are known.

Quintiere, J. (National Bureau of Standards, Gaithersburg, Maryland) "Some Observations on Building Corridor Fires," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania 163 (1975)

Subjects: Corridor fires; Fire tests; Building fires; Hazard analysis

Author's Abstract

Full-scale corridor fire experiments designed to evaluate the potential fire hazard of floor covering materials exposed to a room fire are described. A phenomenological account of events leading to rapid fire propagation along the corridor is presented for one experiment. Mechanisms responsible for the rapid fire propagation, termed flameover, are explored through measurements and analysis of the data. Before flameover the corridor floor is heated by radiation which enables flames to spread into the corridor. On the wood floor considered, flame spread velocity accelerates from $\sim 10^{-2}$ ft/sec to ~ 1 ft/sec following flameover. Causative factors of flameover appear to be the increase in flame height of the floor fire, and a reduction of air supply to the burn room due to a change in flow pattern between the corridor and burn room. Calculations show that air flow to the burn room steadily drops as the corridor fire develops, resulting in incomplete combustion for the room fire.

Rousseau, J. and McDonald, G. H. (AiResearch Manufacturing Company, Torrance, California) "Catalytic Reactor for Inerting of Aircraft Fuel Tanks," *Final Report, June 1971 - June 1974, Contract No. F33615-71C-1901, Air Force Aero Propulsion Laboratory,* Air Force Systems Command (June 1974)

Subjects: Fuel tank inerting; Catalytic fuel oxidation

Authors' Abstract

This program, Catalytic Reactor for Inerting of Aircraft Fuel Tanks, was concerned with the development of a prototype catalytic reactor for the generation of inert gases through jet fuel combustion in engine bleed air. Successful operation of a flight-configured unit was achieved at very high effectiveness. Inert gas oxygen concentrations below 1 percent were achieved repeatedly. Design data were generated related to reactor performance under various operating conditions and also related to thermal and mechanical design of the unit. Corrosion testing of aircraft fuel tank construction materials, including metals, coatings, and sealants, was conducted. These materials were evaluated in terms of resistance to corrosion by SO_2 formed in the fuel oxidation reactor. Using the experimental data generated under this program, a complete fuel tank inerting system was synthesized. This

system weighs 305 lbs, has an overall envelope of 19 by 24 by 55 in., and satisfies all flight conditions, including emergency descent of a large-volume bomber-type of aircraft.

Safety in Mines Research Establishment, "High Voltage Equipment for use in Flammable Atmospheres," *Safety in Mines Research Digest, Electrical Hazards* - 6 (1973)

Subjects: Electrical equipment; High voltage equipment, for flammable atmospheres

Safety in Mines Abstracts 22 No. 274
Safety in Mines Research Establishment

Safety in Mines Research Establishment, "Gas Detection with Semiconductor Metal Oxides," *Safety in Mines Research Establishment Digest, Gas Detection* - 6 (1973)

Subjects: Gas detection; Metal oxides as gas detectors

Safety in Mines Abstracts 22 No. 322
Safety in Mines Research Establishment

A new type of gas-sensing system has been devised at SMRE and is being developed for use in instruments. It relies on the changes in electrical conductivity that can be produced in many semiconductor metal oxides by the adsorption of gases on their surfaces. The selection of suitably "doped" oxides and suitable operating conditions makes it possible, with rugged solid-state sensing elements to detect and measure a wide range of gases.

Schwenker, H. and Sullivan, J. J. "Synthetic Hydrocarbon Fluid is Fire Resistant, Safer Than 5606 Oil," *Hydraulics and Pneumatics 25* (7), 99-100 (1972)

Subjects: Fire-resistant hydraulic oil; Hydrocarbon oil, fire-resistant

Safety in Mines Abstracts 22 No. 258
Safety in Mines Research Establishment

A new formulated synthetic hydrocarbon-base fluid has significantly improved fire resistance compared to MIL-H-5606 (B) petroleum base hydraulic fluid-red oil. The new fluid, designated MIL-H-83282 may be used in the 5606 systems of aircraft, spacecraft, and support equipment without altering the systems. Characteristics and properties of the fluid are outlined together with some conversion considerations.

Spratt, D. and Heselden, A. J. M. (Joint Fire Research Organization, Borehamwood, Herts, England) "Efficient Extraction of Smoke from a Thin Layer under a Ceiling," *Fire Research Note No. 1001, Joint Fire Research Organization* (February 1974)

Subjects: Smoke extraction; Venting; Ceiling smoke

Authors' Summary

A method of smoke control has been advocated in which smoky gases generated by a fire are extracted at ceiling level from the layer they form there because they are buoyant. However, too high an extraction rate at a given point will draw up air from underneath the layer into the extraction duct and this will markedly reduce the actual amount of smoky gases removed.

This note reports experiments showing that the maximum extraction rate before air is drawn up depends mainly on the layer depth and temperature and is not sensitive to the area or shape of the extraction opening over the range of areas of major practical importance. An expression, derived from large and small-scale experiments, is given for this maximum extraction rate.

In practice, to achieve a rate of removal of smoke equal to the rate at which a fire is producing it, extraction at a number of well-separated points may be necessary.

A very simple expression has been derived from this work for the maximum size for a vent in the form of a simple opening in a flat roof, if entrainment and hence inefficient extraction are to be avoided.

Virr, L. E. and Pearson, F. K. (Safety in Mines Research Establishment, Sheffield, England) "Fail-safe Earth Fault Detection Device for Battery Supplies," *Proc. Inst. Electr. Eng. 121* (8) 829 (1974)

Subjects: Coal mine locomotives; Earth fault detection; Detection of earth fault

Authors' Abstract

An electronic method for detecting an earth fault on a fully insulated battery system that fails to safety in the event of supply, component, or connection failure, is described. The particular application to battery-driven coal-mine locomotives is discussed, and a device recently built and tested by the authors for this purpose is described in detail. The device is such that intrinsic safety for methane-air mixtures may be achieved, if desired, with flameproof enclosure of a minimal number of components, and in normal operation even a zero-resistance fault to earth on the battery to which it is connected cannot cause ignition of hydrogen-oxygen gas mixtures.

Watanabe, Y., *et al.* "Effect of Fire Retardants on Combustible Materials Underground," *Mining and Safety Japan 18* (11), 1-8 (1972) (in Japanese)

Subjects: Retardants; Mines; Tunnels; Combustible materials

Safety in Mines Abstracts 22 No. 79
Safety in Mines Research Establishment

Two kinds of fire-retardants (F-10 and P-35) coated on wood, coal, and metal plates were tested by means of applying a propane torch or a furnace which simulated an underground fire. The results obtained showed that both coatings produce only little poisonous gases and are usable in mines; the P-35 coating, especially, has a better retardation effect against fire.

Wiersma, S. J. and Martin, S. B. (Stanford Research Institute, Menlo Park, California) "Evaluation of the Nuclear Fire Threat to Urban Areas," Annual Report, August 1972 - September 1973, Contract No. DAHC20-70-C-0219, *Defense Civil Preparedness Agency* (September 1973)

Subjects: Nuclear fire threat; Dynamic behavior of fires; Structural fires, response to blast waves; Fire spread in debris; Fire-blast interaction

Authors' Abstract

The *nuclear fire threat* to urban areas was evaluated in a four-task program. During three previous years of experiments the *dynamic behavior of fires* in full-scale structures and the nature and magnitude of behavioral changes that result from variations in both structural and environmental factors were studied. This year an attempt was made to integrate the present *structural fire behavior* knowledge with blast knowledge and to predict the combined blast-fire responses of an urban area to a nuclear attack.

In Task 1 a problem definition and sensitivity analysis was conducted to identify the blast damage and fire situations that are important to study and then a description of an *attack environment following a nuclear detonation* was attempted. Further analysis of the *structural response to blast waves* and of the interaction between blast and fire is found necessary before a reliable description of the attack environment can be accomplished.

In Task 2, three field tests of fire development in full-scale structures were made in response to questions raised in the problem definition. In the first field test fire was found not to spread to the interior of a building from a neighboring burning structure so rapidly as expected because induced air currents were drawn toward the initial fire. In the second and third field tests the environment in an improvised basement shelter beneath a burning building and the *fire spread in debris* were measured.

In Task 3, a method of *simulating air blast effects* on structures was investigated. The scale model experiment showed promise for simulating room filling by a blast wave; however, simulating the collapse of a structure by a blast wave using the vacuum-air bag technique is not feasible.

In Task 4, a *blast-fire interaction* experiment was attempted to determine the *influence of air blast* and its effects on the incendiary responses of combustible target areas. At Mixed Company, a 500-ton TNT blast and shock experiment, test plots of burning liquid fuels contained by a series of pans of varying lengths were located at each of three stations at 5-, 2-, and 1-psi peak overpressures. It was anticipated that the flames on some of the smaller pans would be displaced sufficiently by the shock wave to extinguish the flames, but that the larger pans at each station would remain burning and thus the dependence of the size of threshold fires that are extinguished by air shocks on characteristics of shock and flow could be computed. However, no fire at any of the three stations was extinguished by the

shock wave, a result that seemingly contradicts the conclusion of a previous experiment.

Wilson, D. M., Katz, B. S., and Demske, D. (Naval Ordnance Laboratory, Silver Spring, Maryland) "The Use of Water Cooling for Protection Against Thermal Radiation from a Nuclear Weapon Detonation," *Technical Report NOLTR 74-59,* Naval Ordnance Laboratory (April 1974)

Subjects: Water flow cooling; Cooling by water spray; Nuclear weapons effects; Ship structures

Authors' Abstract

An experimental study was completed to determine the effectiveness of water cooling plates which are being exposed to the thermal radiation pulse of a nuclear weapon detonation. Heat transfer rates were measured on heated plates on which water was either sprayed or allowed to flow downward in a thin sheet. The plates in the experiments where cooling water flows over the plate were simultaneously heated by igniting a sheet of rocket propellant which had been placed behind the plate. The plates in the spray cooling experiments were preheated to approximately 300°C and data was taken as the water cooled the plate. One flow rate was used in the flow cooling test (1.0 GPM/foot width) and two flow rates (1.10 GPM and 0.25 GPM/square foot of area) were used in the spray cooling tests. Heat transfer data from both the spray cooling and flow cooling tests were used in a computer program to compute the effectiveness of water cooling aluminum plates on ships exposed to the thermal radiation pulse of a nuclear weapon detonation. The value of water cooling is shown by comparing the maximum plate temperatures with and without cooling for weapon yields of 100 and 1000 kilotons, aluminum plate thicknesses between ⅛″ and ¼″, and ship to weapon distances corresponding to peak airblast overpressures up to 15 psi.

Wraight, H. G. H. (Joint Fire Research Organization, Borehamwood, Herts, England) "The Fire Problems of Pedestrian Precincts, Part 5. A Review of Fires in Enclosed Shopping Complexes," *Fire Research Note No. 1012, Joint Fire Research Organization* (June 1974)

Subjects: Fire hazard; Shopping complexes; Pedestrian precincts; Fires in shopping malls

Author's Summary

This Note describes a number of fire incidents in enclosed shopping complexes and some other buildings also used for retailing. Factors common to different fires are compared. The fires described occurred in the USA, the UK, Canada, and Mexico.

The worst hazards are noted and suggestions are made as to how these may be overcome.

B. Ignition of Fires

Ballal, D. R. and Lefebvre, A. H. (Cranfield Institute of Technology, Cranfield, Bedford, England) "The Influence of Flow Parameters on Minimum Ignition Energy and Quenching Distance," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1473 (1975)

Subjects: Flow effects on ignition; Ignition energy; Quenching distance; Turbulence; Spark ignition

Authors' Abstract

Experiments have been carried out on the effects of pressure, velocity, mixture strength, turbulence intensity, and turbulence scale on minimum ignition energy and quenching distance. Tests were conducted at room temperature in a specially designed closed-circuit tunnel in which a fan was used to drive propane/air mixtures at subatmospheric pressures through a 9 cm square working section at velocities up to 50 m/sec. Perforated plates located at the upstream end of the working section provided near-isotropic turbulence in the ignition zone ranging from 1 to 22 percent in intensity, with values of turbulence scale up to 0.8 cm. Ignition was effected using capacitance sparks whose energy and duration could be varied independently.

The results of these tests showed that rectangular, arc-type sparks of 60 μsec duration gave lower than previously reported values of ignition energy for both stagnant and flowing mixtures. It was found that both quenching distance and minimum ignition energy increased with (a) increase in velocity, (b) reduction in pressure, (c) departures from stoichiometric fuel/air ratio, and (d) increase in turbulence intensity. Increase in turbulence scale either raised or lowered ignition energy, depending on the level of turbulence intensity. Equations based on an idealized model of the ignition process satisfactorily predicted all the experimental data on minimum ignition energy.

Burgess, D., Murphy, J. N., Zabetakis, M. G., and Perlee, H. E. (Bureau of Mines, Pittsburgh, Pennsylvania) "Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 289 (1975) See Section A.

Dixon-Lewis, G. and Shepherd, I. G. (Houldsworth School of Applied Science, The University, Leeds, England) "Some Aspects of Ignition by Localized Sources, and of Cylindrical and Spherical Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1483 (1975)

Subjects: Ignition, localized; Minimum ignition energy; Flame structure; H atom profiles

Authors' Abstract

The time dependent conservation equations governing flame propagation in cylindrical and spherical systems have been set up and solved by finite difference methods for the case of a 60% hydrogen–air flame. By this means it is possible (a) numerically to follow the sequence of events following an "ignition" at the axis of a cylinder or the center of a sphere, or (b) to investigate the effect of flame curvature on burning velocity and other flame properties.

It was found that the minimum ignition energy depended on the form in which the energy was supplied. For a constant total energy, ignition was facilitated by increasing the proportion supplied as H atoms rather than as thermal energy.

The velocities of movement of the freely propagating flames from the ignitions were found to be slightly different from those of the inward propagating, cylindrical and spherical stationary flames. The velocities of the latter were independent of the flame diameter. The effect of curvature on the flame properties is shown to be an effect on reaction rate distribution, which also leads to differences in H atom concentration profiles. Unlike the situation in planar flames, the detailed structure of freely propagating curved flames may not be the same as that of the corresponding stationary flames, and this may lead to the apparent differences in burning velocity.

Frandsen, W. H. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Effective Heating of Fuel Ahead of Spreading Fire," *U.S. Department of Agriculture Forest Service Research Report Paper INT* - 140 (1973)

Subjects: Fire behavior; Ignition; Forest fire; Fire spread model; Fuel crib heating

Author's Abstract

An array of thermocouples was implanted in selected members of a fuel crib (0.6 cm. and 1.3 cm. in thickness) to obtain the heat absorbed by the fuel members prior to ignition. The fraction absorbed compared to the total that would be absorbed if uniformly heated is the effective heating number. It is represented graphically as decreasing exponentially with the reciprocal of the surface area-to-volume ratio.

Gurevich, M. A., Ozerova, G. E., and Stysanov, A. M. (Leningrad) "Critical Conditions of Self-Ignition of a Poly-Dispersed Gas Suspension of Solid-Fuel Particles," *Fizika Goreniya i Vzryva 7* (1), 9-19 (March 1971) (in Russian)

Subjects: Ignition of particles; Particle ignition; Self ignition; Critical ignition conditions

Authors' Conclusions
Translated by L. Holtschlag

A theoretical analysis is made of simplified configurations of the fuel ignition process in order to allow calculation of critical self-ignition conditions for a polydispersed gas suspension of particles, under the following assumptions:

1. Chemical reaction occurs only on the surface of the particles; the dependence of the reaction rate on the temperature and oxidizer content is described by the Arrhenius formula.

2. The heat liberated during reaction is transmitted to the walls by the gas surrounding the particles. The gas temperature at any instant is constant over the whole volume.

3. Mass transfer between the gas suspension and the outer medium is absent, and the oxidizer content is the same and time-constant over the entire volume.

4. The particles are spherical, constant in size, and without a temperature gradient. Particles of each size are uniformly distributed in the gas volume.

5. The gas density, specific heat, and thermal-conductivity coefficient are constant. Ignition limits are obtained for a gas suspension of particles consisting of two fractions and for a suspension with a continuous size distribution of particles.

Handa, T., Suzuki, H., Takahashi, A., and Morita, M. (Science University of Tokyo) "Examination of the Conditions for the Self Ignition of Wood: Part II. Critical Conditions and Anisotropy Effect for the Self Ignition of Wood Spheres Compared with Computer Simulation," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 15 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Ignition; Self ignition; Spontaneous ignition; Wood

Authors' Conclusions

As a continuation of our earlier report, we have discussed the possibility of the self ignition of wood induced by long-term low-temperature heating. Heating either from one side or from both sides greatly alters the interior temperature distribution pattern, and when the wood is wrapped in some other materials, the nature of the wrapper, whether an insulator or a good heat conductor, changes the ignition time and ignition temperature. Moreover, the anisotropy effects of wood fibre direction must be considered in the search for the cause of self ignition.

The activation energy which controls the thermal decomposition rate of wood seems to be related to micromolecular parameters in relation to wood structures, such as oxygen partial pressure on the internal surface or in the opening, vapor density, etc. The nature of the wood, old or new, which determines the activation energy, can be an important factor in fire appraisals concerning ignition points or ignition times.

The fire examples described in our earlier report concerned new materials, and when we considered heating from one side, self ignition became most improbable. The examination of carbonization direction and temperature at the ignition point is to clarify the details in the appraisal of heating direction and ignition. The direction and depth of carbonization in this example have already been reported in the previous report, which excludes the possibility of self ignition. However, the problem of heating conditions and the cracks induced by thermal stress related to the wood fibre direction remain unsolved. The possibility of heated air convection into the cracks, the oxygen supply, and local ignition of fires must be considered; however, the cracks decrease the heat accumulation's effects and the possibility of self ignition becomes small. The problem of heat evolution per unit weight loss, and the activation energy concerning the heat evolution rate which were examined at the end of this report require more detailed investigation.

Hibbard, R. R. and Hacker, P. T. (Lewis Research Center, Cleveland, Ohio) "An Evaluation of the Relative Fire Hazards of Jet A and Jet B for Commercial Flight," *National Aeronautic and Space Administration Technical Memorandum X-71437* (October 1973)

Subjects: Fire hazards of fuels; Jet fuels, fire hazard; Fuel ignition; Flame propagation rate

Authors' Abstract

The relative fire hazards of Jet A and Jet B aircraft fuels are evaluated. The evaluation is based on a consideration of the presence of and/or the generation of flammable mixtures in fuel systems, the ignition characteristics, and the flame propagation rates for the two fuel types. Three distinct aircraft operating regimes where fuel type may be a factor in fire hazards are considered. These are (1) ground handling and refueling, (2) flight, and (3) crash. The evaluation indicates that the overall fire hazards for Jet A are less than for Jet B fuel.

Kashiwagi, T. (National Bureau of Standards, Washington, D.C.) "Flame Spread over a Porous Surface under an External Radiation Field," *National Bureau of Standards Special Publication 411,* 97 (August 1973)

Subjects: Carpet flammability; Flame spread, Ignition

Author's Abstract

Flame spread over carpet surfaces was studied under various constant external radiant fluxes from 0.4 to 1.2 W/cm^2. Characteristics of ignition and flame spread including speed of spread and net heat release rate were measured. The results indicate that these values increase rapidly with increasing external radiant flux. It was also observed that there exists a minimum radiant flux necessary to sustain steady flame spread for each carpet. The underlayment of a carpet has a significant effect on ignition and flame spread speed for nylon carpets due to melting of fibers before flameover. However, this effect is negligible for low pile density acrylic carpets.

Kashiwagi, T. (National Bureau of Standards, Gaithersburg, Maryland) "A Radiative Ignition Model of a Solid Fuel," *Combustion Science and Technology 8* 225 (1974)

Subjects: Radiative ignition; Solid fuel ignition; Ignitability

Author's Abstract

A theoretical model describing radiative ignition of a solid fuel is constructed and is numerically analyzed. The model includes the effects of gas phase reaction and a finite value of the absorption coefficient of the solid (in-depth absorption of incident radiation). It is found that the gas phase reaction must be included in the model in order to understand radiative ignition of a solid fuel and to find its ignition boundary. The in-depth absorption of the incident radiation by a solid fuel significantly affects the ignition delay time. The results indicate that there is a finite range of values for pyrolysis or gas phase reaction activation energy for which ignition will occur. This finding has a direct bearing on efforts to reduce material ignitability.

Kuchta, J. M., Hertzberg, M., Cato, R., Litton, C. D., Burgess, D., and Van Dolah, R. W. (Bureau of Mines, Pittsburgh, Pennsylvania) "Criteria of Incipient Combustion in Coal Mines," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 127(1975)

Subjects: Coal; Mines; Incipient combustion; Spontaneous combustion

Authors' Abstract

The formation of carbon monoxide (CO) and other gases by various American coals was investigated to determine their relevance to spontaneous heating and to the problem of incipient fire detection. Desorption experiments under constant volume showed that ground samples of the coals yield $CO/\Delta O_2$ ratios that are essentially constant for extended explosure periods in air at 25°C and are highest for coals from mines suspected of having a self-heating hazard; the latter coals also yield high CO/CO_2 ratios. These ratios vary with particle size and surface moisture content and correlate best with the oxygen content of the coal, although the correlation was not always consistent with the absolute level of CO production. Similar experiments in an atmosphere containing the $^{18}O_2$ isotope revealed that the O_2 reduction at ambient temperature is most likely due to chemisorption and the CO and CO_2 formation is attributable to decarbonylation, decarboxylation, or desorbed products from previous reaction of the coal in its virgin state. Results of flow experiments at various temperatures indicated that the $CO/\Delta O_2$ and CO/CO_2 ratios are highly sensitive to temperature. The temperature dependence of the rate of CO or CO_2 production between 50° and 150°C was approximately comparable to that derived from the adiabatic self-heating rate for each coal; apparent activation energies were between 10 and 20 kcal/mole. Below 50°C, the rate data were meager but supported the assumption that oxidation was not a significant factor at ambient temperature.

The sensitivity and reliability of combustion product sensors as mine fire detectors were investigated with heated coal samples in flowing air. Submicron particulates appeared earlier than measurable CO emissions, suggesting that pyrolysis is a precursor to rapid oxidation. Data are presented to compare the autoignition temperature of the coal and the detection threshold temperature as functions of particle size of the coal.

Rae, D. (Safety in Mines Research Establishment, Sheffield, England) "Initiation of Weak Coal-Dust Explosions in Long Galleries and the Importance of the Time Dependence of the Explosion Pressure," *Fourteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1225 (1973)

Subjects: Coal dust explosions; Ignition; Time dependence of explosion pressure; Weak coal dust explosions; Long gallery coal dust explosions

Author's Abstract

Weak coal-dust explosions in galleries (large horizontal tubes) are defined in the paper as the early stages of what may eventually become a self-sustaining, steady-state situation, if the scale is large enough. An initiating explosion producing a pressure rise of at least 12 kPa is needed to start an explosion from any additional dust that lies beyond the initiating zone; entrainment of this additional dust leads to the main explosion. In long galleries, initiating explosions in the range 16±2 kPa are mostly used. The early stages of the main explosion resemble explosions in which combustion of a very low concentration of coal-dust particles is taking place over a considerable volume at any given time, rather than explosions in which a flame, having a more or less definable front and rear, is propagating through a preformed explosive mixture. The explosions are described in terms of the general shape of the pressure changes occurring at a point near the outermost extent of the flame that is produced by the initiation explosion alone. The initial pressure rise is determined by the form of the initiating explosion and is followed by a roughly exponential pressure increase (from atmospheric pressure), whose time constant depends on the nature of the coal-dust, its dispersion, and the dimensions and characteristics of the gallery. The effects on the development of the explosion of the presence of short dust deposits, suppressive devices, and the ignition of predispersed clouds are briefly discussed. It is concluded that, in weak explosions, propagation results from dust being swept from the floor into the zone of combustion behind the flame front. However, as pressures increase to above, say 100 kPa, other mechanisms become responsible and, perhaps, a pre-detonation regime sets in.

Richard, J. R., Vovelle, C., and Delbourgo, R. (Centre de Recherches sur la Chemie de la Combustion et des Hautes Températures C.N.R.S., Orléans la Source, France) "Flammability and Combustion Properties of Polyolefinic Materials," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 205 (1975)

Subjects: Flammability; Combustion properties, Polyolefin polymers; Oxygen index; TGA (thermogravimetric analysis); Polystyrene; Char limits; Pyrolysis; Flame structure

Authors' Abstract

Polyolefin samples were subjected to thermogravimetric analysis, pyrolysis, and flame structure studies. Polyethylenes (low and high density) and polypropylene

give stable counter-diffusion and diffusion flames for which temperature and species profiles can be determined with excellent reproducibility. Low oxygen indices and mass burning rates were measured for these materials, whereas the tendency of polystyrene to char limits the application of these methods.

Evidence is given for the composition of the gaseous phase generated by the pyrolysis process. The flames are fed by the flammable mixture produced by the pyrolysis reaction mixed with traces of oxygen that appear to be present in the "feeding space" between the flame and the polymer melt. Complete analysis and profiles are given.

The limitations of the Low Oxygen Index determination as a practical test are discussed and its validity questionned.

Shivadev, U. K. (University of California, San Diego, La Jolla, California) **and Emmons, H. W.** (Harvard University, Cambridge, Massachusetts) "Thermal Degradation and Spontaneous Ignition of Paper Sheets in Air by Irradiation," *Combustion and Flame 22,* 223-236 (1974)

Subjects: Irradiation of paper sheets; Thermal degradation of paper; Spontaneous ignition of paper

Authors' Abstract

The temperature and surface-density histories of a radiantly heated, thermally thin filter-paper sheet held freely in air were measured in order to study the dynamics of the ignition of paper. Analyses of these histories indicate that the chemically complex degradation reactions can be approximately represented for fire dynamics purposes by two competitive first-order reactions with Arrhenius kinetics as observed by Tang [3]. One of these reactions with a preexponential factor 5.9×10^6 sec^{-1} and an activation energy 26 kcal/gm-mole is dominant at less than about 655°K. At higher temperatures, the other reaction with a preexponential factor 1.9×10^{16} sec^{-1} and an activation energy 54 kcal/gm-mole is dominant. The heat-transfer rates to and from the test sheet were measured in order to estimate the energetics of the reactions. The data were insensitive to the small heat of the low-temperature reaction. Assuming this heat to be –88 cal/g (endothermic), based on DTA measurements of Tang and Neill [8], the heat of the high-temperature reaction is estimated to be about 444 cal/g (exothermic). An approximate formula is developed to predict the spontaneous ignition of a thermally thin sheet under known heating and cooling conditions, provided the Arrhenius kinetics and the heat of a first-order reaction in the sheet are known. Using the measured kinetics and heat of the high-temperature reaction in this formula, the results are compared with the measured data as well as with Martin's [9] ignition data.

Wraight, H. (Joint Fire Research Organization, Borehamwood, Herts, England) "The Ignition of Corrugated Fibreboard (Cardboard) by Thermal Radiation," *Fire Research Note No. 1002, Joint Fire Research Organization* (February 1974)

Subjects: Ignition; Radiation; Fibreboard; Cardboard

Author's Summary

The ignition characteristics of corrugated fibreboard (commonly called corrugated cardboard) are of considerable interest in view of its widespread use for packing cases in high stack storage warehouses. Samples of this material have, therefore, been tested to determine their ease of ignition by thermal radiation.

The results have been tabulated and displayed for three thicknesses of material for both spontaneous and pilot ignition and compared with corresponding results for common softwood.

The minimum irradiance for pilot ignition was 1.5 W/cm^2 - only slightly below that for European whitewood, but the minimum intensity for spontaneous ignition was about 1.7 W/cm^2, about 1/3 of that for European whitewood.

C. Detection of Fires

Custer, R. L. P., and Bright, R. G. (National Bureau of Standards, Washington, D.C.) "Fire Detection: The State of the Art," Final Report No. NASA CR-134642, Contract No. NASA Order C-506273, National Aeronautics and Space Administration, *Aerospace Research and Data Institute* (June 1974)

Subjects: Fire detection; Code requirements, for fire detection; Fire detector testing and standards; Fire signatures; Fire detectors

Authors' Abstract

The current state-of-the-art in fire detection technology is reviewed considering the nature of fire signatures, detection modes used, test methods, performance requirements, and code requirements for fire detection. Present trends in standards development and recommendations for future work are included. An extensive bibliography is provided.

Electrical Review "Sniffing the Fire and Snuffing It," *Electrical Review 192* (7) 253-254 (1973)

Subjects: Fire detector; Ionization detector

Safety in Mines Abstracts 22 No. 263
Safety in Mines Research Establishment

Ionization detectors sometimes react to transient peaks of combustion products where no real danger exists. The article describes a new design of ionization fire detector that overcomes this problem by incorporating an integration period which enables the device to be set to a finer sensitivity. The manufacturing company concerned has also developed a new extinguishant which is claimed to be of particular importance to areas containing electrical equipment (bromotrifluoremethane). The toxicity is low enough to allow personnel to see and breathe in the area of the fire.

Hertzberg, M., Litton, C. D., Donaldson, W. F., and Burgess, D. (Bureau of Mines, Pittsburgh, Pennsylvania) "The Infrared Radiance and The Optical Detection of Fires and Explosions," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 137 (1975)

Subjects: Fire detector; Explosion detectors; Optical detectors; Detectors for fire and explosion; Infrared detectors for fire

Authors' Abstract

The optical detection of an explosion or fire event is considered quantitatively in terms of the source radiance, background, or stray irradiances, and the spectral responsitivities of the available sensors. The infrared spectral source radiances from spherical methane-air "ignitions" were measured and the data analyzed. They served as a basis for the development of a new detector which uses wavelength selection about the 4.4-μm CO_2 band to detect fires and explosions rapidly and reliably; and to discriminate effectively against false sources. The data are also of fundamental interest, yielding consistent temperatures and spectral growth patterns. An equation is derived for the fraction of combustion power radiating to free space which seems to approach a natural limit for slow explosion of large size.

Typical radiance data from hydrocarbon pool flames are also considered. An earlier, empirical, linear correlation of large pool burning rate with the ratio, $\Delta H_c / \Delta H_v$, is revised and related to radiative transport factors and the limit burning velocity for quenching by natural convection at the flammability threshold.

Luck, H. "The Relationship Between the Testing, Utilization and Assessment of Fire Detectors," *Ztschr. VFDB 22* (1), 28-32 (February 1973) (in German)

Subject: Fire Detectors

Safety in Mines Abstracts 22 No. 260
Safety in Mines Research Establishment

The article describes detectors based on the principles of temperature, smoke, and flame detection and discusses the control and inspection of detectors.

O'Neill, J. H., Sommers, D. E., and Nicholas, E. B. (National Aviation Facilities Experimental Center, Atlantic City, New Jersey) "Aerospace Vehicle Hazard Protection Test Program: Detectors; Materials; Fuel Vulnerability, " Final Report, October 1970 - September 1972, Contract No. USAF F33615-71-M-5002, U.S. Air Force Systems Command (February 1974), *Air Force Aero Propulsion Laboratory Report No. AFAP-TR-73-87.* See Section A.

Pickard, R. W. "Approvals Criteria for Automatic Fire Detectors and Alarm Systems," *Electrical Review 192* (7), 250-251 (1973)

Subjects: Fire detectors; Alarm systems

Safety in Mines Abstracts 22 No. 261
Safety in Mines Research Establishment

The article deals with the testing and criteria adopted in assessing the performance of detector and alarm systems and lists the requirements set in BS 3116: Part I: 1970 (Heat sensitive detectors for automatic fire alarm systems in buildings) and reviews requirements for control and indicating equipment and transmission of alarm systems.

Watanabe, A. and Takemoto, A., "Response Characteristics of Smoke Detectors in the Early Stage of Fire," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 70 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Fire detector response; Smoke detector; Detectors

Authors' Conclusions

The effects of smokes generated from various combustible substances on the response characteristics of smoke detectors: the light scattering type smoke detector operated at the rated smoke density for cellulosic smoke. It operated at a density equal to four times that of the rated density for sooty smokes generated from burning kerosene and polystyrene, and at intermediate density for smouldering cellulosic smoke. Ionization chamber type detectors were sensitive to flaming combustion, insensitive to smouldering smoke. Tests were conducted in a small-sized room under various conditions of combustion for various combustible substances. However, additional fire tests in rooms which have different space dimensions should be conducted.

The influence of change in smoke properties with the passage of time due to the smoke movement upon the response characteristics of smoke detectors: the smoke density at the time of operation increased with the increase of distance from the origin of the fire for both types of smoke detectors.

The fire tests conducted by the authors may serve not only for the assessment of detectors, the establishment of effective test methods to be conducted at the site of test fires, the adequate scale for fire detection, and technical assessment for the new fire detection system, but should also help the optimum choice of smoke detectors. Consequently, further improvements of methods of maintenance, ignition, and selection of samples are desired in order to promote reproducibility of the tests.

Whitehouse, R. B. "Automatic Fire Detection Equipment," *Electrical Review 192* (7), 248-250 (1973)

Subjects: Fire detectors; Fire systems design

Safety in Mines Abstracts 22 No. 259
Safety in Mines Research Establishment

The article discusses the design of precaution systems over and above the requirements of legislation - heat sensitive detectors, optical smoke detectors, rate of temperature rise detectors, and ionization detectors are covered. The matching of the various types of circuit to suit the type of detector is discussed.

D. Propagation of Fires

Campbell, A. S. (University of Maine, Orono, Maine) "Fire Spread Over Paper," *Journal of Fire and Flammability-5,* 167-178 (1974)

Subjects: Fire Spread; Paper, fire spread

Author's Abstract

An experimental study of the influences of sheet thickness and initial temperature on the steady state rate of spread of a fire moving downward over filter paper. The data indicates that a simple relationship exists between rate of spread and heat flux from the flame.

Fernandez-Pello, A. and Williams, F. A. (University of California, San Diego, La Jolla, California) "Laminar Flame Spread Over PMMA Surfaces," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 217 (1975)

Subjects: Flame spread; Surface burning; Polymers; PMMA (Polymethyl Methacrylate); Laminar flames on polymers; Diffusion flame; Modeling flame structure

Authors' Abstract

A study is made of the mechanisms by which laminar flames spread over flat surfaces of polymethylmethacrylate, in directions ranging from downward to horizontal. Measurements of spread rates, temperature fields, and velocity fields are reported. Techniques employed include thermocouple probing, photography, interferometry, radiometer measurements, sampling followed by gas chromatography, and particle-track photography. A simplified theoretical model of the spread process is developed, involving forward heat conduction through the solid as the major mode of the energy transfer and thermal runaway of a gas-phase ignition reaction of methylmethacrylate vapor in a boundary layer just upstream from the point of flame attachment. The extent to which this physical model applies to other materials will depend on the thermal and chemical-kinetic properties of those materials.

Frandsen, W. H. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Fire Spread Through Porous Fuels from the Conservation of Energy," *Combustion and Flame 16,* 9-16 (1971)

Subjects: Fire spread; Porous fuels; Heat flux; Energy conservation

Author's Abstract

The rate of spread of fire through a fuel bed in the quasi-steady state was evaluated on an energy flux conservation basis. Another heat flux term, in addition to the forward horizontal heat flux, was found to be of significance in the description

of fire propagation. The additional term involves the vertical gradient of the vertical component of the overall forward heat flux and is shown to be dependent on the shape of the combustion zone interface within the fuel bed.

Frandsen, W. H. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Effective Heating of Fuel Ahead of a Spreading Fire," *U.S. Department of Agriculture Forest Service Research Report Paper INT - 140* (1973). See Section B.

Handa, T. and Takahashi, A. (The Science University of Tokyo) "Analysis of the Surface Flame Spread of Organic Building Materials, Part I. Surface Flame on Plywood Materials in an Inclined Tunnel Furnace as a Model of the Initial Cause of Fire," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 101 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Building materials; Flame spread

Authors' Conclusions

An inclined tunnel-furnace was used to simulate the actual situation of a flame propagation which starts from the four corners of the ceiling or walls of a building.

From Experiments and analytical computation of the flame propagation properties in the inclined tunnel-furnace, it was concluded that: (a) the external driving force to propagate the flame is attributable to the draught effect induced by the growth of flame; (b) buoyancy acts inversely proportional to draught, i.e., the more the buoyancy increases, the more the draught effect decreases; and (c) the direct driving force to propagate the flame is considered to be an effect of the remaining heat quantity derived from a thermal radiation normal to the surface of a sample. Therefore, the shapes of wall, ceiling, and corners, as well as flame face evolved along them, are considered as the decisive factors to determine the flame-spread velocity at the initial stage of ordinary building fires.

The vibration phenomenon that appeared in flame propagation requires a two-dimensional analysis regarding heat transmission towards the surface of a sample as well as heat conduction to the thickness of the sample. The analysis, however, failed in explaining the velocity fluctuation that appeared in flame propagation. It has been considered that mass transfer flux also vibrates with time.

An experiment is required to separate the draught effect caused by the intense hot air flow from the radiation effect, by using a U. L. furnace which controls hot air flow velocity at inclination angle O = O.

Hibbard, R. R. and Hacker, P. T. (Lewis Research Center, Cleveland, Ohio) "An Evaluation of the Relative Fire Hazards of Jet A and Jet B for Commercial Flight," *National Aeronautic and Space Administration Technical Memorandum X-71437* (October 1973). See Section B.

Hirano, T. and Sato, K. (Ibaraki University, Ibaraki, Japan) "Effects of Radiation and Convection on Gas Velocity and Temperature Profiles of Flames Spreading Over Paper," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 233 (1975)

Subjects: Radiation; Convection; Gas velocity; Temperature profiles; Flame structure; Paper

Authors' Abstract

The effects of radiation and convection on the mechanism of flame spread over a thin combustible solid have been studied. The gas velocity and temperature profiles near flames spreading downward over paper were measured using particle tracer techniques and fine-wire thermocouples.

The air stream moving vertically upward was decelerated as it approached the leading edge of a stably spreading flame, and a lower velocity region appeared near the paper surface in front of the leading flame edge. When a low-velocity air stream flowed vertically downward, vortices appeared near the spreading flame. The temperature profiles near a stably spreading flame indicated that a large amount of heat flowed to the unburned material in a narrow region adjacent to the pyrolysis front. When the air flowed vertically downward, hot gas flowed along the paper surface in front of the pyrolysis front. The increase of the flame spread rate with the increase of the radiative heat flux was attributed mainly to the increase of the surface temperature due to radiative heating. The flame spread rate was shown to be closely related to the velocity profile just in front of the leading edge of the spreading flame.

Kashiwagi, T. (National Bureau of Standards, Washington, D.C.) "Experimental Observation of Flame Spread Characteristics over Selected Carpets," *Journal of Fire and Flammability - Consumer Product Flammability 1* 367 (1974)

Subjects: Carpets; Flame spread

Author's Abstract

A small laboratory size experiment was used to observe the characteristics of flame spread over various carpets under various constant external radiant fluxes ($0.10\sim0.27$ cal/cm^2 sec or $0.4\sim1.15$ w/cm^2). The results indicate that a minimum radiant flux is necessary to sustain flame spread over a carpet surface for the carpets tested. By increasing radiant flux, the flame spread velocity increases sharply and can reach several cm/sec. At a high external radiant flux, preheating time is the controlling factor for flame spread velocity. Ignitability, weight loss, and net heat release rate were also measured under various radiant fluxes. The effect of an underlayment on ignitability, flame spread speed, weight loss, and net heat release rate, was also observed for various carpets.

Kashiwagi, T. (National Bureau of Standards, Washington, D.C.) "Flame Spread over a Porous Surface under an External Radiation Field," *National Bureau of Standards Special Publication 411,* 97 (August 1973). See Section B.

Kashiwagi, T. (National Bureau of Standards, Washington, D.C.) "A Study of Flame Spread over a Porous Material under External Radiation Fluxes," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 255 (1975)

Subjects: Flame spread; Porous materials; Radiation; Carpets

Author's Abstract

Characteristics of horizontal flame spread over the surface of a porous material, a carpet in this study, are studied experimentally and theoretically under various external radiant fluxes (0.1–0.27 cal/cm²sec). It is observed that the size of flame is increased significantly by increasing the external radiant flux. This increases the radiative heat feedback from the flame so that it becomes comparable to or greater than the convective heat feedback. The external radiation can also cause an unstable motion of the flame front. This effect is probably due to the production of volatile pyrolysis products ahead of the flame front instead of under it. The theoretical calculation indicates that the thermal emission loss from the heated sample is significant and the internal radiation in the porous material must be included in the model.

Ksandopulo, G. I., Kolesnikov, B. Ya., Zavadskii, V. A. Odnorog, D. S., and Elovskaya, T. P. (Alma Ata) "Mechanism of the Inhibition of Combustion of Hydrocarbon-Air Mixtures by Finely Dispersed Particles," *Fizika Goreniya i Vzryva 7* (1), 92-99 (March 1971) (in Russian)

Subjects: Inhibition mechanism; Hydrocarbon-air flames; Powdered inhibitors; Dispersed particles

Authors' Conclusions
Translated by L. Holtschlag

Samples taken from the flame by a quartz microsampler are analyzed with a mass spectrometer to determine the profiles of compositions of stable species in the combustion zone of a propane-air mixture inhibited by a potassium iodide mixture. The premixed propane-air flame was produced in a glass burner with an outer diameter of no more than 0.35 mm and a length of 8 mm. The potassium-iodide inhibitor was in the form of powdered particles 0.006 to 0.008 mm in size; the amount introduced was 0.5 mg/1. The results are presented as graphs giving the dependence of the concentration in the flame gases on the distance along the normal to the flame front. It is established that the process of inhibition by solid particles reduces to the accelerated formation of formaldehyde as well as to the deceleration of the decrease of formaldehyde by recombination of the OH radical on the surface of the solid particles. The variation in the efficiency of inhibition is proportional to the total surface area of the particles and is a function of the nature of the particles, which is a proof of the heterogeneous mechanism of deceleration of combustion.

Kung, H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "The

Burning of Vertical Wooden Slabs," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 243 (1975)

Subjects: Wood burning; Vertical wood slabs; Convection, natural; Laminar burning; Scaling of wood burning

Author's Abstract

A theoretical treatment is presented on the laminar, natural convective burning of vertical wooden slabs, coupling both the gas-phase laminar diffusion flame processes and the in-depth wood pyrolysis in the solid phase. The problem considered in this paper is symmetrical with respect to the central plane of the slab. The mechanisms included in the model for transient solid phase pyrolysis are conduction and internal convection with variable thermal properties, and a single Arrhenius decomposition with a heat of decomposition. In the gas phase, the following major assumptions are made: (1) unit Lewis number; (2) a single global chemical reaction; and (3) no radiative emission or absorption by the flame. The radiant heat flux emitted by the slab surface, however, is considered. Comparisons with experimental results are quite favorable. Sample computations show that the maximum burning rate per unit surface area varies very slowly with slab thickness for slabs with half-thicknesses between 0.1 cm and 0.35 cm (approximately as the —0.041 power). For slabs of half-thickness greater than 0.4 cm, but smaller than 0.6 cm, the maximum burning rate per unit surface area varies more rapidly (approximately as the —0.324 power of the half-thickness). It is also shown that the maximum total burning rate varies approximately as the 0.625 power of the height for slabs with half-thicknesses between 0.1 cm and 0.4 cm.

Orloff, L., de Ris, J., and Markstein, G. H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Upward Turbulent Fire Spread and Burning of Fuel Surface," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 183 (1975)

Subjects: Fire spread; Turbulent fires, Surface combustion; Polymer fires

Authors' Abstract

Two-dimensional upward flame spread and subsequent steady turbulent burning of a thermally thick vertical fuel surface is examined theoretically and experimentally. The upward spread rate for vertical PMM slabs is observed to increase exponentially with time. This result is predicted in terms of measured fuel thermophysical properties, flame heights, and heat feedback to the fuel surface. The local steady burning rates established after completion of upward spread exhibit a minimum at a height of 18 cm from the bottom edge and increase continuously beyond this height, becoming 70% larger at a height of 140 cm. This increase is shown to be entirely attributable to increasing flame radiation.

Individual measurements of the various energy transfer components during steady burning of the PMM slabs are obtained from radiant intensity measurements of (1) the surface alone and (2) flame plus surface. Above 76 cm flame radia-

tion ranges from 75 to 80% of the total (radiation plus convection) heat transfer from the flames to the fuel surface. Surface heat transfer by convection decreases slightly with height.

Torrance, K. E. and Mahajan, R. L. (Cornell University, Ithaca, New York) "Fire Spread Over Liquid Fuels: Liquid Phase Parameters," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 281 (1975)

Subjects: Fire spread; Liquid fires; Margolis effect

Authors' Abstract

Fire spread over liquid fuels at sub-flash temperatures is known to be controlled mainly by flows induced in the liquid. The liquid flows are driven by surface tension and buoyancy forces, and depend upon Prandtl number, fuel depth and flame speed. The effect of these parameters has been obtained from numerical solutions of the equations governing the liquid phase and results are reported and summarized in the present paper. The induced surface velocities are found to depend principally upon surface tension and layer depth, and, therefore, emerge as a property of a liquid fuel layer. The surface velocity is hypothesized as rate-determining, and is found to be in good agreement with experimental flame spread rates for hydrocarbon and alcohol fuels reported by Glassman, Akita, and others.

Waterman, T. E. (IIT Research Institute, Chicago, Illinois) "Experimental Structural Fires," *Final Report, February 1972 - January 1974 Contract No. DAHC 20-72-C-0290, Defense Civil Preparedness Agency* (July 1974)

Subjects: Structural fires; Full-scale building burns; Fire spread in buildings; Noxious gas concentrations; Environmental factors in building fires

Author's Abstract

Results of four full-scale building fire experiments are reported. The experiments were performed by IIT Research Institute for the Defense Civil Preparedness Agency on residential structures scheduled for removal from the Indiana Dunes National Lakeshore. Where appropriate comparisons are made with past theoretical analyses, laboratory experiments, and other field studies.

Data gathered provided further input to a catalog of volumetric fire spread characterizations. Window flame radiation models were shown to provide reasonable predictions. The best correlation for roof flames observed was offered by NFPA 80-A. Moderate blast damage raised measured radiation above levels characteristic of the undamaged structure. Several modes of fire enhancement (connective heating, radiant reinforcement, and increased air-flow through structures) were attributed to interaction of adjacent structures. Limited information on proximate shelters and firebrands was gathered.

E. Suppression of Fires

Alger, R. S. (Naval Ordnance Laboratory, Silver Spring, Maryland) **and Alvares, N. J.** (Stanford Research Institute, Menlo Park, California) "The Destruction of High Expansion Fire-Fighting Foam by the Components of Fuel Pyrolysis and Combustion. III. Tests of Full Scale Foam Generators Equipped with Scrubbers," *Final Report, July 1974, Report No. NOLTR 74-101,* Naval Ordnance Laboratory (1974)

Subjects: Fire fighting foam; High expansion foam; Pyrolysis products; Smoke products; Defoaming agents

Authors' Abstract

Parts I and II of this report series explored the problem of high expansion fire fighting foam distruction by the pyrolysis and combustion products of the fire. The most effective foam breakers were identified mechanisms of foam destruction were determined, and both chemical and physical countermeasures were explored on a laboratory scale. Physical cooling of the hot gases and removal of the destructive products with a water spray scrubbing unit were the most effective countermeasures.

The final phases of the project and the basis of this report involved (1) pilot tests of an intermediate scale scrubber-generator unit, (2) development of a full scale foam supply for a typical ship's engine room, and (3) tests on the scrubber-generator system with several types of foam under a variety of fire conditions at the Philadelphia Damage Control Center.

These full scale tests confirmed the previous laboratory observation that regardless of the chemical countermeasures, inlet air above 212° F must be cooled before foam can be produced. With the degree of cooling and scrubbing achieved in the pilot tests, a 50 percent reduction in foam yield occurred; therefore, the engine room system was designed with twice the capacity required to achieve the specified fill rate of three feet per minute. With this safety factor, the system was only marginally successful. The design fill rate was readily exceeded for spray fires, but only one of the fresh water foams met the requirements for bilge and bilge plus spray fires. Either a layer safety factor or improved scrubbing efficiency will be required for the salt water compatible foams.

Amaro, A. J. and Lipska, A. E. (Stanford Research Institute, Menlo Park, California) "Development and Evaluation of Practical Self-Help Fire Retardants," Annual Report, August 1973, Contract No. DAHC20-70-0219, *Defense Civil Preparedness Agency* (August 1973)

Subjects: Retardants, "self-help"; Fire retardants; Cellulose retardants

Authors' Abstract

A study was conducted to (1) determine whether high molecular weight, high oxygen containing inorganic additives can be effectively used in developing non-

leachable flame retardants for self-help applications to existing roofs, (2) investigate the kinetics and thermal decompositions of cotton and synthetic polymers, and (3) modify the Parker-Lipska (P-L) model to more closely predict the empirical increase in char yield in retardant treated cellulosics. The sprayed-on interstitially precipitated ammonium phosphomolybdate, ammonium phosphotungstate, and magnesium ammonium phosphate afford seasonal (no more than 30 inches of rain) protection against firebrands. These formulations are more weather resistant than the water-soluble retardants, but because of their shallow penetration they are not totally weather resistant.

Similarities in the weight-loss kinetics and products of pyrolysis of cotton and wood-derived cellulose suggest that the guidelines used in the P-L model in choosing retardants might be applied to all cellulosic materials.

There are some similarities in the decomposition mode of the synthetics and cellulosics. However, more work is needed on the details of degradation of the synthetics before suggesting that principles analogous to the P-L model could be applied to the synthetics in selecting effective fire retardants for these materials.

The modified P-L model can now predict more closely the empirical value of increased char yield, ΔC_E, in cellulosics to be treated with retardants up to concentrations of about 10^{-4} mol of retardant per gram of cellulosic material.

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (Bureau of Mines, Pittsburgh, Pennsylvania) "Flame Structure Studies of CF_3Br - Inhibited Methane Flames. II. Kinetics and Mechanisms," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 917 (1975)

Subjects: Flame structure; CF_3Br inhibition; CH_4 - O_2 flames; Inhibited flames; Kinetics

Authors' Abstract

Composition profiles for atomic, radical, and stable species, as well as temperature and area expansion ratio profiles, have been determined for a nearly stoichiometric $CH_4{-}O_2{-}Ar$ flame and for one to which 0.3% CF_3Br inhibitor had been added. Net reaction rate profiles were calculated for all the observed species. For the normal flame, these and the mole fraction profiles gave rate coefficient information about the elementary reactions in the methane flame, viz.,

$$CH_3+O\xrightarrow{4}H_2CO+H, \qquad k_4=1.05\times10^{14}\ \text{cm}^3\ \text{mole}^{-1}\ \text{sec}^{-1}$$

for $1550\leq T\leq1725°$ K;

$$CO+OH\xrightarrow{6}CO_2+H, \qquad k_6=4.7\times10^{11}\ \text{cm}^3\ \text{mole}^{-1}\ \text{sec}^{-1}$$

for $1350\leq T\leq1750°$ K. Comparison between the inhibited and normal flame showed that [H] and [CH_3] were significantly reduced at the lower temperatures in the inhibited flame even though in the hot gas region the [H], [OH], and [O] were the

same in both flames. The CF_3Br disappears very early in the flame, relative to the fuel, and the reaction primarily responsible for its disappearance is

$$H+CF_3Br \xrightarrow{7} HBr+CF_3,$$

where k_7 is found to be $2.2\times10^{14} \exp(-9460/RT)$, 700–1550° K. Reaction of the inhibitor with methyl radicals provides for the relatively small amounts of CH_3Br observed, but

$$CH_3+Br_2 \rightarrow CH_3Br+Br$$

must also occur. The HBr formed reacts rapidly with H atoms to form H_2 and Br, but the reaction is soon "balanced" in the flame as demonstrated by calculation of the equilibrium constant at various temperatures. The fluorocarbon fragment produced in reaction (7) also reacts rapidly, in part weith methyl radicals to give the observed elimination product CH_2CF_2. The magnitude of the net reaction rate for both HF and F_2CO early in the flame indicates that these, too, are formed by rapid reactions involving CF_3. Later in the flame, above~1400° K, F_2CO is formed from the reaction

$$CH_2CF_2+O \xrightarrow{18} F_2CO+CH_2$$

and $k_{18}\sim1.5\times10^{13}$ at 1600° K. The rather slow decay of carbonyl fluoride is attributed to reaction with H atoms, and the sequence $F_2CO+H \rightarrow HF+FCO$ and $FCO+H \rightarrow HF+CO$ plus reaction (6) provides an additional radical recombination route in the inhibited flame.

Geyer, G. B. (Department of Transportation, Federal Aviation Administration, Washington, D.C.) "Firefighting Effectiveness of Aqueous - Film - Forming - Foam (AFFF) Agents," Final Report, April 1973, Contract No. F33615-71-M-5004, *Department of Defense, Ground Fire Suppression and Rescue Office* (April 1973)

Subjects: Aircraft crashes; Extinguishants; Pool fires; Suppression; Foams; Aqueous film forming foams (AFFF)

Author's Abstract

Information was obtained by conducting laboratory experiments and full-scale fire-modeling tests which were of value in estimating the firefighting effectiveness of two aqueous-film-forming-foam (AFFF) agents. Minimum quantities and application rates were established for each AFFF agent in relation to the size and configuration of simulated aircraft ground fuel-spill fires involving JP-4, JP-5, and aviation gasoline.

Grumer, J. (Bureau of Mines, Pittsburgh, Pennsylvania) "Recent Research Concerning Extinguishment of Coal Dust Explosions," *Fifteenth Symposium (Inter-*

national) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania, 103 (1975)

Subjects: Extinguishment; Coal; Dust; Explosions; Quenching

Author's Abstract

Current practices of protection against coal dust explosions propagating through mines are examined and found to be basically methods of cooling flames below the temperature limits for flame propagation. Such is the case with rock (stone) dusting and with passive barriers (extinguishant dispersed by the explosion) using rock dust or water. Chemical fire extinguishants such as sodium and potassium compounds used in recent research seeking to develop triggered barriers (extinguishant dispersed by a contained energy source on signal from a flame detector) do not appear to have a great advantage over thermal quenching agents.

Hayashi, T. and Turumi, H. "Interruption of Explosions by Flame Arresters: First Report on the Quenching Ability of Sintered Metals," *(Report of the Research Institute of Industrial Safety)* (Japan) *21* (1) 19p. (November 1972) (in Japanese) See Section A.

Kaimakov, A. A. and Bauer, A. N. "Cooling Explosive Products from Methane-Air Mixtures in a Slot Between Steel and Plastic Flanges," *Trudy Vostochnyi n-i Institut po Bezopasnosti Rabot v Gornoi Prom. 8,* 211-217 (1967) (in Russian)

Subjects: Flame quenching; Gaps for flame quenching

Safety in Mines Abstracts 22 No. 445
Safety in Mines Research Establishment

A general rule was obtained for the reduction in the average temperature of the products of explosion of a methane-air mixture in a flat slot between steel and plastic flanges, during ignition with a magneto spark at a distance of 20 and 10 mm from the internal edges of the flanges. A general relationship was worked out for the dependence of the averge temperature of the products of the explosion at the exit from the slot and the magnitude of the gap. Values for the critical flame-quenching gaps are calculated.

Kent, J. H. and Williams, F. A. (University of California, San Diego, La Jolla, California) "Extinction of Laminar Diffusion Flames for Liquid Fuels," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 315 (1975)

Subjects: Extinction; Liquid fuel flames; Diffusion flames; Flame structure; Flame inhibition

Authors' Abstract

A flat, laminar diffusion flame was produced in a stagnation-point boundary layer by directing an oxidizing gas stream downward onto the surface of a burning liquid fuel at atmospheric pressure. Fuels studied were mainly *n*-heptane, but also *n*-decane, *n*-hexadecane, iso-octane and kerosene. Gases were O_2 mixed with N_2, CO_2, He or CF_3Br. For steady burning near extinction, concentration profiles of major stable species were measured by gas chromatographic analysis of samples withdrawn through a fine quartz probe. In addition, temperature profiles were measured with a coated Pt–Pt 10%Rh thermocouple, and flame temperatures were recorded as a function of gas velocity in the approach stream, up to the point of extinction. The gas velocity required for extinction was measured as a function of the concentration of the additive in the gas stream. Also, visual and photographic observations of flame structure were made, including streamline shapes shown by illumination of MgO dust added to the gas. Results help to clarify various aspects of diffusion-flame extinction and chemical inhibition. In particular, overall rate parameters are obtained through evaluation of a critical Damköhler number for extinction from the experimental data.

Ksandopulo, G. I., Kolesnikov, B. Ya., Zavadskii, V. A., Odnorog, D. S., and Elovskaya, T. P. (Alma Ata) "Mechanism of the Inhibition of Combustion of Hydrocarbon-Air Mixtures by Finely Dispersed Particles," *Fizika Goreniya i Vzryva 7* (1), 92-99 (March 1971) (in Russian). See Section D.

Leonard, J. T. and Burnett, J. C. (Naval Research Laboratory, Washington, D.C.) "Suppression of Evaporation of Hydrocarbon Liquids and Fuels by Films Containing Aqueous Film Forming Foam (AFFF) Concentrate FC-196," *Naval Research Laboratory Interim Report No. 7842* (December 1974)

Subjects: Evaporation; Evaporation suppression; Aqueous fire fighting foams; Hydrocarbon liquids; Hydrocarbon fuels

Authors' Abstract

Suppression of evaporation of hydrocarbon liquids and fuels by aqueous films containing a fluorocarbon surfactant has been examined as a function of film thickness, time, and hydrocarbon type. The hydrocarbon liquids included the homologous series of n-alkanes from pentane to dodecane, aromatic compounds, motor and aviation gasolines and jet fuels JP-4 and JP-5, and Navy distillate fuel. The surfactant solution used to form the films was a 6% solution of Aqueous Film Forming Foam (AFFF) concentrate FC-196. Films of the surfactant solution, ranging in thickness from 5 to 100 μm, were placed on the surface of the hydrocarbon liquid to test the ability of the film to suppress evaporation over a 1-hr period. Results indicated that for the n-alkanes and the hydrocarbon fuels a certain critical thickness of surfactant solution was required for optimum vapor suppression. Increasing the film thickness beyond this point did not lead to a significant increase in evaporation suppression, but rather to eventual failure of the film. The critical film thickness for the n-alkanes was found to increase with increasing volatility of the hydrocarbon.

In comparison with the n-alkanes, it was considerably more difficult to suppress evaporation of the aromatic compounds. For example, the maximum vapor suppression obtained with benzene was less than 40% as compared with over 90% for the n-alkanes. The difference was attributed to the greater solubility of the aromatics in the aqueous film.

Lunn, G. A. and Phillips, H. (Safety in Mines Research Establishment, Sheffield, England) "A Summary of Experimental Data on the Maximum Experimental Safe Gap," *Safety in Mines Research Establishment Report No. R2* (1973)

Subjects: Quenching distances; Safe gaps

Authors' Abstract

Since research on the flameproof enclosure of electrical equipment for use in flammable atmospheres was initiated by Beyling (1906), many organizations have carried out work to determine maximum experimental safe gaps, with the result that the data are widely scattered and not always easily available. This report collects together experimental data from a wide range of literature and gives a list of MESGs for 25.4-mm (1-inch) and 25-mm flanges. The experimental conditions are described, with information on the numbers of tests and the gap size increments employed (only data from tests in which the increments were 0.05 mm or less are included). The two main types of vessel that have been used for MESG determinations are the British 8-litre spherical vessel and its modifications, and the IEC 20-ml vessel and its modifications. Earlier determinations in other vessels have been repeated in one of these 'standard' vessels.

Magee, R. S. and Reitz, R. D. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Extinguishment of Radiation Augmented Plastic Fires by Water Sprays," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 337 (1975)

Subjects: Extinguishment; Radiation augmented flames; Plastic fires; Water sprays

Authors' Abstract

The extinguishment of plastic fires by water is investigated experimentally. Single slabs of four different plastics are subjected to turbulent burning, two as a vertical wall and all four as a pool fire. The thickness of each specimen is such as to maintain a thermally thick solid. The water is applied as a uniform spray from a single nozzle. Electrical radiant heaters, directed at the burning surface, are employed to enhance the burning rate of the plastic, thus simulating real fire condition.

The steady-state burning rates of the various plastics are measured as a function of the externally applied radiant flux both with and without water spray. The time taken to extinguish the fire under suppressive action is also determined as a function of external radiant flux. All steady-state burning rate data are analyzed on the basis of a steady-state energy balance at the fuel surface.

All data, without water spray, indicate a linear dependence of burning rate on external radiant flux. The slopes of these curves are interpreted to represent the effective heats of gasification of the plastics. The effectiveness of water in suppressing the fire is determined to be primarily a thermal effect, i.e., a cooling of the fuel surface, for those plastics which do not melt excessively. Finally, for each plastic, critical conditions for extinguishment are identified.

Phillips, H. "Theory of Suppression of Explosions by Narrow Gaps," Fourth Symposium on Chemical Process Hazards with Special Reference to Plant Design, *Industrial Chemical Engineering Symposium Series No. 33* (1972)

Subjects: Explosion suppression; Narrow gap theory

Safety in Mines Abstracts 22 No. 249
Safety in Mines Research Establishment

The safe gap between the flanges of a flameproof enclosure is shown to prevent the transmission of an explosion by the combined action of the cooling of gas passing through the flange gap, and cooling by the entrainment of cold gas when the hot explosion products emerge from the gap. This counteracts the heat release by burning of the entrained gas. Computer solutions of the equations for heat transfer, entrainment, and heat release predict the change in jet temperature with time. The final temperature may be either the maximum flame temperature, denoting ignition, or ambient temperature, denoting a failure to ignite, depending on the initial conditions, one of which is the site of the flange gap. The results enable prediction of the effect on the safe gap of a change in fuel, flange breadth, vessel volume, ambient pressure, and internal ignition position. The same analysis is also applied to a flameproof enclosure.

Roberts, A. F. (Safety in Mines Research Establishment, Sheffield, England) "Extinction Phenomena in Liquids," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 305 (1975)

Subjects: Extinction; Liquid fires; Fire point

Author's Abstract

A burning liquid is extinguished when its surface temperature is reduced to the fire point of the liquid. The fire point depends on properties of the liquid and of the atmosphere in which it is burning and a theoretical relationship is given which describes this dependence. This relationship is used to calculate the variation of fire point and critical heat loss at extinction of *n*-butanol with the oxygen concentration of the ambient atmosphere. The proximity of heat sinks to the surface of a burning liquid may cause extinction and this effect was studied experimentally; the data suggested that liquid layers up to 0.5 mm deep were stationary and heat losses from the suface to the heat sink took place by conduction. Effects of convection were apparent for greater liquid depths.

For multi component liquids, mass transfer in the liquid phase also plays a part in determining extinction behaviour. The effects of the degree of internal recirculation on the relationship between the mean composition of a liquid mixture, the surface concentration and the composition of the evolved vapour are discussed. Data illustrating the importance of these effects are given for the ethanol/water system; the minimum concentration of ethanol which would sustain burning in air varied from 7–45%, depending on the degree of recirculation within the liquid.

A burner was developed in which the effects of heat and mass transfer in the liquid phase and the oxygen concentration of the surrounding atmosphere on the extinction of a burning liquid could be studied. Some early experiments with this burner are described.

Sridhar Iya, K., Wollowitz, S. and Kaskan, W. E. (State University of New York, Binghamton, New York) "The Mechanism of Flame Inhibition by Sodium Salts," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 329 (1975)

Subjects: Inhibition; Sodium salts; Flame structure; Dry chemicals; OH concentrations

Authors' Abstract

A study has been conducted to determine whether the mode of action by the "dry chemical" flame inhibitors, sodium bicarbonate, and sodium tartrate, was heterogeneous or homogeneous. The method used was the correlation of the amount of inhibitor vaporized in the flame zone with a measure of the degree of inhibition. For the first, Na atoms were determined by absorption spectroscopy at the end of the reaction zone of partially quenched premixed CH_4/air flames burning at atmospheric pressure on a flat flame burner. The degree of inhibition was indicated by the extent of the temperature rise of the quenched flame on addition of inhibitor. Tests were conducted on six "siliconized" and size classified salt fractions, three each of the two salts. Four of the six powder samples completely evaporated by the end of the reaction zone. The results for all six fractions can be represented by an approximately linear relationship between Na concentration at the end of the reaction zone and the temperature rise on inhibition. It is shown that this correlation is much better than one based on surface area presented to the flame. These results are interpreted as an essentially conclusive proof of the homogeneous mechanism. In addition, measurements of hydroxyl concentrations have shown that addition of inhibitor reduces peak OH concentrations and catalyzes radical recombination. Na atoms are unusually effective in this regard. While a complete mechanism has not been worked out, some discussion is given of the limitations on such a scheme The existance of dipole-induced dipole stabilized complexes between alkali atoms and water molecules is suggested as a means by which recombination might very effectively be catalyzed.

U.S. Patent 3,684,021, August 15. 1972 "Mine Explosion Suppression Method and Apparatus," *Coal Age 77* (12) 114 (1972)

Subjects: Mine explosion, suppression; Fire detector; Fire suppression

Safety in Mines Abstracts 22 No. 348
Safety in Mines Research Establishment

The apparatus contains sealed containers that are ruptured to release a flame-suppressing agent. Explosive squibs are detonated in response to UV sensors. The agent-filled containers also are mounted on the mining machine and are oriented to release suppressing agent into a discharge zone that is spaced to the rear of the detection zone optically monitored by the sensors. The longitudinal spacing between discharges and detection zones compensates for movement of the flame front during the period required to rupture the containers and fill the discharge zone with the agent. Thus, the method is effective to prevent potentially catastrophic explosions ignited at the face, but ignores harmless sources of radiation.

F. Fires, Damage, and Salvage

Morgan, H. P. and Bullen, M. L. (Joint Fire Research Organization, Borehamwood, Herts, England) "Smoke Extraction by Entrainment into a Ducted Water Spray," *Fire Research Note No. 1010, Joint Fire Research Organization* (June 1974)

Subjects: Smoke extraction; Entrainment of smoke; Spray extraction of smoke; Water spray extraction of smoke

Authors' Summary

This report presents a smoke extraction system which has no moving parts in the hot smoky gases, employing momentum transfer from a high velocity water spray in a duct to extract smoke. The gas velocity for different duct configurations and water pressures was measured in an experimental rig. A theory was developed to explain the experimental results and to enable the performance of practical smoke extraction systems to be predicted.

Morris, W. A. and Hopkinson, J. S. (Joint Fire Research Organization, Borehamwood, Herts, England) "Effects of Decomposition Products of PVC in Fire on Structural Concrete," *Fire Research Note No. 995, Joint Fire Research Organization* (February 1974)

Subjects: Corrosion; PVC fires; Structural concrete; Vinyl Chloride (poly); Pyrolysis of PVC; Decomposition of PVC

Authors' Summary

Full scale fire tests have been conducted in buildings to compare the effect of combustion products on concrete building elements when the fire load was totally

cellulosic and when 30 per cent of the fire load was PVC. After the fire the buildings were kept under observation and at intervals concrete roof elements were removed and loaded to structural failure. Samples of the concrete were then analyzed for chloride content.

The tests have shown that in fires involving PVC, chloride deposition can occur on concrete surfaces under both dry and humid conditions. Observations and analyses of the concrete for periods of up to 13 months after the fires showed no indications that the building suffered structurally because of the effects of the chloride. Under the conditions of these tests, corrosion is unlikely to be a problem in dense concrete constructions whether of a reinforced or prestressed nature provided the relevant British Standard Codes of Practice have been complied with.

Saito, F. (Building Research Institute, Japanese Ministry of Construction, Tokyo, Japan) "Smoke Generation from Building Materials," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 269 (1975)

Subjects: Smoke generation; Building materials; Tests on smoke

Author's Abstract

It is very important to determine the characteristics of smoke production from a burning room. For this purpose the fundamental properties of smoke production from building materials were studied in a series of experiments based on the material test using an electric furnace, and on the model chamber test.

In the material test we found that the quantity of smoke produced is determined mainly by the chemical composition of the material and the ambient temperature. For a burning materials, the relation between weight loss of the material W and amount of smoke production C, is given by $C=KW$, where K is a smoke generation coefficient that expresses the tendency of the material to produce smoke at a given temperature; K is generally given by $K=A-BT$, where, A and B are constants that depend on the type of material and on the burning conditions, such as smoldering or flaming combustion.

The amount of smoke produced in a burning room is determined by the area of the air inlets and the materials of the interior surface.

The relationship between K and T obtained in the model chamber test agrees fairly well with that obtained in the electric furnace test.

G. Combustion Engineering and Tests

Abdel-Khalik, S. I., Tamaru, T. and El-Wakil, M. M. (University of Wisconsin, Madison, Wisconsin) "A Chromatographic and Interferometric Study of the Diffusion Flame Around a Simulated Fuel Drop," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 389 (1975)

Subjects: Diffusion flames; Chromatographic analysis; Interferometry; Flame structure; Droplet flames

Authors' Abstract

The structure of the diffusion flame surrounding a simulated burning drop of *n*-heptane was investigated. The drop was examined while burning at atmospheric pressure in a uniform air flow field at several air velocities. The composition and temperature profiles along several radial lines around the drop were determined by means of gas chromatography and optical interferometry. The composition analysis yielded concentrations of the fuel vapor as well as O_2, CO_2, CO, N_2, CH_4, C_2H_2, and C_2H_4 in dried samples. The composition and temperature profiles were used to evaluate the mass and heat-flux distributions around the drop. The radiative heat-flux distributions from gas and soot were also evaluated.

It was found that the flame structure varies markedly around the drop and that the air velocity has a large effect on the temperature profiles. At high air velocities, double-peaked temperature profiles were observed in the trailing half of the flame. Radiation, often ignored in the past, was found to be about 40% of the total heat transferred to the drop. Gas radiation is about 10% of the total radiation, the remainder being due to soot.

Allen, D. E. and Lie, T. T. (National Research Council, Ottawa, Canada) "Further Studies of the Fire Resistance of Reinforced Concrete Columns," *National Research Council of Canada Report No. 14047* (June 1974)

Subjects: Fire resistance of concrete columns; Critical fire load of concrete columns; Concrete columns, stress under fire load

Authors' Abstract

The fire resistance of square, reinforced concrete columns is studied under load and fire conditions that more closely represent actual conditions than those in current standard fire tests. Based on calculated temperature and stress distributions in the column, the effect of interaction of an interior column with the surrounding building structure is examined. The influence of fire severity, which depends on the fire load and ventilation, is also investigated. Results indicate that restraint of an individual column does not decrease its fire resistance and that the critical fire load, below which no failure takes place, increases with increased ventilation. If the fire load is greater than critical, the time to failure decreases considerably with increased ventilation.

Ames, S. A. (Joint Fire Research Organization, Borehamwood, Herts, England) "Gas Explosions in Buildings, Part 2. The Measurement of Gas Explosion Pressures," *Fire Research Note No. 985, Joint Fire Research Organization* (December 1973)

Subjects: Gas explosions; Explosion of gas in buildings; Explosion pressures

Author's Summary

Following the Ronan Point disaster and the report of the Investigating Tribunal,

it was decided that the Fire Research Station of the Building Research Establishment would undertake a study of gas explosions in large compartments. In particular, the study would cover the factors affecting the development and severity of the explosions and the extent to which the pressures obtained could be relieved by venting.

In the context of the problem as a whole, the study is intended to provide the basic data on the form and magnitude of the transient stresses likely to be experienced by buildings, in the event of gas explosions involving one or more compartments. This information is required as a guide for safe structural design and for any re-appraisal of the relevant parts of Building Regulations 1972, Part D, England, or Building Standards (Scotland) (Consolidation) Regulations 1971.

The study has begun with explosions in a single compartment of realistic dimensions (1000 ft^3, 28 m^3) provided with a single opening of simple configuration, the size of which can be varied and which can be closed with panels having a range of bursting pressures.

Benson, S. P., Bevan, P. R., and Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts, England) "A Laboratory Fire Test for Foam Liquids," *Fire Research Note No. 1007, Joint Fire Research Organization* (April 1974)

Subjects: Foam; Laboratory fire test; Protein; Fluoroprotein; Fluorochemical; Burn-back

Authors' Summary

A fire test which can be conducted in the laboratory and which is suitable for the quality control of foam liquids is described.

The test fire was 56.5 cm dia and 9 litres of fuel were used for each test. The foam was applied as a jet from a model branchpipe at 3.0 l/m^2/min. Control and extinction times were measured and a burn-back resistance test was made.

Test results are given for 17 samples of foam liquid representing all groups. Duplicate fire tests were made with each foam liquid and three aviation fuels.

Values are proposed for the quality control of protein, fluoroprotein, and fluorochemical foam liquids.

Bilger, R. W. and Beck, R.E. (The University of Sydney, Australia) "Further Experiments on Turbulent Jet Diffusion Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 541 (1975)

Subjects: Diffusion flames; Turbulent jet flames

Authors' Abstract

The earlier investigation of Kent and Bilger on the turbulent diffusion flame of a jet of hydrogen in a co-flowing stream of air is extended to give more detailed measurements of the nitric oxide field in the flame. Nitric Oxide measurements appear to be particularly sensitive to the sampling method used and the results obtained

with a small slender nosed sampling probe at near isokinetic conditions are considered to be more reliable than those for the large blunt nosed probe used in the earlier investigation or those for the sonic sampling probe used by Lavoie and Schlader. Nitric oxide concentrations are found to peak on the rich side of stoichiometric and the mass balance on the centre line indicates maximum nitric oxide production also on the fuel rich side.

Experiments were also conducted for a vertical jet diffusion flame into still air at constant Froude number so that fluid dynamic similarity is obtained. The results indicate that nitric oxide concentrations peak on the rich side of stoichiometric and that peak concentrations are not proportional to the bulk or convective time constant of the flow but rather the Kolmogoroff time constant associated with the smallest eddies in the flow.

Brenden, J. J. (Forest Products Laboratory, Madison, Wisconsin) "How Fourteen Coating Systems Affected Smoke Yield from Douglas Fir Plywood," *U.S. Department of Agriculture Forest Service Research Paper FPL 214* (1973)

Subjects: Flaming and nonflaming conditions; Irradiation energy level; Fire retardant paints; Light transmission; Length of light path

Author's Abstract

Effect of smoke yield of coatings is measured in a closed, instrumented chamber.

Bröll, R. "Standardization of Halogen Fire Extinguisher Agents," *Ztschr. VFDB 22* (1), 12-13 (February 1973) (in German)

Subjects: Fire extinguishers in Germany, requirements; Halogen extinguishing agents

Safety in Mines Abstracts 22 No. 262
Safety in Mines Research Establishment

The present official requirements for halogen extinguishing agents in West Germany are described (draft appeared in Spring 1972 and gave the material properties and regulations for the use of Halon 1211). The second part of the standard will give requirements for Halon 1301. The author suggests that test standards should also be established on a physiological basis.

Burgess, D., Murphy, J. N., Zabetakis, M. G., and Perlee, H. E. (Bureau of Mines, Pittsburgh, Pennsylvania) "Volume of Flammable Mixture Resulting from the Atmospheric Dispersion of a Leak or Spill," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 289 (1975). See Section A.

Butlin, R. N., Ames, S. A., and Berlemont, C. F. J. (Joint Fire Research Organization, Borehamwood, Herts, England) "Gas Explosions in Buildings, Part III.

A Rapid Multichannel Automatic Chromatographic Gas Analysis System," *Fire Research Note No. 986, Joint Fire Research Organization* (March 1974)

Subjects: Gas explosions; Explosions of gas in buildings; Gas analysis system

Authors' Summary

An apparatus is described which has been developed for high-speed analysis of gas samples taken from different positions in an experimental chamber used for large-scale gas explosions. The equipment is automatic (with manual override), can be controlled remotely, gives a quantitative output and is sufficiently versatile to have many other applications.

de Ris, J. and Orloff, L. (Factory Mutual Research Corporation, Norwood, Massachusetts) "The Role of Buoyancy Direction and Radiation in Turbulent Diffusion Flames on Surfaces," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 175 (1975)

Subjects: Diffusion flames; Turbulent flames; Radiation

Authors' Abstract

A large-scale gas-supplied sintered-metal burner was used to study radiation and spatial orientation effects on steady turbulent fires over a range of mass transfer driving forces, B. Three principal burning modes are evident: (1) turbulent pool fires from $\theta = 0°$ to $\theta = 15°$; (2) upward turbulent burning from $\theta \sim 15°$ to $\theta \sim 168°$; and (3) cellular ceiling fires from $\theta \sim 168°$ to $\theta = 180°$. Steady burning rates decrease rapidly with inclination from the horizontal within the pool regime, followed by a more gradual decrease with inclination within the upward turbulent burning regime being minimum $\theta \sim 168°$, i e., 12° from the horizontal ceiling orientation. This trend is ascribed to the decreasing direct gravitational generation of turbulent kinetic energy, causing a reduction in the turbulent flame thicknesses with their reduced radiant fluxes. Previous laminar burning studies showed opposite trends, with minimum burning rates in the "pool" orientation. Increased cellular flow mixing is accompanied by a sharp increase in burning rate as the fuel surface rotates from 168° to the horizontal ceiling fire.

Radiometer comparison of outward and surface directed radiant flux for a vertical burning surface indicate at least 7% absorption by combustion products and intermediates near the surface. Radiation is found to exceed convective heat transfer to the fuel surface for $B > 1.0$. At large B numbers the burning is increasingly radiation-dominated as convection decreases due to heat blockage.

De Soete, G. G. (Institut Francais du Petrole, Rueil-Malmaison, France) "Overall Reaction Rates of NO and N_2 Formation from Fuel Nitrogen," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 1093 (1975)

Subjects: NO_x formation; Fuel nitrogen; Flame structure; Pollution

Author's Abstract

From measurements carried out on flat premixed hydrocarbon/oxygen argon (or helium) flames, into which small amounts of ammonia, or cyanogen are added, overall reaction rates of formation of NO and N_2 are determined. From similar measurements effected on nitrogen-diluted ethylene/oxygen flames, an overall rate of prompt NO formation is obtained.

The discussion of these rate constants indicates that the relative importance of HCN molecules as intermediates in the fuel NO mechanism increases according to the following sequence of primary fuel nitrogen compounds: ammonia, cyanogen, and molecular nitrogen; this last is found to behave like a true fuel nitrogen compound in the early flame stages.

Experimental values of the total yield of nitric oxide obtained from the added nitrogen compounds have been determined; they are found to be in good agreement with yields calculated by numerical integration of the empirical overall reaction rates of NO and N_2 formation, showing almost the same dependence of the NO yield on temperature, initial fuel nitrogen concentration and oxygen concentration.

Eickner, H. W. (Forest Products Laboratory, Madison, Wisconsin) "Fire Resistance of Solid-Core Wood Flush Doors," *Forest Products Journal 23* (4), 38-43 (1973)

Subjects: Fire resistant wood doors; "Solid-core" doors; Wood doors

Author's Abstract

Research was conducted to determine the fire resistance of five types of "solid-core" 1¾-inch wood flush doors as currently produced to the industry standard. The results of ASTM E152-66 fire resistance tests showed that four types of doors successfully withstood 30 minutes of the fire exposure, conducted under a slightly negative furnace pressure, and then withstood the hose-stream exposure as specified in the standard. These were framed wood flush doors with (1) glued wood block core; (2) glued wood block, drop-in core; (3) nonglued wood block, drop-in core; and (4) particleboard glued core. The fifth type of door, particleboard with drop-in core, marginally passed the 30-minute fire exposure condition, but failed the hose stream test because of excessive warping deflection of a corner of the door. Some ⅛- and ¼-inch voids intentionally located in the door cores did not cause failure.

Fang, J. B. (National Bureau of Standards, Washington, D.C.) "Measurements of the Behavior of Incidental Fires in a Compartment," Interim Report No. NBSIR 75-679 *Department of Housing and Urban Development* (February 1973)

Subjects: Building fires; Combustibility of furnishings; Ignition; Smoke; Thermal radiation

Author's Abstract

A variety of upholstered chairs and wood cribs were burned within a ventilated

compartment. The experimental measurements of weight loss, smoke concentration, temperature, and heat flux levels are summarized. A reproducible fire obtained from burning a standardized wood crib array was found to be capable of representing the essential features of incidental fires of moderate intensity.

Fang, J. B. and Gross, D. (National Bureau of Standards, Washington, D.C.) "Contribution of Interior Finish Materials to Fire Growth in a Room," *National Bureau of Standards Special Publication 411,* 125 (August 1073)

Subjects: Flame spread; Room fires; Material ignitibility; Building materials; Smoke; Heat release

Authors' Abstract

Characterization of the fire environment from the burning of the combustible contents of wastebaskets, upholstered furniture, and interior finish materials is important for developing rational tests and establishing design criteria for reduction of fire hazard in buildings. Some experimental results on the burning characteristics of an upholstered chair, contents of waste receptacles, and wood crib arrays in a well-ventilated room are presented. A procedure has been developed for evaluating the contribution to fire growth of wall and ceiling panels in a full-scale room corner with a standardized wood crib duplicating the conditions produced by an incidental fire. Results of full-scale and laboratory tests with selected interior finish materials on ease of ignition, surface flammability, flame penetration, and smoke and heat generation measurements are presented and compared.

Frandsen, W. H. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "Fire Spread Through Porous Fuels from the Conservation of Energy," *Combustion and Flame 16,* 9-16 1971). See Section D.

Gollahalli, S. R. and Brzustowski, T. A. (University of Waterloo, Waterloo, Ontario, Canada) "The Effect of Pressure on the Flame Structure in the Wake of a Burning Hydrocarbon Droplet," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 409 (1975)

Subjects: Droplet burning; Diffusion flames; Flame structure; Pressure dependence of flame structure

Authors' Abstract

Data are presented on the structure of the flame in the wake of a model (6 mm dia porous sphere) *n*-heptane droplet burning in air. The following measurements were made: axial and radial temperature profiles, axial and radial composition profiles showing H_2O, CO_2, N_2, O_2, CO, C_7H_{16}, CH_4, C_2H_2, and C_3H_8. Envelope flames were studied at pressures up to 40 atm. Wake flames were studied at 5 atm only. The velocity of transition from the envelope flame to the wake flame was measured up to 25 atm.

The results show that the effect of pressure on flame structure can be explained in terms of the effect of pressure on the following processes: diffusion and pyrolysis of fuel in the near-wake zone of the envelope flame, premixed combustion, and pyrolysis of fuel in the near-wake zone of the wake flame, combustion and coagulation of soot in the far-wake zone of both flames. As pressure increases, the increased rate of pyrolysis becomes predominant in the near wake. In the far wake, the peak temperature drops with increasing pressure and coagulation of soot becomes important. The data are consistent with the model developed by the authors to explain the effect of pressure on flame length.

The velocity of transition from an envelope flame to a wake flame increases approximately as $P^{1/2}$, suggesting overall 3/2 order kinetics for *n*-heptane and air at the stagnation point.

Gurevich, M. A., Ozerova, G. E., and Stysanov, A. M. (Leningrad) "Critical Conditions of Self-Ignition of a Poly-Dispersed Gas Suspension of Solid-Fuel Particles," *Fizika Goreniya i Vzryva 7* (1), 9-19 (March 1971) (in Russian). See Section B.

Hallman, J. R., Welker, J. R., and Sliepcevich, C. M. (University of Oklahoma Research Institute, Norman, Oklahoma) "Polymer Surface Reflectance Absorptance Characteristics," *Polymer Engineering and Science 14* (10), 717 (1974)

Subjects: Polymeric materials, radiant heating; Radiant heating of polymers; Reflectance-absorptance of polymer surface

Authors' Abstract

During an investigation of the time for ignition of polymeric materials under the influence of radiant heating, it was found that the polymer surface reflectance-absorptance characteristics were a major factor in the variance of the ignition times. A subsequent research study was made of the reflectance-absorptance characteristics of those polymers used in the ignition testing. Reflectance values were obtained over the wavelength of 0.3 to 2.5 microns using a double-beam Cary model 14 spectrophotometer with an integrating sphere reflectometer and over the wavelengths of 1.0 to 10.0 microns using a Gier-Dunkle Hohlraum with a Perkin-Elmer spectrophotometer. Absorptance values were obtained by means of Kirchoff's Law,

$$\alpha_\lambda + r_\lambda = 1$$

Average absorptances of the polymers over the monochromatic wavelength span of the heat sources were calculated using the equation

$$\alpha_{av} = \frac{\int_{\lambda_1}^{\lambda_2} \alpha_\lambda e_\lambda \, d\lambda}{\int_{\lambda_1}^{\lambda_2} e_\lambda \, d\lambda}$$

Mathematical analyses were developed and are presented for both the integrating sphere reflectometer and Gier-Dunkle Hohlraum unit.

Drawings and graphs are included which illustrate the test apparatus and type of data collected. A table of average absorptances of several polymers are given and listed according to the particular type of heat source used.

Handa, T., Suzuki, H. and Takahashi, A. (Science University of Tokyo) "Characterization of the Mode of Combustion and Smoke Evolution of Organic Materials in Fires. Part II. Analysis of the Change in Particle Size of Polystyrene Smoke Particles Due to Secondary Oxidation," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 58 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Smoke; Particles; Soot

Authors' Conclusions

The experimental results obtained from measurements using the dissymmetry factor method are summarized as follows:

(1) The change in radius of smoke particles at the initial stage of evolution before the smoke particles condense to become so called "sooty smokes" has hardly been recognized in the microphotographic observations shown in the previous report.

(2) The change in dissymmetry factor Z has been recognized to be sensitive to the change in radius of smoke particles, as shown in Fig. 6. Consequently, the smoke concentration C^2 is considered to show the number of smoke particles which relate to the weight loss in the sample, and its particle size at the final stage stored in the smoke box indicates the mean radius of a smoke particle generated from organic substances, which depends on the type of sample.

(3) The partial pressure of oxygen exercised a logarithm-type influence on the activation energy induced by the secondary oxidation of smoke particles in a hot bath (radiation temperature). It is considered that the oxidation reaction rate increase with the increase of the oxygen partial pressure in a high temperature environment has led to the lowering of the reduction rate of particle size due to insufficient amount of oxygen.

Details on the problem of smoke colorization which depends on the temperature, the air flow velocity around the smoke particle due to the temperature rise, the effect of oxygen partial pressure, and the chemical reaction which is considered to proceed on the particle surface as well as the change in particle size at the initial stage of smoke evolution will be reported later.

Handa, T., Suzuki, H., Takahashi, A., Ikeda, Y., and Saito, M. (Science University of Tokyo) "Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part II. Checks on Factors Concerning the Surface Flame Spread Rate and Smoke Evolution of Organic Building Materials by Small Inclined Type Test Furnace," *Bulletin of the Fire Prevention Society of*

Japan 21 (1) 1971 (2) 1972 44 (English translation by Trans. Sec., Brit. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.). See Section A.

Harmathy, T. Z. (National Research Council of Canada Division of Building Research, Ottawa, Canada) "Commensurability Problems in Fire Endurance Testing," *Fire Study No. 31, Division of Building Research, National Research Council of Canada* (November 1973)

Subjects: Fire endurance testing; Fire testing; Furnace design; Commensurability in fire testing

Author's Abstract

A simple method is described by which characteristics of the performance of fire test furnaces can be determined more conveniently and accurately than with methods so far employed. The commensurability of the results of fire tests obtained by furnaces of different design is discussed and a possible solution to putting the fire test procedure on a more realistic basis is described.

Hartzell, L. G. (National Bureau of Standards, Washington, D.C.) "Development of a Radiant Panel Test for Flooring Material," *Final Report No. NBSIR 74-495, National Bureau of Standards* (May 1974)

Subjects: Fire tests; Flammability; Ignition; Flooring; Radiant panel

Author's Abstract

This paper summarizes the work of a year long program to continue the development of a radiant panel type test for flooring materials, the original concept of which was developed at the Armstrong Cork Company's Research and Development Center in Lancaster, Pennsylvania. This program at the National Bureau of Standards had as its goal the further development of the test for possible adoption as a standard ASTM test method.

The program work was divided into five phases. During the first phase, an attempt was made to duplicate the performance of the original apparatus in a similar one at the National Bureau of Standards Laboratory. The proof of this duplication was shown in replicate testing using a wide range of flooring on both apparati.

In the second phase of the program, a new set of test conditions were found in an attempt to eliminate some of the more serious equipment and procedural problems of the test. These new conditions provided the test with the ability to rate flooring materials according to their ability to resist the surface spread flames.

Under the third and fourth phases of the program, the effects of changes in some test parameters was investigated and other test characteristics were measured. Phase V, the data analysis and report, concluded the program.

Haynes, B. S., Kirov, N. Y. (University of New South Wales, Kensington, Australia) **and Iverach, D.** (Air Pollution Control Branch, State Pollution

Control Commission, Lidcombe, Australia) "The Behavior of Nitrogen Species in Fuel Rich Hydrocarbon Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1103 (1975)

Subjects: Nitrous oxide; CN species; NH species; Hydrocarbon flames; Flame structure

Authors' Abstract

Measurements of NO, CN-species and NH-species are made in a number of fuel-rich hydrocarbon flames, with and without the addition of pyridine. Concentrations of all these species in excess of equilibrium are found even in the absence of pyridine.

Formation of cyano-species (mainly HCN) is related to decay of hydrocarbons and in very rich flames occurs well into the post-flame gas. In the absence of hydrocarbons the cyano-pool is found to decay via the CN radical:

$$CN+CO_2 \rightarrow OCN+CO$$

with $k = (3.7 \pm 0.4) \times 10^{12}$ cm^3/mole-sec in the range 1830° to 2400°K.

Both formation and decay of NO are observed and the results are consistent with a mechanism of the type

$$I+O_x \rightarrow NO+\cdots \qquad (21)$$

$$I+NO \rightarrow N_2+\cdots \qquad (22)$$

where I is a nitrogeneous intermediate, and O_x is an oxidant (probably OH). In some cases NO formation can be predicted from measured HCN decay on the basis of reactions (21) and (22).

In the presence of sufficient pyridine added to the flame, NO decreases in the post-flame gases to a constant value, characteristic of the flame, regardless of the level of pyridine added.

The behavior of NH_i species is not as clear as that of HCN, although it is possible that there is a relation between NH_i formation and HCN decay, and the NH_i-system may be the identity of the intermediate I.

Hirano, T. and Konoshita, M. (Ibaraki University, Ibaraki, Japan) "Gas Velocity and Temperature Profiles of a Diffusion Flame Stabilized in the Stream over Liquid Fuel," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 379 (1975)

Subjects: Flame structure; Diffusion flames; Velocity of gas; Temperature profiles

Authors' Abstract

The gas velocity and temperature profiles across the laminar boundary layer with

a diffusion flame established over methanol or ethanol were measured with the free stream of air parallel to the liquid-fuel surface. The flame stabilizing mechanism and fuel consumption rate are discussed.

The results show that the maximum velocity appearing near the blue-flame zone, where the gas stream is accelerated, increases downstream and exceeds the free-stream velocity at a point about 0.2 cm from the leading edge of the fuel vessel. The temperature at the blue-flame zone is found to increase downstream about 1.5 cm from the leading edge of the fuel vessel and then to decrease slightly still farther downstream. The fuel consumption rate is observed to increase monotonically with the increase of the free-stream velocity. It is shown that in order to elucidate the flame stabilizing mechanism, the velocity profile change due to the flame reaction must be taken into account. The diffusion flame over the liquid fuel can be considered to remain stable until the leading flame edge shifts beyond the leading edge of the fuel vessel due to the increase of the free stream velocity.

Hirano, T. and Sato, K. (Ibaraki University, Ibaraki, Japan) "Effects of Radiation and Convection on Gas Velocity and Temperature Profiles of Flames Spreading over Paper," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 233 (1975). See Section D.

Holmes, C. A. (Forest Products Laboratory, Madison, Wisconsin) "Correlations of ASTM Exposure Tests for Evaluating Durability of Fire-Retardant Treatments of Wood," *U.S. Department of Agriculture Forest Service Research Paper FPL 194* (1973)

Subjects: Fire retardant ASTM exposure test; Durability of wood

Author's Abstract

Describes comparability of two methods of exposure testing provided in ASTM D2898-70T. Results show overall exposure by either method can provide conditions to differentiate between leach-resistant and nonleach-resistant treatments.

Holmes, C. A. (Forest Products Laboratory, Madison, Wisconsin) "Flammability of Selected Wood Products Under Motor Vehicle Safety Standards," *Journal of Fire and Flammability 4,* 156-164 (1973). See Section A.

Holve, D. J. and Sawyer, R. F. (University of California, Berkeley, California) "Diffusion Controlled Combustion of Polymers," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 351 (1975)

Subjects: Polymer combustion; Diffusion controlled combustion; Opposed flow diffusion flames; Regression rate; Flame structure

Authors' Abstract

A theoretical and experimental study of polymer combustion in an opposed flow diffusion flame (OFDF) is presented. An algebraic formula is derived, expressing the burning rate as a function of the fluid mechanic and thermodynamic variables. A polymer sample feed system has been developed which continuously positions the burning polymer surface within ±0.01 mm of a given set point, allowing accurate regression rate and detailed solid and gas phase flame structure measurements. Regression rate measurements of twelve commercial polymers as a function of oxygen concentration and oxidizer flowrate are reported. From these measurements and the theory, values of the Spalding transfer number, B, are derived and can serve as a useful flammability index for these materials. The OFDF technique also provides a quantitative method for evaluating the effectiveness of flame retardants. Solid and gas phase temperature profiles for charring and non-charring polymers under various oxygen concentrations and oxidizer flow conditions indicate markedly different chemical reaction mechanisms for charring and non-charring polymers.

King, M. K. (Atlantic Research Corporation, Alexandria, Virginia) "Predictions of Laminar Flame Speeds in Boron - Oxygen - Nitrogen Dust Clouds," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 467 (1975)

Subjects: Dust flames; Flame speed; Boron flames

Author's Abstract

A detailed model of boron–oxygen–nitrogen dust-cloud flames, including consideration of the details of boron particle ignition and the effects of oxygen depletion, has been developed and used for prediction of flame speeds as functions of numerous parameters. Reasonably good agreement between measured flame speeds for the only two data points available on laminar boron dust cloud combustion and those predicted by this model has been obtained, although uncertainty concerning details of the experimental parameters results in this agreement being somewhat inconclusive. In addition, a simplified closed-form flame speed expression has been developed and the effects on predicted flame speeds of the various assumptions used in its development have been examined. The models have been used to study the effects of initial temperature, pressure, initial oxygen mole fraction, weight fraction particles, initial particle size, initial thickness of the oxide coating on the particles, radiation feedback from the post-flame zone, and Nusselt Number. Mechanisms leading to the predicted dependencies are discussed.

Ksandopulo, G. I., Kolesnikov, B. Ya., Zavadskii, V. A., Odnorog, D. S., and Elovskaya, T. P. (Alma Ata) "Mechanism of the Inhibition of Combustion of Hydrocarbon-Air Mixtures by Finely Dispersed Particles," *Fizika Goreniya i Vzryva* 7 (1), 92-99 (March 1971) (in Russian). See Section D.

Lie, T. T. and Harmathy, T. Z. (National Research Council of Canada, Ottawa, Canada) "Fire Endurance of Concrete-Protected Steel Columns," Journal of the American Concrete Institute No. 1, Proceedings V. 71, 29-32 (January 1974): Research Paper No. 597, *Division of Building Research, National Research Council of Canada*. See Section A.

Lunn, G. A. and Phillips, H. (Safety in Mines Research Establishment, Sheffield, England) "A Summary of Experimental Data on the Maximum Experimental Safe Gap," *Safety in Mines Establishment Report No. R2* (1973). See Section E.

Markstein, G. H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Radiative Energy Transfer from Gaseous Diffusion Flames," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 1285 (1975)

Subjects: Radiation; Diffusion flames; Emission; Adsorption; Energy transport

Author's Abstract

Emission and absorption measurements were performed with an array of ten laminar-diffusion-flame burners. The radiative properties of the flames of various gaseous hydrocarbon fuels were determined by varying the number of ignited burners, and thus the optical depth of the flames. The results for the fuels of highest tendency for soot formation, propylene, isobutylene, and 1,3-butadiene, could be represented by a grey-gas model. The data for the less sooty flames of aliphatic hydrocarbons and of ethylene required a representation as the sum of two weighted gray-gas terms. Radiance values for one flame, N_1, ranged from 0.156 W/cm^{2}sr for methane to 0.801 W/cm^{2}sr for 1,3-butadiene, while values extrapolated to an infinite number of flames, N_∞, ranged from 5.18 W/cm^{2}sr for methane to 16.0 W/cm^{2}sr for ethylene.

Mulvihill, J. N. and Phillips, L. F. (University of Canterbury, Christchurch, New Zealand) "Breakdown of Cyanogen in Fuel Rich H_2 - N_2 - O_2 Flames," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 1113 (1975)

Subjects: Flame structure; H_2 - N_2 - O_2 flames; C_2N_2 breakdown; Fuel rich flames

Authors' Abstract

The reactions involved in the breakdown of C_2N_2 in a flame of unburnt composition $H_2/N_2/O_2$ = 4.5/8/1 have been investigated experimentally by mass spectrometry of the burnt gases and theoretically by computer simulation. Experimentally we find that the C_2N_2 is converted, by passage through the reaction zone of the flame, into approximately equal amounts of HCN and CO/CO_2 mixture. This implies that the main primary reaction:

$$H+C_2N_2 \rightarrow HCN+CN \qquad (13)$$

is followed almost exclusively by

$$CN+O_2 \rightarrow NCO+O \qquad (15)$$

rather than by

$$CN+H_2 \rightarrow HCN+H \qquad (14)$$

CO is assumed to be produced from NCO by

$$NCO+O \rightarrow CO+NO \qquad (16)$$

and

$$NCO+H \rightarrow CO+NH \qquad (26)$$

The low yield of NO when C_2N_2 alone is introduced, and the observed consumption of NO in the reaction zone when both C_2N_2 and NO are added, are attributed to the reaction

$$NH+NO \rightarrow products \qquad (27)$$

The main alternative reaction

$$CN+NO \rightarrow N_2+CO \qquad (21)$$

is too slow to account for removal of NO at the temperature of the early reaction zone. The rate constant for reaction (21) at the temperature of the burnt gas has been determined by measuring the rate of disappearance of HCN above the reaction zone with both C_2N_2 and NO added, the concentration of CN in this part of the flame being governed by the equilibrium constant of reaction 14. We find $k_{21} = 7.3 \times 10^9$ m^3 kg mol^{-1} sec^{-1} at 1500 K. Theoretical concentration profiles of CO and HCN in the reaction zone are consistent with the experimental observations, provided the rate constant for reaction (14) is allowed to increase only slowly with temperature so that it cannot compete effectively with reaction (15). The computer program allows useful numerical predictions to be made concerning the effect of additives such as C_2N_2 on radical concentrations and burning velocity.

O'Neill, J. H., Sommers, D. E., and Nicholas, E. B. (National Aviation Facilities Experimental Center, Atlantic City, New Jersey) "Aerospace Vehicle Hazard Protection Test Program: Detectors; Materials; Fuel Vulnerability," Final Report, October 1970 - September 1972, Contract No. USAF F33615-71-M-5002, U.S. Air Force Systems Command (February 1974), *Air Force Aero Propulsion Laboratory Report No. AFAP-TR-73-87*. See Section A.

Onuma, Y. and Ogasawara, M. (Osaka University, Osaka, Japan) "Studies on the Structure of a Spray Combustion Flame," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 453 (1975)

Subjects: Flame structure, Spray flames

Authors' Abstract

To clarify the flame structure of a spray burner, the following experiments and analysis were carried out. (1) Droplet and temperature distributions, flow velocity, and gas composition were measured in the flame of an air-atomizing burner. It was found that the region where the droplets exist is limited to a small area above the burner nozzle. From the correlation between the above various distributions, it was concluded that most of the droplets in the flame do notburn individually, but that vuel vapor from the droplets concentrates and burns like a gas diffusion flame. (2) Various measurements were then made on a spray combustion flame and a turbulent gas diffusion flame under the same conditions. Comparing the two sets of data, it was found that the flames are similar in structure. (3) Assuming that the droplets evaporate in the flame, their behavior was analyzed by making use of the knowledge which has been obtained for a single droplet. The calculated results were in fairly close agreement with the experimental results.

The above facts suggest the possibility that the spray combustion flame could be treated theoretically by applying the information for a single droplet and for a turbulent gas diffusion flame.

Pandya, T. P. and Srivastava, N. K. (Lucknow University, India) "Counterflow Diffusion Flame of Ethyl Alcohol," *Combustion Science and Technology 5,* 83-88 (1972)

Subjects: Diffusion flames; Counterflow diffusion flames; Opposed jet diffusion flames

Authors' Abstract

A method for stabilizing diffusion flames of liquid fuels has been described. Results are presented for the thermal structure of such a flame of ethyl alcohol as determined by an interferometric study.

Parker, W. J. and Lee, B. T. (National Bureau of Standards, Washington, D.C.) "Fire Build Up in Reduced Size Enclosures," *National Bureau of Standards Special Publication 411,* 139 (August 1973)

Subjects: Fire tests; Flashover; Heat release rate; Scale models; Thermal radiation

Authors' Abstract

A 30 × 30 × 32 inch enclosure was constructed to study the fire build-up process

in a room. Conductive and radiative heat flux, temperature, air velocity, fuel supply rate, and oxygen concentration were measured. In order to relate the phenomena observed in the small enclosure to that in a full size room, the possibility of small-scale modeling with combustible walls was examined. This was done on a preliminary basis by comparing the results of some corner fire tests conducted both in the model and in a full size room. A preliminary examination was also made of the effect of the fuel flow rate and the location of the burner on the temperature and oxygen profiles in the enclosure. Since the ceiling temperature closely follows the upper air temperature the latter is a suitable measure of the degree of fire build-up in the room. Any analysis of the fire build-up process must account for this temperature.

Peeters, J. and Vinckier, C. (Universite Catholique de Louvain, Louvain-de-Neuve, Belgium) "Production of Chemi-Ions and Formation of CH and CH_2 Radicals in Methane - Oxygen and Ethylene - Oxygen Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 969 (1975)

Subjects: Chemionization; Flame structure; Ethylene - oxygen flame; Methane - oxygen flame

Authors' Abstract

The mole fractions of CH, CH_2, CH_3, O, H, OH, O_2, and some other species were measured throughout the reaction zones of a series of low-pressure flames burning methane or ethylene in oxygen, diluted by argon. In some flames, the C atom was detected; its ionization potential was found to be 11.1±0.2 eV.

For each flame, the total amount of ions produced in unit time was also determined, using the saturation current method. The values for all flames were directly proportional to the corresponding volume integrals $\int[CH][O]dz$ over the whole reaction zone. It is concluded, therefore, that the reaction $CH+O\rightarrow CHO^{+}+e^{-}$ is indeed the source of chemi-ions in hydrocarbon flames. The rate constant was found to be 1.7×10^{11} mole^{-1} cm^{3} sec^{-1} at $t = 2000$–$2400°$ K. The ions are formed in a fairly wide region, extending from about the middle of the visible luminous zone to its outer edge.

It is established that CH is not formed firectly from CH_3; instead, CH is derived from CH_2 via $CH_2+H(OH)\rightarrow CH+H_2(H_2O)$. The rate constants of these reactions were found to be about ten times smaller than the kinetic coefficient of the important CH-removal process $CH+H\rightarrow C+H_2$, which in turn is some twenty times larger than the rate constant of $CH+O_2\rightarrow$(products).

Evidence has been obtained that the predominant source of CH_2 in ethylene flames is the reaction $C_2H_4+O\rightarrow CH_2+CH_2O$, which is shown to be only a few times slower at $T = 2000°$ K than the simultaneous process $C_2H_4+O\rightarrow CH_3+CHO$.

In methane flames, CH_2 is produced from CH_3 via the reaction $CH_3+OH\rightarrow CH_2+H_2O$: its rate constant is nearly three times less than that of the reaction $CH_3+O\rightarrow$ (products), which in fuel-lean flames is the major CH_3-removal path. The rate constant of the latter reaction was found to be about $1.2\times10^{[illegible]}$ at $T\simeq2000°$ K.

Pereira, F. J., Beer, J. M., Gibbs, B., and Hedley, A. B. (University of Sheffield, Sheffield, England) "NO_x Emissions from Fluidized - Bed Coal Combustors," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1149 (1975)

Subjects: Fire structure; Flame structure; NO_x; Coal combustion; Fluidized bed

Authors' Abstract

Measurements of NO emissions from two different fluidized bed coal combustors are reported. In a 30×30 cm bed the emission was found to increase with bed temperature and excess air; detailed profiles of NO and species concentrations were obtained from within the bed and the freeboard. The NO concentrations increased along the center line of the bed (being virtually zero at the distributor plate). The transverse distributions of NO were ununiform: NO concentrations were higher near the wall than in the centre region of the combustor.

Experiments carried out with a laboratory size (7.5 cm dia) fluidized bed using mixtures of argon and oxygen have confirmed that most of the NO results from the nitrogen in the coal. The relative contributions of the volatiles and char burning to the total NO emission were assessed by the separation of the two stages of combustion. The char was found to contribute largely at temperatures below 800°C above which the NO formed from volatile combustion became the main source. Above this temperature the formation of thermal NO could also be detected.

Peters, N. (Institut für Thermo- und Fluiddynamik, Technische Universität, Berlin, Germany) "Theory of Heterogeneous Combustion Instabilities of Spherical Particles," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 363 (1975)

Subjects: Combustion instability; Instabilities; Oscillations; Particle combustion

Author's Abstract

The linear and nonlinear stability characteristics of the heterogeneous combustion of spherical particles are investigated on the basis of a simplified mathematical approach using integral relations. A condition for instability is derived which relates the parameters of the problem in an algebraic inequality and reflects the influence of internal diffusion and reaction. In a case where three steady states exist only the lower one was found to be stable to infinitely small and to finite disturbances. Calculations of the transient behavior of the combustion of carbon particles are able to explain the nature of experimentally observed oscillatory instabilities. They appear to be caused by the unsteady heat exchange between the surface and the interior of the particle which produces a time lag. At large values of the thermal conductivity inside the particle the oscillations are damped and stability is obtained.

Phillips, H. (Safety in Mines Research Establishment, Sheffield, England) "The

Use of a Thermal Model of Ignition to Explain Aspects of Flameproof Enclosure," *Combustion and Flame 20,* 121-126 (1973)

Subjects: Flameproof enclosures; Ignition; Maximum safe experimental gap (M.S.E.G.); M.S.E.G.; Thermal model of flameproof enclosures

Author's Abstract

In an earlier paper (*Combustion and Flame* **19,** 187 (1972)) Phillips described the ignition process that occurs when a transient of hot inert gas is ejected into a flammable atmosphere through the equatorial flange gap of an 8-litre sphere for the determination of the Maximum Experimental Safe Gap (MESG) for flameproof enclosure. The analysis of the mechanism of ignition is now extended to take into account changes in flange breadth, vessel volume, internal ignition position, oxygen concentration, humidity, pressure, and ambient temperature. The results of the calculations agree with experimental data.

Quintiere, J. and Huggett, C. (National Bureau of Standards, Washington, D.C.) "An Evaluation of Flame Spread Test Methods for Floor Covering Materials," *National Bureau of Standards Special Publication 411,* 59 (August 1973)

Subjects: Fire test methods; Flame spread; Flammability tests; Corridor fires; Floor covering flammability

Authors' Abstract

Flammability properties of materials have traditionally been measured by small scale laboratory tests. The relationships between test results and performance in real fires have been largely inferred by intuition or subjective judgement. Flame spread test methods for floor covering materials are examined. Through full-scale fire experiments and laboratory studies the nature of the potential flame spread hazard of flooring materials is presented. The factors promoting flame spread in each test method are identified. Test method results are compared with relevant full-scale fire experiments involving floor covering materials in a corridor. An effort is made to relate test results, where possible, to the potential flame spread hazard of floor covering materials in building corridors and exitways.

Quintiere, J. (National Bureau of Standards, Gaithersburg, Maryland) "Some Observations on Building Corridor Fires," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 163 (1975). See Section A.

Richard, J. R., Vovelle, C., and Delbourgo, R. (Centre de Recherches sur la Chemie de la Combustion et des Hautes Temperatures C.N.R.S., Orleans la Source, France) "Flammability and Combustion Properties of Polyolefinic Materials," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 205 (1975). See Section B.

Roberts, A. F. "Some Aspects of Fire Behavior in Tunnels," *Tunnels and Tunnelling 5* (1), 73-76 (1973)

Subjects: Fire Behavior; Mines; Tunnels; Polymers; Wood

Safety In Mines Abstracts 22 No. 76
Safety in Mines Research Establishment

The report discusses fires in ventilated tunnels and their effect on tunnel environment. The author deals in some detail with factors determining the size of a fire and the behavior of materials such as polyurethane foam, mineral oil, and wood.

Romodanova, L. D., Pepekin, V. I., Apin, A. Ya., and Pokhil, P. F. (Moscow, USSR) "Relationship Between the Burning Rate of a Mixture and the Chemical Structure of the Fuel," *Fizika Goreniya i Vzryva 6* (4), 419-424 (December 1970) (in Russian)

Subjects: Burning rate; Chemical structure and burning fuels; Structure and burning

Authors' Conclusions
Translated by L. Holtschlag

A study is made of the burning rate of mixtures with an ammonium perchlorate base and a fuel containing various functional groupings. The heating capacity of these compounds was determined experimentally. The experimental value of the burning rates were considered from the viewpoint of the heating capacity of the compounds and the strength of the chemical bonds of the fuel. The following classes of organic compounds were used as fuels: monobasic and dibasic unsaturated acids, saturated fatty acids, aromatic hydrocarbons, amines, nitramines, polynitro compounds, and organometallic compounds. Stoichiometric compounds with APC were prepared with these fuels. The compounds were compressed in a 5 mm diameter mold to maximum density. The particle size of the APC was less than 100 μ. The compounds were ignited in a bomb under nitrogen pressure, the burning rate was determined by a photorecorder. The results indicate that the burning rate does not depend on the calorific value of the compounds, but is governed by the strength of the weakest bond in the fuel molecule.

Saito, F. (Building Research Institute, Japanese Ministry of Construction, Tokyo, Japan) "Smoke Generation from Building Materials," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 269 (1975). See Section F.

Senior, M. (Joint Fire Research Organization, Borehamwood, Herts, England) "Gas Explosions in Buildings. Part V. Strain Measurements on the Gas Explosion Chamber," *Fire Research Note No. 987, Joint Fire Research Organization* (March 1974)

Subjects: Gas explosions; Explosions of gas in buildings; Strain measurement in explosion

Author's Summary

This paper describes the methods employed for the measurement of the dynamic strains occurring in the structure of the large scale explosion test chamber at Cardington, during gas explosions produced within the chamber.

The general considerations for the measurement of strain are discussed and particular reference is made to the choice of resistance foil gauges. Single active element, self temperature compensated gauges have been adopted for use in the experimental work. A limited number of results are presented for illustrative purposes; more comprehensive results will be the subject of a later report. Strains produced within the structure have been extremely small for explosions of non-stoichiometric gas mixtures and vent covers of low bursting strength; much larger values have been obtained for stoichiometric gas mixtures.

Modifications are at present in hand to increase the overall sensitivity of the system.

Sibulkin, M. (Brown University, Providence, Rhode Island) "Estimates of the Effect of Flame Size on Radiation from Fires," *Combustion Science and Technology 7,* 141-143 (1973)

Subjects: Radiation form fires; Flame size effect on radiation

Author's Abstract

The effect of flame size on the relative contributions of luminous (soot) radiation and nonluminous (molecular band) radiation is calculated for typical combustion conditions. It is found that for small flames nonluminous radiation is dominant while for larger flames both luminous and nonluminous radiation are important. Estimates of the fraction of the energy released by combustion which is emitted as radiation $\dot{Q}_R/\dot{Q}_c$ are made. It is shown that $\dot{Q}_R/\dot{Q}_c$ increases with increasing burner dimension d. For two particular types of fires, a simple power law dependence is obtained.

Stark, G. W. V. and Field, P. (Joint Fire Research Organization, Borehamwood, Herts, England) "Smoke and Toxic Gases from Burning Building Materials 1. A Test Rig for Large Scale Fires," *Fire Research Note No. 1015, Joint Fire Research Organization* (July 1974)

Subjects: Smoke; Toxic gases; Building materials; Fire tests

Authors' Summary

A test rig, consisting of a room communicating with a corridor, has been constructed for examining the products of combustion arising from fires in the compartment or corridor. Tests with wood fuel have shown that thermally reproducible fires are obtained from a given weight of fuel in the compartment and a given arrangement of ventilation.

Under the conditions of ventilation used, the smoke produced from relatively small loads of wood (14.5 to 29 kg/m²) was sufficiently dense to impede escape, even when the smoke and fire gases were diluted with cool air to a temperature that could be borne for a short time during which an attempt to escape could be made.

The concentration of the principal toxic gas, carbon monoxide, in the fire gases is primarily dependent upon the weight of the fire load of wood. Dilution of the fire gases with cool air to a temperature that could be borne for a short time during escape produced atmospheres with fire gases from the greater weight of wood that were hazardous for short exposure, whereas those from the lesser weights were not so.

The production of carbon monoxide from the tests with the greatest degree of ventilation examined rose and fell simply during fires, whereas tests with the lesser degrees of ventilation resulted in periodic variations in concentration. The former test condition is more amenable to calculations concerning toxic gas evolution.

Strömdahl, I. (Fire Engineering Laboratory, National Swedish Institute for Materials Testing, Stockholm, Sweden) "The Tranas Fire Tests. Field Studies of Heat Radiation from Fires in a Timber Structure," *National Swedish Building Research Summaries, Document D3:1972,* Swedish Council for Building Research, 72 pages (in English). Available from Svensk Byggtjänst, Box 1403, S-111 84 Stockholm, Sweden, cost 20 Sw. Kr.

Subjects: Heat radiation; Temperature curve; Fire load; Fire cell; Timber structure fire

Author's Summary

This report has a bearing on an earlier report by the same author: Stromdahl, 1970, Fire risks and fire precautions in dense developments of wooden houses, Swedish Fire Protection Association. The present report describes and compares two full-scale fire tests conducted in two idential dwellings in the same building. The dwellings had the same fire load and opening factors and each corresponded to a modern terraced dwelling with a floor area of 80 m². In one of the tests, walls and ceilings were given an internal fire-retardant finish. Records were obtained of heat radiation, temperatures and the appearance of the flames with the aid of radiation pyrometers, thermocouples, a Thermovision camera and colour film. The results confirm previous assumptions regarding the radiation from a burning dwelling given an internal finish of fire-retardant material; in the case of a non-fire-retardant finish no such confirmation was obtained because of a technical mishap.

Background and aims

A question of particular interest for modern fire engineering is that of the temperatures and levels of radiation prevailing in a fire in a one-family dwelling forming part of an up-to-date dense development of wooden houses. The author of the present report was commissioned by the National Board of Urban Planning to carry out a problems analysis in order to provide a basis for its coming directives on this subject. It was hoped that by conducting full-scale fire tests it would be possible to see the extent to which the accepted hypotheses fitted in with actual conditions. With the assistance of the Tranås fire brigade, tests were carried out in the autumn of 1969 under the direction of the National Swedish Institute of Materials Testing. The site of the tests was a building in the center of Tranas scheduled for demolition.

The building was a two-storey, timber structure with plastered external finish and an outside staircase. It was judged suitable as an object for two comparative tests, one to be conducted on the upper storey and the other on the lower. Each storey was made to represent a modern, one-storey terraced house with a floor area of 80 m^2. The two dwellings were rendered identical as regards room layout, the portable part of the fire load (furniture and loose fittings) and opening factor. The only difference was that the dwelling on the upper storey was given an internal finish of fire-retardant material while the dwelling on the lower storey lacked this.

Preparation of the test building

The building was occupied up to the time when alterations were begun. Changes were made in order to simulate the open-plan character of a modern one-family house. Window openings were made only in the gables of the building in order to minimize the effect of wind direction. The floor of the upper storey was covered with sheets of fibreboard in order to delay the spread of fire to the lower storey. Sawdust insulation between the joists in the loft floor was also replaced by mineral wool. The fire-retardant material used as a finish on the walls and ceilings of the upper storey consisted of 13 mm plasterboard.

Air spaces in partition walls exposed due to the making of new doorways were filled with mineral wool. Existing windows on the longitudinal walls plus the original entrances were blocked with mineral wool on the inside and then covered with plasterboard. Window openings in gable walls were shielded with mineral wool and then covered in plastic sheeting. Ventilation ducts and holes left by former pipes for water supply and waste were blocked with mineral wool. Pasteboard on the ceilings of both storeys was removed.

Characteristics of the fire cells

Each of the dwellings represented a fire cell in which the area of the openings was equal to the sum of the areas of the windows in the gable walls. The opening factor for each storey was 0.04 $m^{1/2}$ calculated according to Swedish Building Standard (Svensk Byggnorm).

In the dwelling on the upper storey the volume of masonry present represented 3.1% of the total volume of the fire cell and the surface area of this masonry 16.5% of the area of the surfaces enclosing the fire cell. The corresponding values for the lower storey were 3.0 and 9.5% respectively. These values are high for a modern wooden house.

The fire load was composed of furniture, linoleum, a source of fire (ignition decive), lightweight partition walls and enclosing surfaces of combustible material. The furniture was some 20–30 years old, dry and in good condition. The source of fire consisted of a pile of spruce laths over a metal container for the methylated spirits. The position of this ignition device was the same in both tests.

The tests

Both the test building and the storage premises housing the furniture for the tests were heated during the alterations period. On September 9th, the day of the tests, the weather was fair and warm and the wind force 2–5 m/s.

Temperatures were recorded with the help of thermocouples mounted 25 cm below the ceilings of all rooms and in window openings. During Test II thermocouples were also mounted on a water-cooled stand outside window openings.

Two pyrometers were used to determine heat radiation. These were positioned 11 and 13.5 m from the gables. Simultaneous tests of the distribution of heat radiation in window openings and escaping flames were made using the Thermovision system. The fire was also documented by a series of colour photographs taken at one minute intervals.

In both tests, flash-over occurred 13 minutes after ignition. Extinguishing operations after Test I proved extremely time-consuming due to a mishap with a pressurized fan. This in its turn meant it could not be prevented that considerable amounts of water were sprayed on to the structure. It was nevertheless still possible to conduct the second test.

Results

Temperature curves were the same for both fire cells during the initial phase showing an increase of around 100°C some 6–8 minutes after ignition, followed by a fall in temperature to 50°C. Removal of the plastic sheeting from window openings was followed by flashover and a rapid rise in the temperature of the fire cell to 600°C. In Test I, the temperature continued to rise until it had reached approximately 750°C after 18 minutes. In the case of Test II, the temperature of the fire cell was still only 600°C after 33 minutes. The tests were discontinued following upward spread of the fire 20 minutes after flash-over before the temperature curve had reached its natural peak.

On the basis of observations of the destruction wrought by the fire on furniture and fittings and also in view of the depth to which the fire had penetrated ceiling structures, it was possible to estimate the rates of combustion. In Test I, this was calculated to be 70 kg of wood/min. and in Test II 100 kg of wood/min.

The low value of the opening factor and the unusually large volume of masonry probably reduced the rate of combustion and temperature of fire cell. It was not possible to determine whether these factors affected temperatures in window openings and thus the intensity of radiation.

A maximum rise in temperature of 1000°C on the windward side and 900°C on the leeward side was recorded in Test I. In Test II the figures were 850–950°C and 750°C respectively. Thus, higher temperatures were recorded in window openings than inside the fire cells; 200–300°C on the windward side and 100°C on the leeward. The heat radiation escaping from a burning building should thus not be determined on the basis of the temperature in the fire cell as is now normally the case.

Thermograms and colour photographs made it possible to establish the ratio of heat radiation from flames round window openings to radiation from the openings themselves. This varied between 0.3:1 and 5:1.

Suzuki, H., Handa, T., Ikeda, Y. and Saito, M. (Science University of Tokyo) "Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part I. Checks on the Factors in Estimating Fire Hazard of Several Organic Building Materials," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 1 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Tests; Fire hazard; Furnace tests; Building material tests

Authors' Conclusions

As a fire-simulation for the initial stage of fire, comparisons of the dependence of wall ignition properties on the variation in the size of the fire source between the new JIS A 1321 furnace and the ex-JIS A 1321 furnace have been conducted.

An equation has been given to hold for the weight loss of the sample, which decreases linearly as the sample thickness increases and is determined mainly by the Nusselt number in the convection period and by $1/\alpha$ in radiation. The coincidence of the rates in these two tests has been found at about 10-mm thickness for the wood samples.

In the present JIS A 1321 furnace, where the effect of radiation is predominant, the covering of the wood surfaces with light metals such as aluminum foil or the like, or the coating of foaming paint and the like gives the materials temporary resistance to the intense radiation. However, their long-term mechanical strength, appearance, and stability remain unsatisfactory. Especially with aluminum foil-covered materials, there is a danger of quick flame ignition at the crack in the junction caused by thermal shrinkage. This makes some new technical developments in the joint very necessary.

In the fire-modelling test, an increase in radiation intensity is necessary for the tests of fire-resistant buildings, but it must be followed by some solution to the everyday problems. So we suggest here that a better testing method for organic material's fire hazard might lie in an examination of the initial fire-simulating pattern and changes in the radiation intensity according to the actual places where the materials are used; namely, for floors, walls, ceilings and partitions. That is, we must have some auxiliary testing methods which take into account the characteristics and classification of the materials used.

Thomas, P. H. (Joint Fire Research Organization, Borehamwood, Herts, England) "The Effect of Crib Porosity in Recent CIB Experiments," *Fire Research Note No. 999, Joint Fire Research Organization* (February 1974)

Subjects: Crib fires; Porosity in crib fires; Compartment fires

Author's Summary

Some of the data obtained in the CIB program on fully developed fires refer to fires controlled by crib porosity. An approximate criterion, based on Nilsson's experiments is suggested for identifying them and so excluding them from general correlations based on fuel surface area and compartment properties.

Tsuchiya, Y. and Sumi, K. (Division of Building Research, National Research Council, Ottawa, Canada) "Smoke Producing Characteristics of Materials," *Journal Fire and Flammability 5* 64 (1974)

Subjects: Smoke generation; Combustion; Polymeric materials

Authors' Abstract

The various methods available for the determination of the smoke-producing characteristics of materials have been critically reviewed. These characteristics depend on both the material and the conditions under which smoke is produced. Two important factors are oxygen concentration and temperature. Most of the existing methods represent combustion under a limited set of environmental conditions that exist at actual fires. As a result the validity of the determination is limited to the specific conditions defined by the test; different tests may produce conflicting results. The rate of smoke generation depends on two factors; rate of combustion and smoke generation coefficient or the amount of smoke produced from a unit weight of materials. These two factors have different characteristics. A method to determine the smoke generation coefficient alone is needed in order to obtain data for a better understanding of smoke production. A method to meet this need has been developed and the smoke generation coefficient of various polymeric materials has been determined under various conditions of temperature and oxygen concentration in the atmosphere.

Watanabe, Y., *et al* "Effect of Fire Retardants on Combustible Materials Underground," *Mining and Safety in Japan 18* (11), 1-8 (1972) (in Japanese). See Section A.

Waterman, T. E. (IIT Research Institute, Chicago, Illinois) "Experimental Structural Fires," *Final Report, February 1972 - January 1974, Contract No. DAHC 20-72-C-0290, Defense Civil Preparedness Agency* (July 1974). See Section D.

Wersborg, B. L., Yeung, A. C., and Howard, J. B. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Concentration and Mass Distribution of Charged Species in Sooting Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania 1439 (1975)

Subjects: Ions in flames; Sooting flames; Flame structure; Molecular beam sampling

Authors' Abstract

Total concentration and mass distribution of charged species larger than about 300 amu were measured along the centerline of a premixed sooting acetylene/oxygen flat flame at 20 mmHg. Charge concentration was determined by measuring the electric current delivered to a Faraday cage in the detection chamber of a staged molecular beam flame sampling instrument having a quenching time of about 1 μs. Charge/mass ratio distributions were measured by the incremental electrical filtration of charged species from the beam. Mass and diameter distributions were then calculated by assuming unicharged species of density 2 g/cm^3. The observed species, which include heavy hydrocarbon ions and charged soot particles, are of positive polarity. Their total concentration at fuel equivalence ratios in the range 2.1–3.0 and cold gas velocities of 31 and 38 cm/s ranges from 10^8 to 10^{12} cm^{-3}, exhibits a distinct peak near the onset of soot formation, increases strongly with increasing fuel equivalence ratio, and decreases with increasing cold gas velocity. The mass distribution of charged species peaks sharply at a mass which increases with increasing height above the burner or time. At a fuel equivalence ratio of 2.25 and a cold gas velocity of 31 cm/s, the peak mass and its equivalent diameter increase from 1390 amu and 13 Å just prior to the onset of visible soot formation to 7700 amu and 23 Å about 2 ms later. The concentration of heavy hydrocarbon ions and that of heavy hydrocarbon molecules estimated previously decrease rapidly with the onset of soot formation in a manner that correlates with the initially fast surface growth of soot particles. Thus the heavy hydrocarbons appear to include both soot nuclei and surface growth intermediates. The concentrations of heavy hydrocarbon ions are much larger than the peak concentrations of soot particles. Therefore, ionic nucleation of soot particles is feasible for these conditions, and a tentative mechanism is described.

Yamao, S. "The Smoke Emission Properties of Materials Used in Mines," *Bull. Nat. Res. Inst. Pol. and Res. 2* (1), 69-84 (1972)

Subjects: Smoke; Tests; Mines

Safety in Mines Abstracts 22 No. 75
Safety in Mines Research Establishment

A prototype smoke-measuring apparatus which can simulate mine conditions in a wide range was developed. The apparatus gave satisfactory distinction between smoke emission indices of test materials. The number of materials used in the present tests was fifteen, of which low density plastics such as flexible polyurethane foam and low density rigid polyurethane foam produced much smoke even at the low temperature 300°C; other plastic materials such as high density rigid polyurethane foam, polypropylene, polyethylene, and polyvinyl-chloride produced a huge amount of smoke at the evaluated temperature 700°C; all hydraulic fluids produced a tremendous amount of smoke throughout all test temperatures compared with other test materials, whereas phenolic moulding which is applied widely for electric insulation was fairly stable throughout all test temperatures. The work described was carried out at SMRE, Buxton in 1970.

H. Chemical Aspects of Fires

Alger, R. S. (Naval Ordnance Laboratory, Silver Spring, Maryland) **and Alvares, N.J.** (Stanford Research Institute, Menlo Park, California) "The Destruction of High Expansion Fire-Fighting Foam by the Components of Fuel Pyrolysis and Combustion. III. Tests of Full Scale Foam Generators Equipped with Scrubbers," *Final Report, July 1974, Report No. NOLTR 74-101,* Naval Ordnance Laboratory (1974). See Section E.

Amaro, A. J. and Lipska, A. E. (Stanford Research Institute, Menlo Park, California) "Development and Evaluation of Practical Self-Help Fire Retardants," *Annual Report, August 1973, Contract No. DAHC20-70-0219, Defense Civil Preparedness Agency (August 1973).* *See Section E.*

Biordi, J. C., Lazzara, C. P., and Papp, J. G. (Bureau of Mines, Pittsburgh, Pennsylvania) "Flame Structure Studies of CF_3Br - Inhibited Methane Flames. II. Kinetics and Mechanisms," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 917 (1975)

Bredo, M. A., Guillaume, P. J., and Van Tiggelen, P. J. (Universite Catholique de Louvain, Louvain-de-Neuve, Belgium) "Mechanism of Ion and Emitter Formation Due to Cyanogen in Hydrogen - Oxygen - Nitrogen Flames," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania 1003 (1975)

Subjects: Ions in flames; Chemionization; H_2 - C_2N_2 flames; Flame structure

Authors' Abstract

A detailed investigation of chemi-ionization and chemi-luminescence in $H_2/O_2/N_2+C_2N_2$ flames has led to the following conclusions:

(a) A sigle molecule of C_2N_2 is required for the formation of an ion or excited species such as CN* or NH*.

(b) The very high ionic yield and the large over-all activation energy suggest a bimolecular process for the primary ionization. The variation of the ionic yield with pressure shows that the overall order of the chemi-ionization process is greater by one than that of the combustion process.

(c) Since the thickness of the flame front depends on the pressure as $P^{-0.7}$, the over-all combustion reaction corresponds to a 1.4 order, and therefore a 2.4 apparent order for the over-all chemi-ionization reaction can be deduced.

(d) These results lead us to propose the following mechanism for the formation reactions of the primary ion (NO^+):

$$CN+O \rightarrow N(^2P)+CO$$

$$CN+O \rightarrow N(^2D)+CO$$

$$N(^2P) \rightarrow N(^2D)+h\nu$$

$$N(^2P)+O \rightarrow NO^+ + e^-$$

$$N(^2D)+O \rightarrow NO^+ + e^-$$

Such a mechanism accounts for all our experimental results for NO^+ and the other ionic species detected by mass spectrometry. Some data for the excited CN-radical are also discussed.

Burdett, N. A. and Hayhurst, A. N. (University of Sheffield, Sheffield, England) "The Kinetics of Formation of Chloride Ions in Atmospheric - Pressure Flames by $HCl + e^- \rightarrow Cl^- + H$." *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 979 (1975)

Subjects: Kinetics; Cl^- formation; Ions; Flame structure; H_2 flames; Ethylene flames; HCl in flames.

Authors' Abstract

The production of Cl^- ions has been studied in atmospheric-pressure premixed flames of H_2 or C_2H_2 with O_2 and N_2 over the temperature range 1810–2750K. Ion concentrations were measured by continuously sampling a fraction of a flame into a mass spectrometer. The observations indicate that the two processes:

$$HCl+e^- \underset{k_{-1}}{\overset{k_1}{\rightleftarrows}} Cl^- + H \qquad (1)$$

account for the production and disappearance of Cl^- ions in these systems. There is clear evidence that the rates of these two opposing steps are fast enough to equal one another, so that the overall reaction is equilibrated everywhere in each flame. The consequence of this state of affairs is that reaction (1) is shifted, as the temperature falls during flame sampling, in the direction that Cl^- ions disappear. It proved possible to measure the extent of this loss of Cl^- by reaction (1) adjusting to local conditions during sampling. This in turn enabled the rate constants k_1 and k_{-1} to be measured from observations over a wide range of conditions. The results indicate that:

$$k_2 = 7 \pm 5 \times 10 \ T \ \ \exp(- \ 9500 \ T)$$

and

$$k_{-1}=7\pm5\times10^{-10}$$

each in units of ml molecule^{-1}s^{-1}.

Butlin, R. N., Ames, S. A., and Berlemont, C. F. J. (Joint Fire Research Organization, Borehamwood, Herts, England) "Gas Explosions in Buildings, Part III. A Rapid Multichannel Automatic Chromatographic Gas Analysis System," *Fire Research Note No. 986, Joint Fire Research Organization* (March 1974). See Section G.

Cernansky, N. P. and Sawyer, R. F. (University of California, Berkeley, California) "NO and NO_2 Formation in a Turbulent Hydrocarbon - Air Diffusion Flame," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania 1039 (1975)

Subjects: Pollution; NO_x formation; Turbulent flames; Flame structure; Diffusion flame; Hydrocarbon flames

Authors' Abstract

Experimental results are presented for turbulent diffusion flames of a round jet of propane in a coflowing mildly swirled, $S=0.3$, stream of air. The jet diameter was 8.7 mm and the total flow was confined in a 58 mm diameter combustion tunnel. Buoyancy effects were found to be negligible. Measurements were made at air stream to fuel stream velocity ratios of 45, 61, and 75 to 1 for initial reactant temperatures of 300°, 440°, and 550° K. Measurements inlude the spatial distribution of nitric oxide, nitrogen dioxide, and temperature as well as the major stable species: propane, nitrogen, oxygen, water vapor, carbon dioxide, and carbon monoxide.

Substantial concentrations of nitrogen dioxide were measured and nitrogen dioxide appears to peak slightly on the fuel rich side of the nitric oxide maxima. No completely satisfactory explanation for the existance and peaking behavior of the nitrogen dioxide was found.

Nitrogen dioxide formation mechanisms are examined and discussed. It appears that the formation of nitrogen dioxide occurs through the rapid oxidation of nitric oxide by radicals found in superequilibrium concentrations.

De Soete, G. G. (Institut Francais du Petrole, Rueil-Malmaison, France) "Overall Reaction Rates of NO and N_2 Formation from Fuel Nitrogen," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1093 (1975). See Section G.

Dixon-Lewis, G., Greenberg, J. B., and Goldsworthy, F. A. (Houldsworth School of Applied Science, The University, Leeds, England) "Reactions in the Recombination Region of Hydrogen and Lean Hydrocarbon Flames," *Fifteenth Symposium (International) on Combustion,* Pittsburgh, Pennsylvania, 717 (1975)

Subjects: Radical reactions; Elementary reactions; Recombination reactions; Hydrogen flames; Lean hydrocarbon flames; Flame structure

Authors' Abstract

A numerical approach which is an extension of the methods discussed by Dixon-Lewis[4] for the computation of detailed temperature and composition profiles in flames has been applied to the simulation of recombination in a number of rich and lean hydrogen–nitrogen–oxygen flame systems. It is found that the recombination in all the systems studied can be adequately explained in terms of the reaction mechanism previously deduced[5,6] for the main reaction zone of fuel-rich flames. Of the actual recombination steps

$$H+O_2+M \rightleftharpoons HO_2+M \quad \text{(iv)}$$

$$H+H+M \rightleftharpoons H_2+M \quad \text{(xv)}$$

$$H+OH+M \rightleftharpoons H_2O+M \quad \text{(xvi)}$$

$$H+O+M \rightleftharpoons OH+M \quad \text{(xvii)}$$

reaction (xvii) is never of major importance in the systems studied. For reaction (xv), studies in fuel-rich flames, assuming equal chaperon efficiencies for all molecules, give as an optimum expression (cm mole sec units)

$$k_{15,M}=2.04\times10^{16}T^{-0.31}$$

In lean flames, reaction (iv) is the major primary recombination step. The subsequent reactions of HO_2 with H, OH, and O are discussed. Experimental information from a number of flame and explosion limit systems, using measurements by Kaskan,[13] Friswell and Sutton,[14] and Dixon-Lewis, *et al.*,[3] at temperatures between 500 and 2150°K, lead to somewhat conflicting results when attempts are made to derive a smooth temperature dependence of k_4. For chaperon efficiencies (relative to H_2=1.0) of 0.35, 0.44, and 6.5 for O_2, N_2, and H_2O, the analyses give k_{4,H_2}= $(9.1\pm1.2)\times10^{15}$ at 773°K, 7.7×10^{15} at 1500°K, and 4.2×10^{15} at 2130°K. At 300°K Bishop and Dorfman[44] find $k_{4,H}=(1.7\pm0.4)\times10^{16}$.

Reaction (xvi) contributes to the recombination in both rich and lean flames not too far from stoichiometric, but it never dominates the recombination. Because of this the precise estimation of k_{16} is not easy. Assuming equal chaperon efficiencies for H_2, N_2, and O_2, and with $k_{16,H_2O}=5k_{16,N_2}$, the most satisfactory Arrhenius expression for k_{16} appears to be

$$k_{16,N_2}=3\times10^{15}\exp(+750/T)$$

This is quite close to the similar expression for k_4.

The extension of the mechanism to recombination in lean hydrocarbon flames is discussed briefly.

Haynes, B. S., Kirov, N. Y. (University of New South Wales, Kensington, Australia), and Iverach, D. (Air Pollution Control Branch, State Pollution Control Commission, Lidcombe, Australia) "The Behavior of Nitrogen Species in Fuel Rich Hydrocarbon Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1103 (1975). See Section G.

Jones, A., Firth, J. G., and Jones, T. A. (Safety in Mines Research Establishment, Sheffield, England) "Calorimetric Bead Techniques for the Measurement of Kinetic Data for Gas Solid Heterogeneous Reactions," *Journal of Physics E: Scientific Instruments 8* 37 (1975)

Subjects: Calorimetric bead systems; Gas solid kinetics; Kinetics of gas solid reactions

Authors' Abstract

A critical assessment has been made of present experimental methods using calorimetric bead systems for the measurement of gas solid catalytic kinetic data. Two distinct methods, the isothermal and nonisothermal, are identified and their relative merits are discussed.

Melvin, A. (British Gas Corporation, London Research Station, London, England) **and Moss, J. B.** (Department of Aeronautics and Astronautics, The University, Southampton, England) "Structure in Methane - Oxygen Diffusion Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 625 (1975)

Subjects: Diffusion flames; Methane-oxygen flame; Flame structure

Authors' Abstract

The fine structure of a methane-oxygen diffusion flame is discussed in the light of perturbation techniques already developed and applied to hydrogen–oxygen flames. The flame model is supported by a modestly realistic chemical kinetic scheme comprising ten reactions and is investigated in circumstances of reaction-broadening. The competition between reaction and mass diffusion which determines reaction zone structure is revealed to be particularly sensitive to the choice of reactions describing methyl radical removal. The structure predicted on the assumption that the reaction between methyl radicals and oxygen atoms predominates is revealed to be incompatible with concentration measurements of stable species and radicals made on a Wolfhard-Parker burner. In particular, predictions regarding methyl radical concentration, reaction zone thickness and

the extent of reaction zone penetration by methane are not substantiated. The inclusion of reactions of methyl with hydroxyl and molecular oxygen does, however, lead to diffusion flame structure consistent with experiment and similar in many respects to that of the hydrogen–oxygen flame. Some ambiguity remains in respect of some detailed aspects of fuel-rich structure.

Merryman, E. L. and Levy, A. (Battelle Columbus Laboratories, Columbus, Ohio) "Nitrogen Oxide Formation in Flames: The Roles of NO_2 and Fuel Nitrogen," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1073 (1975)

Subjects: NO_x formation; Pollution; Flame structure; Nitrogenous fuels

Authors' Abstract

Flat methane flames were probed in the presence and absence of nitrogen-containing compounds (referred to as fuel-N). Methylamine, pyridine, and piperidine at about 120 ppm were added to the flames. The data, based on detailed NO and NO_2 profiles, for flames with and without the fuel-N additives, indicate a sequence of reactions consistent with the following mechanism,

$$NH \text{ and/or } CH+O_2=NO+OH \text{ and/or } CO \quad (1)$$

$$NO+HO_2=NO_2+OH \quad (2)$$

$$NO_2+O=NO+O_2 \quad (3)$$

Spectroscopic data indicate that NH and CN are present in the visible flame. The NO produced from the N-containing radicals is rapidly consumed in the visible flame region by HO_2 radicals, producing NO_2 in accordance with step 2 of the mechanism. The NO–HO_2 kinetics appear to be sufficiently rapid since NO was detected in the visible flame region only when fuel-N was addedto the flames, i.e., only after saturation of Reaction 2. This is further supported by the fact that NO added to methane flames is also rapidly removed in the preflame region. The NO_2 produced in the flame was subsequently converted to NO to varying degrees in a narrow reaction zone in the near postflame region where the O-atom concentration was rapidly increasing to its maximum level [Reaction (3)]. The extent to which NO_2 was consumed depended on the oxygen content of the flame—complete consumption of NO_2 occurring only in the fuel-rich flames. Profiles of the fuel-N compounds obtained from the probings indicate that methylamine produces more NO_2 and NO in the combustion process than pyridine or piperidine. Piperidine, however, appeared least stable in terms of NO and NO_2 produced via the preflame reactions. The relative stability of the three fuel-N compounds in the flames appeared to be pyridine, the most stable, followed by methylamine and piperidine. The fuel-N materials produce a thermally stable, as yet unidentified, intermediate during oxidation, which reacts readily with the O-atoms in the flame.

Mulvihill, J. N. and Phillips, L. F. (University of Canterbury, Christchurch, New

Zealand) "Breakdown of Cyanogen in Fuel Rich H_2 - N_2 - O_2 Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1113 (1975). See Section G.

Oda, N. and Naruse, I. "Emission of Small Quantities of Gas and Odours in the Spontaneous Combustion of Coal," *Nippon Kogyokai - shi 88* (6), 324-388 (1972) (in Japanese)

Subjects: Spontaneous combustion; Coal; Odors

Safety in Mines Abstracts 22 No. 44
Safety in Mines Research Establishment

The authors first of all characterize odors by reference to chemical compositions and review technical literature on the subject. They tabulate and describe odors that may occur during the various stages of combustion of coal. The progress recently made in gas chromatography and its application to research on coal combustion is reviewed. They conclude that fly ash produces CO and CO_2 with increasing temperature. Wood produces CO_2 even at normal temperature and produces alcohols with increasing temperature.

Peeters, J. and Vinckier, C. (Universite Catholique de Louvain-de-Neuve, Belgium) "Production of Chemi-Ions and Formation of CH and CH_2 Radicals in Methane - Oxygen and Ethylene - Oxygen Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 969 (1975). See Section G.

Philpot, C. W., George, C. W., Blakely, A. D., Johnson, G. M., and Wallace, W. H. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "The Effect of Two Flame Retardants on Particulate and Residue Production," *U.S. Department of Agriculture Forest Service Research Paper INT - 117* (January 1972)

Subjects: Flame retardants; Diammonium phosphate retardant; Ammonium sulfate retardant; Particle production; Crib fires; Smoke

Authors' Summary

Two flame retarding chemicals, DAP and AS, reduced the intensity of large wood crib fires. The DAP treatments were somewhat more effective. However, DAP greatly increased particulate production. The AS treatments had much less effect on particulate formation. Total organic residue was increased by DAP treatment; it amounted to as much as 14 percent original organic weight.

As conditions for slash burning are presently dictated from a control standpoint, it is being done at low intensities and at times when weather conditions are not conducive to minimum air pollution. This burning results in large amounts of smoke, poor fuel consumption, and public displeasure. It might be possible to control intensity during the drier months, keep smoke production down, and insure more complete combustion by chemically treating the slash. Obviously DAP would not do the job.

This study supports the possibility that DAP does polymerize the tars and make them more thermally stable. If these tars become less available to combustion, they will add to the particulate in the effluent. Apparently, a large amount of the phosphate ends up as some form of phosphorus in the particulate. The question of why AS and DAP act differently in particulate formation might partially be answered by continued study of the effect of phosphate on the tars.

Philpot, C. W. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "The Pyrolysis Products and Thermal Characteristics of Cottonwood and Its Components," *U.S. Department of Agriculture Forest Service Research Paper INT - 107* (September 1971)

Subjects: Pyrolysis of cottonwood; Treated cottonwood, pyrolysis rate

Author's Abstract

This study was undertaken to determine the thermal properties of, and the pyrolysis products from, western cottonwood (*Populus trichocarpa)* and two of its major components: cellulose and xylan. The modifications due to treatment of the wood and its components with an acid and alkali were also documented. Differential thermal analysis (DTA) and thermogravimetric analysis (TGA), as well as direct pyrolysis into a temperature-programed gas-liquid chromatograph, were used in this investigation.

The components of cottonwood were found to generally behave the same in a thermal environment, both in isolated form and when combined in the whole wood. The hemicellulose, xylan, was completely pyrolyzed prior to the onset of cellulose pyrolysis. The acid salt treatment decreased pyrolysis rate of wood, cellulose, and xylan, and increased char, water, and furan compounds while decreasing the major two and three carbon fragments. The alkali treatment also decreased the pyrolysis rate and increased the production of char and water, but decreased the furan compounds while increasing the two and three carbon fragments.

Romodanova, L. D., Pepekin, V. I., Apin, A. Ya., and Pokhil, P. F. (Moscow, USSR) "Relationship Between the Burning Rate of a Mixture and the Chemical Structure of the Fuel," *Fizika Goreniya i Vzryva* 6 (4), 419-424 (December 1970) (in Russian). See Section G.

Rousseau, J. and McDonald, G. H. (AiResearch Manufacturing Company, Torrance, California) "Catalytic Reactor for Inerting of Aircraft Fuel Tanks," *Final Report, June 1971 - June 1974, Contract No. F33615-71C-1901, Air Force Aero Propulsion Laboratory,* Air Force Systems Command (June 1974). See Section A.

Senior, M. (Joint Fire Research Organization, Borehamwood, Herts, England) "Gas Explosions in Buildings, Part V. Strain Measurements on the Gas Explosion Chamber," *Fire Research Note No. 987, Joint Fire Research Organization* (March 1974). See Section G.

Stone, J. P., Williams, F. W., and Carhart, H. W. (Naval Research Laboratory, Washington, D.C.) "The Role of Soot in Transport of Hydrogen Chloride from Fires," Interim Report, April 1974, *Naval Research Laboratory Report No. 7723,* Naval Ship Systems Command, Department of the Navy (April 1974)

Subjects: Soot; Toxic gas transport; Polyvinyl chloride fires; Soot characterization; Polyvinyl chloride soot; Hydrogen chloride adsorption

Authors' Abstract

As predicted by E. A. Ramskill at NRL, soot has been shown to transport HCl in fires of polyvinyl chloride and polyethylene, but less HCl is carried by the soot particles than Ramskill predicted. A nitrogen gas purge of the soot easily removes 19 milligrams of HCl per gram of soot, whereas 23 milligrams of chlorine, tightly bound, remains. The spherical, amorphous soot particles formed in the combustion vary in size from 0.03 to 0.11 microns. Simple agglomeration theory suggests that the clusters grow rapidly but remain below 2.5 microns in diameter for an hour. We estimate that, when exposed to this dense smoke (1.57 grams/cubic meter) for 1 hour, a man would retain in his lungs 36 milligrams of easily removed HCl. Our work implies the importance of water in transport of HCl by soot. In the last section of the report, we discuss implications for future work.

Takagi, T., Ogasawara, M., Daizo, M. (Osaka University, Osaka, Japan) **and Fujii, K.** (Kawasaki Heavy Industry, Kobe, Japan) "A Study on Nitric Oxide Formation in Turbulent Diffusion Flames," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 1051 (1975)

Subject: Pollution; NO_x formation; Turbulent diffusion flames; Flame structure

Authors' Abstract

Characteristics of nitric oxide (NO) formation in turbulent diffusion flames of hydrogen and propane in air are investigated experimentally and the potential of the Zeldovich mechanism for predicting NO formation is examined.

It is observed that NO is likely to form in the narrow region corresponding approximately to the flame front where the gas temperature is maximum and in the region not far from the fuel nozzle.

The NO formation rate estimated from the experiments is compared with calculated results applying the well-known extended Zeldovich mechanism. It is pointed out that the NO formation rate cannot be predicted by the Zeldovich mechanism for hydrogen and propane diffusion flames if the assumption of the equilibrated oxygen atom is applied.

Kinetic calculations, including 35 elementary reactions in H–O–N system, reveal that the concentration of excess oxygen atom remains high as long as fresh hydrogen and air are continuously mixed with each other, and that such a non-equilibrium oxygen atom concentration is somewhat insensitive to the temperature level.

Based on the above behavior, the NO formation rate and its temperature dependence may be predicted for hydrogen flames if the oxygen atom overshoot is taken into account. For propane flames, the NO formation rate seems too fast and its temperature dependence is too low to be explained by the Zeldovich mechanism, especially for relatively low temperature flames.

Vandooren, J., Peeters, J., and Van Tiggelen, P. J. (Universite Catholique de Louvain, Louvain-de-Neuve, Belgium) "Rate Constant of the Elementary Reaction of Carbon Monoxide with Hydroxyl Radical," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 754 (1975)

Subjects: Rate constants; Elementary reactions; CO + OH reaction; Flame structure

Authors' Abstract

Using a supersonic molecular beam sampling technique coupled with a mass spectrometer, the concentrations of all stable and unstable species have been measured in the reaction zone of a lean carbon monoxide-hydrogen-oxygen flame (9.4%CO, 11.4%H_2, 79.2%O_2) burning at 40 Torr.

Reaction (1) $CO+OH \rightarrow CO_2+H$ is the main process for CO conversion to CO_2. From radical concentration profiles, it was determined that reaction (4) $CO+HO_2 \rightarrow CO_2+OH$ is negligible as compared to (1). The rate constant k_1 was determined from the CO_2 mole fluxes over a large temperature range (400°–1800°K).

The experimental data exhibit a marked and significant curvature in the plot of $\log k_1$ vs $1/T$. From 400° to 800°K, k_1 (8×10^{10} cm^{3}mole^{-1} s^{-1}) increases only slightly, but above 1000°K the Arrhenius expression $k_1 = 2.32\times10^{12} \exp(-5700/RT)$ cm^3 mole^{-1} s^{-1} up to 1800°K. The rate constant of reaction (9) $H_2+OH \rightarrow H_2O+H$ was determined similarly and found to be $7\times10^{12} \exp(-4400/RT)$ cm^{3}mole^{-1} s^{-1} in the temperature range of 600° to 1300°K. A curvature, less pronounced than for k_1, was observed.

Westley, F. (National Bureau of Standards, Washington, D.C.) "Chemical Kinetics of Reactions of Chlorine, Chlorine Oxides and Hydrogen Chloride in Gas Phase: A Bibliography," *National Bureau of Standards List of Publications 71,* 22 pages (December 1973) U.S. Department of Commerce

Subjects: Chemical kinetics; Gas phase reactions; Chlorine; Chlorine oxides; Hydrogen chloride

I. Physical Aspects of Fires

Bürkholz, A. "Measuring Methods for Determining Droplet Size," *Chemie-Ingr.-Tech. 45* (1), 1-7 (1973) (in German)

Subjects: Particles, sizing of; Droplets, holography

Safety in Mines Abstracts 22 No. 18
Safety in Mines Research Establishment

The importance of droplet size determination is increasing with increasing application of liquid atomization. The measuring methods are more difficult and newer than those used in grain size determination and also less accurate. With the exception of a few special methods, one still has to resort to deposition of the droplets on a suitable surface followed by microscopic measurement in the case of raining or spraying liquids (3,000 to 30 μm). In contrast, mist is accessible to measuring instruments and fractional collection according to droplet size (cascade impactors, frit cascades, measuring cyclones). The amounts deposited afford an approximate measure of the required droplet spectrum on the basis of a single calibration with droplets of known size. More recent optical methods measure the droplets without previous deposition. Commercially available counting equipment registers the light scattering by the individual droplets. Droplet holography affords an instantaneous record of a could of droplets. Subsequent three-dimensional reproduction permits measurement and counting of the droplets.

Fernandez-Pello, A. and Williams, F. A. (University of California, San Diego, La Jolla, California) "Laminar Flame Spread Over PMMA Surfaces," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 217 (1975). See Section D.

Greuer, R. E. (Michigan Technological University, Houghton, Michigan) "Influence of Mine Fires on the Ventilation of Underground Mines," *Bureau of Mines Report OFR-72-73,* 179 p. (July 1973)

Subjects: Mine fires; Ventilation flow, fire interaction

Author's Abstract

A comprehensive report was prepared dealing with the influence of accidental fires in underground mines on the ventilation of underground mines. The primary objective of the study was to obtain and evaluate all available information (mostly from foreign sources) dealing with methods of prediction of disturbances in a ventilation system by a mine fire. Particular aspects considered are: properties of mine fires, temperatures of fumes behind the fire zone, forces developed by fumes, qualitative and quantitative prediction of disturbances caused by fires. The compilation of results indicates that the interaction of ventilation flows and fires can be predicted with more accuracy than was previously assumed.

Hallman, J. R., Welker, J.R., and Sliepcevich, C. M. (University of Oklahoma Research Institute, Norman, Oklahoma) "Polymer Surface Reflectance Absorptance Characteristics," *Polymer Engineering and Science 14* (10), 717 (1974) See Section G.

Hinds, W. and Reist, P. C. "Aerosol Measurement by Laser Doppler Spectroscopy. I. Theory and Experimental Results for Aerosols Homogeneous." *Journal of Aerosol Science 3* (6), 501-514 (1972)

Subjects: Aerosols; Particle sizing; Doppler sizing of particles; Laser Doppler spectroscopy

Safety in Mines Abstract 22 No. 20
Safety in Mines Research Establishment

The basic theory, experimental techniques, and results are presented describing a technique for sizing aerosol particles in situ using laser Doppler spectroscopy. Unlike conventional light scattering procedures which use average intensity information, this technique utilizes the Doppler shifted frequency of the scattered light produced by the Brownian motion of the aerosol particles to determine particle diffusion coefficients and size. Experiments were carried out using monodisperse dibutylpthalate aerosols and monodisperse polystyrene latex spheres, in concentrations ranging from 10^3 to 10^6 particles per cubic centimeter. Measured particle sizes were within 10 per cent of the size predicted by conventional light scattering methods for the DBP particles and the reported sizes of the PSL particles. Based on these results it is concluded that laser Doppler spectroscopy can be utilized to accurately measure aerosol particle size in situ.

Hinds, W. and Reist, P. C. "Aerosol Measurement by Laser Doppler Spectroscopy. II. Operational Limits, Effects of Polydispersity, and Applications." *Journal of Aerosol Science 3* (6), 515-527 (1972)

Subjects: Aerosols; Particle sizing; Doppler sizing of particles; Laser Doppler spectroscopy

Safety in Mines Abstracts 22 No. 21
Safety in Mines Research Establishment

The theoretical basis and the results of a computer simulation are presented which describe the operational limits of size and concentration for aerosol sizing by laser Doppler spectroscopy LDS. This analysis suggests that a state of the art LDS system has the capability of sizing 0.03 μm diameter particles when the number concentration is 10^6 cm^{-3} or greater and 0.2 μm diameter for concentrations as low as 100 particles cm^{-3}. An evaluation of the effect on the laser Doppler spectroscopy measurements of a polydisperse aerosol having a log normal size distribution is presented and methods for combining these measurements with other averaged measurements to determine both count median diameter (CMD) and geometric standard deviation (σg) are proposed. For aerosols having log normal distributions with $0.3 < CMD < 3\ \mu m$ and $1.0 < \sigma g < 2.0$, laser Doppler spectroscopy is able to measure the surface area median diameter within ±15 per cent, independent of polydispersity. Applications of LDS to aerosol sizing are evaluated and its advantages and disadvantages relative to other sizing methods are discussed.

Jin, T. (Fire Research Institute of Fire Defense Agency, Ministry of Home Affairs, Japan) "Visibility Through Fire Smoke," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 31 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.)

Subjects: Fire smoke; Smoke, visibility through

Author's Conclusions

The visibility of a black and white sign at the obscurity threshold in smoke generated from various kinds of building materials under various combustion conditions is found to be calculated with the use of Equation (1). That is to say, for k in Equation (1), the values tabulated in Tables 1 and 2 can be used, and as a mean value, k can be 1.0 for smouldering smoke and 0.5 for black flaming smoke. ζc value is given in Fig. 8 and, as an average, values of 0.01-0.02 can be adopted. Values for L in white smoke are given by the measured value without smoke, and for black smoke L can be calculated from Equation (4).

The smoke particles which determine the mean illuminance in smoke are spherical with diameters little less than 1 μ for smouldering smoke, but flaming smoke consists mainly of non-spherical particles with a small mixture of spherical ones. The particle size has a wide distribution, but particles with a 1-20 μ diameter are predominant.

Kamra, A. K. "Experimental Study of the Electrification Produced by Dispersion of Dust into the Air," *Journal of Applied Physics 44* (1), 125-131 (1973)

Subjects: Electrostatics; Particles; Dust electrification

Safety in Mines Abstract 22 No. 16
Safety in Mines Research Establishment

Some laboratory experiments have been performed to study the electrification of dust clouds created by blowing different types of dusts into a dust chamber. The polarity and magnitude of the space charge in such dust clouds have been found to be sensitive to the mineral constituents of the dust. Even a single dust cloud, if allowed to settle under gravity in a field-free space with no charge added to it, can have opposite polarities of space charge at different times of its sedimentation. The space charge produced increases with an increase in the length of the surface over which the dust is blown. It also increases with an increase in the temperature and velocity and a decrease in the relative humidity of the blowing air. External electric fields of up to a few hundred V/cm, applied to the surface from which the dust is blown, have little effect on the generated space charge. Size distributions of positively and negatively charged particles show a greater abundance of smaller ($\sim 3\ \mu$) particles compared with those of small neutral particles.

Lee, S. L. and Otto, F. W. (State University of New York, Stony Brook, New York) "Gross Vortex Activities in a Simple Simulated Urban Fire," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 157 (1975)

Subjects: Vortex urban fire model; Model for urban fires; Fire brands; Brands

Authors' Abstract

A report is hereby given to the results of an originally seemingly inconspicuous burn in a simple simulated urban street arrangement which is inductive to probable gross vortex formation. These results reveal in vivid details a series of most unusual and exciting events of gross vortex development and their related fire-brand spotting activities. These findings point to a promise of an understanding of, among other things, some of the strangest fire behaviors observed in large urban fires.

Leschonski, K. "Characterization of Dispersed Systems, Particle Size Analysis," *Chemie-Ingr. - Tech. 45* (1) 8-18 (1973) (in German)

Subjects: Particles; Sizing of particles; Dust dispersed systems

Safety in Mines Abstracts 22 No. 17
Safety in Mines Research Establishment

The article provides an introduction and a survey of the principles and measurements involved in particle size analysis. Particular attention has been directed towards provision of a brief account of the great variety of measuring methods, which can prove confusing even for the experienced engineer, although more recent but not generally available techniques have been largely left unconsidered. An insight into special fields of particle size analysis is facilitated by a comprehensive bibliography.

Markstein, G. H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Radiative Energy Transfer from Gaseous Diffusion Flames," *Technical Report No. 22356-1, Basic Research Department, Factory Mutual Research Corporation* (November 1974)

Subjects: Flame radiation; Diffusion flames

Author's Abstract

Emission and absorption measurements were performed with an array of ten laminar-diffusion-flame burners. The radiative properties of the flames of various gaseous hydrocarbon fuels were determined by varying the number of ignited burners, and thus the optical depth of the flames. The results for the fuels of highest tendency for soot formation, propylene, isobutylene, and 1, 3-butadiene, could be represented by a grey-gas model. The data for the less sooty flames of aliphatic hydrocarbons and of ethylene required a representation as the sum of two weighted grey-gas terms. Radiance values for one flame, N_1, ranged from 0.156 W/cm²sr for methane to 0.801 W/cm²sr for 1, 3-butadiene, while values extrapolated to an infinite number of flames, N_∞, ranged from 5.18 W/cm²sr for methane to 16.0 W/cm²sr for ethylene.

Modak, A. T. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Nonluminous Radiation from Hydrocarbon - Air Diffusion Flames," *Factory Mutual Research Corporation Technical Report 22355-1* (October 1974)

Subjects: Nonluminous radiation; Diffusion flames; Radiation, analytical solutions

Author's Abstract

Explicit analytical solutions for the radiation from nonluminous regions of hydrocarbon laminar diffusion flames are obtained using a wide band model for nonisothermal, nongray radiation from inhomogeneous mixtures of combustion gases. The spatial distributions of the reactant species, of the combustion products, carbon dioxide and water vapor, and of the temperature in these flames are derived from a one-dimensional model with the Shvab-Zel'dovich assumptions. A wide band, theoretical closed form expression for the total band absorptance of infrared radiating gases used in conjunction with wide band correlation parameters, allows a simple analytical solution for nongray radiation from nonisothermal and nonuniform distributions of carbon dioxide and water vapor observed in hydrocarbon laminar diffusion flames. The isothermal limit of this solution not only provides good agreement with experimental isothermal emissivity data for carbon dioxide but also yields the correct functional dependence on temperature, for both carbon dioxide and water vapor. Agreement with absolute water vapor emissivity is reasonable. A tentative soot model to compute soot distribution profiles in diffusion flames is discussed. In the future, the techniques which have been developed here will be applied to soot containing luminous flames.

This work will be presented at the Fall Meeting of the Western States Section, The Combustion Institute, in October 1974.

Oppenheim, A. K. and Soloukin, R. I. "Experiments in Gasdynamics of Explosions," *Annual Review of Fluid Mechanics 5*, Annual Reviews Inc., Palo Alto, California (1973)

Subjects: Explosion gasdynamics; Gasdynamic experiments of explosions

Safety in Mines Abstracts 22 No. 420
Safety in Mines Research Establishment

Summarizes the work carried out during the period under review on detonation phenomena, shock-wave research and blast wave studies; the latter two are considered with special reference to chemically reacting media. Attention is drawn to the particular interest shown by researchers in transient processes and the concomitant progress made in the development of novel experimental means especially suited for this purpose.

Richmond, J. K. and Liebman, I. (Bureau of Mines, Pittsburgh, Pennsylvania) "A Physical Description of Coal Mine Explosions," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania 115 (1975)

Subjects: Coal; Mines; Explosions, physical model of, in mines; Flammability index

Authors' Abstract

Among the many hazards of underground coal mining, explosions of natural gas and coal dust continue to pose a threat, in spite of advances in safety practices. The U.S. Bureau of Mines has conducted research in the causes and prevention of coal mine explosions in its Experimental Mine. As a result of extensive instrumentation of this full-scale facility and systematic analysis of results, a physical description of coal mine explosions is presented, with emphasis upon unsteady fluid dynamics. In a single long entry, useful correlations are shown between flame speed, particle velocity, and statis pressure rise. How this knowledge may be applied to the design and application of explosion barriers is presented and the role of coal volatiles in dust explosions is briefly discussed.

Shivadev, U. K. (University of California, San Diego, La Jolla, California) **and Emmons, H. W.** (Harvard University, Cambridge, Massachusetts) "Thermal Degradation and Spontaneous Ignition of PaperSheets in Air by Irradiation," *Combustion and Flame 22,* 223-236 (1974). See Section B.

Sibulkin, M. (Brown University Providence, Rhode Island) "Estimates of the Effect of Flame Size on Radiation from Fires," *Combustion Science and Technology 7,* 141-143 (1973). See Section G.

Waterman, T. E. (IIT Research Institute, Chicago, Illinois) "Experimental Structural Fires," Final Report, February 1972 - January 1974, Contract No. DAHC 20-72-C-0290, *Defense Civil Preparedness Agency* (July 1974). See Section D.

J. Meteorological Aspects of Fires

Lee, S. L. and Otto, F. W. (State University of New York, Stony Brook, New York) "Gross Vortex Activities in a Simple Simulated Urban Fire," *Fifteenth Sym-*

posium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania, 157 (1975). See Section I.

K. Physiological and Psychological Problems from Fires

Autian, J. (University of Tennessee Medical Units, Memphis, Tennessee) "Toxicologic Aspects of Flammability and Combustion of Polymeric Materials," *Journal of Fire and Flammability 1,* 239-268 (1970)

Subjects: Fire toxicology; Toxicity of polymer combustion products; Polymers combustion, toxicology of

Author's Abstract

Each year fires kill thousands of persons, injur several hundred thousands, and cause property damage running into the hundreds of millions of dollars. Since the advent of synthetic polymers for textiles, house furnishings, construction material and portions of various types of vehicles, the fire problem has taken on yet another dimension—that of the possible toxic effects from the degradation and combustion products of new man-made materials. With the trend toward greater use of these newer polymeric materials for all aspects of life, from clothing to space vehicles, the toxicity aspects due to fire and heat must be considered as an important facet when new materials are to be considered for a specific application. This article looks at the toxicity problems which may results from the burning or heating of manmade polymetic materials.

Birky, M. M. (National Bureau of Standards, Washington, D.C.) "Physiological and Toxicological Effects of the Products of Thermal Decomposition from Polymeric Materials," *National Bureau of Standards Special Publication 411,* 105 (August 1973)

Subjects: Combustion; Pyrolysis; Polymers; Smoke; Specific optical density; Toxic gases; Toxicity

Author's Abstract

A program that combines the capabilities of the College of Medicine and the College of Engineering of The University of Utah has been instituted to evaluate the physiological and toxicological effects of the products of thermal degradation and combustion of cellulose, a polyvinyl chloride, a flexible polyurethane, and wood (Douglas fir). The products produced from these materials are being identified and quantified with a gas chromatograph-mass spectrometer-computer system. In addition, a National Bureau of Standards smoke chamber has been modified with a weight loss transducer to correlate, on a continuous basis, the quantities of smoke produced with sample weight loss. Extensive studies on the effects of these degradation products on rats is in progress. The results of exposure of the rats to carbon monoxide are reported. All of the laboratory results are being correlated with full-scale fire studies at the National Bureau of Standards.

Buchbinder, B. and Vickers, A. (National Bureau of Standards, Washington, D.C.) "A Comparison Between Potential Hazard Reduction from Fabric Flammability Standards, Ignition Source Improvement, and Public Education," *National Bureau of Standards Special Publication 411* 1 (August 1973). See Section A.

Lynch, J. R. "Respirator Requirements and Practices," Coal Mine Health Seminar. Joint Staff Conference of the Bureau of Mines and the National Institute for Occupational Safety and Health, September 1972, U.S. Bureau of Mines Information Circular 8568 (1972). See Section A.

MacArthur, J. D. (Harvard Medical School, Boston, Massachusetts) **and Moore, F. D.,** (Peter Bent Brigham Hospital, Boston, Massachusetts) "Epidemiology of Burns, The Burn-Prone Patient," *Journal of the American Medical Association 231* (3) 259 (1975)

Subjects: Burns, epidemiology of; Burn-prone patients

Authors' Abstract

Predisposition to burning was identified by history, by conversation with the family, or by physical examination. Factors that decreased the patient's ability to respond appropriately were considered as predisposing.

A consecutive series of 155 hospitalized, burned, adult patients was reviewed. Approximately 50% of the entire series showed predisposition to burning; among the more severe burns, this fraction was 57%. Among women, predisposition was more prominent in all categories than among men. Among women, those predisposed to burning had larger burns and a greater likelihood of dying.

Alcoholism led the list of predisposing factors, with senility, psychiatric disorders, and neurological disease following in order. The patient's own home was usually the site of the burn in those predisposed, with the initial ignition being in the patient's hair or clothing, the mattress, bedclothes, or an overstuffed chair. All of the burns occurring in hospital or mental institution patients were among those predisposed to burning.

Safety in Mines Research Establishment, "Breathing Resistance of Respiratory Apparatus," *Safety in Mines Research Establishment Digest, Respiratory Apparatus - 1* (1973)

Subjects: Respirators, design; Testing of respirators

Safety in Mines Abstracts 22 No. 265
Safety in Mines Research Establishment

Any form of respiratory apparatus: (a) produces some discomfort and restriction on the wearer's activities, (b) has some effect on the way in which the wearer breathes. It is important that the adverse effects should be kept to the minimum so that the wearer can work efficiently and without danger. SMRE, working in co-operation with NCB Physiology Branch, is studying some of these effects with the aim of providing data for use both in improving design and in determining realistic standards of test.

Stone, J. P., Williams, F. W., and Carhart, H. W. (Naval Research Laboratory, Washington, D.C.) "The Role of Soot in Transport of Hydrogen Chloride from Fires," *Interim Report, April 1974, Naval Research Laboratory Report No. 7723,* Naval Ship Systems Command, Department of the Navy (April 1974). See Section H.

Tsuchiya, Y. and Sumi, K. (National Research Council of Canada, Ottawa, Canada) "Combined Lethal Effect of Temperature, CO. CO_2 and O_2 of Simulated Fire Gases," *Journal of Fire and Flammability 4,* 132 (1973)

Subjects: Lethal fire gases; Fire gases and temperature toxicity

Authors' Abstract

Animal experiments have been used by Pryor et al [1, 2] in investigating the hazard connected with combinations of toxic gases (CO and CO_2), oxygen depletion, and high temperature that may occur at fires. They report finding a synergistic effect with some combinations. The authors of the present paper have examined their data in the light of statistical techniques whereby synergistic or antagonistic effects are detected as interaction of factors and have found that the effect of combinations of factors is generally additive. Some of the data involving combinations of O_2 and CO, O_2 and temperature, CO and temperature, and CO_2 and temperature indicated possible synergism. Variance analysis showed that the effect of interactions of pairs of factors was minor in comparison with that of the main factors.

Zarem, H. A. (Los Angeles, California), **Rattenborg, C. C.** (Chicago, Illinois), **and Harmel, M. H.** (Durham, North Carolina) "Carbon Monoxide Toxicity in Human Fire Victims," *Archives of Surgery 107,* 851-853 (December 1973)

Subjects: Carbon monoxide toxicity; Fire victim carbon monoxide levels; Carboxyhemoglobin; Toxicity by carbon monoxide

Authors' Abstract

Arterial blood gases and carbon monoxide hemoglobin analyses were done on 13 patients admitted to the University of Chicago Hospitals and Clinics emergency room after exposure to smoke or fire (house fires). Significant levels of carbon monoxide hemoglobin in each of the 13 patients explained in retrospect the signs and symptoms of carbon monoxide poisoning (headache, weakness, confusion, and reckless behavior) that were present in each patient to varying degrees. The study suggests that the surprisingly high incidents of carbon monoxide hemoglobin in house-fire fictims and firemen warrants oxygen therapy at the site of the fire when feasible.

L. Operations Research, Mathematical Methods, and Statistics

Babrauskas, V. (University of California, Berkeley, California) "COMPF: A Program for Calculation Post Flashover Fire Temperatures," *Report UCB FRG 75-2, University of California Fire Research Group*, National Science Foundation Grant GI - 43 and Department of Housing and Urban Development and National Bureau of Standards sponsorship, 51 (January 1975)

Subjects: Fire protection; Fire resistance;Fire tests; Computer programs; Safety engineering

Authors' Abstract

COMPF is a computer program for calculating gas temperatures in a compartment during the post-flashover period of a fire. It is intended both for performing design calculations and for facilitating further research in endurance requirements for fire-resistive building assemblies. In addition to the capability of performing calculations for a compartment with completely determined properties, routines are included for calculating the fire behvaior under certain worst expected conditions. A comprehensive output format is provided which gives gas temperatures, heat flow terms, and properties of the fire gases. The report includes input instructions, sample problems, and a listing of the program.

Brannigan, F. L. (Montgomery College, Rockville, Maryland) "A Field Study of Non-Fire Resistive Multiple Dwelling Fires," *National Bureau of Standards Special Publication 411,* 178 (August 1973). See Section A.

Chandler, S. E. (Joint Fire Research Organization, Borehamwood, Herts. England) "Preliminary Analysis of Fire Reports from Fire Brigades in the United Kingdom, 1973," *Fire Research Note No. 1008, Joint Fire Research Organization* (April 1974)

Subjects: Fire reports 1973; U.K. fire reports; Fire brigade reports

Author's Summary

A preliminary analysis shows that there were 322,037 fires attended by local authority fire brigades in the United Kingdom, the highest ever total recorded. There were 944 deaths reported in the year of which three were fire brigade personnel; it is likely that the final figure will exceed 1,000. There were 6,377 non-fatal casualties reported in the United Kingdom. The direct fire loss was £193.9M, the highest figure ever reported.

Loomis, R. M. (North Central Forest Experimental Station, Saint Paul, Minnesota) "Predicting the Losses in Sawtimber Volume and Quality from Fires in Oak-Hickory Forests," *U.S. Department of Agriculture Forest Service Research Paper NC* - 104 (1974)

Subjects: Forest fire damage appraisal; Effects of forest fire

Author's Abstract

Presents a method for predicting future sawtimber losses due to fire-caused wounds. Losses are in terms of: (1) lumber value in dollars, (2) volume in board feet, (3) length of defect in feet, and (4) cross sectional area of defect in square inches. The methods apply to northern red, black, scarlet, white, and chestnut oaks.

Rothermel, R. C. and Philpot, C. W. (Intermountain Forest and Range Experimental Station, Northern Forest Fire Laboratory, Missoula, Montana) "Fire in Wildland Management Predicting Changes in Chaparral Flammability," *Journal of Forestry 71* (10) (1973)

Subjects: Brush fires, fuel model; Flammability of wildland brush

Authors' Abstract

A dynamic fuel model for the chapparal brush fields of southern California shows that (a) the fire threat for the first few years after a fire primarily is related to forbs and grasses; and (b) after 10 to 20 years, the brush fields will sustain very fast-spreading, high-intensity fires, depending upon the ratio of the live-to-dead fuel. The mathematical models described permit systematic analysis of the consequences of fuel treatment and fire control and projection of these consequences for the future.

Slater, J. A., Buchbinder, B., and Tovey, H. (National Bureau of Standards, Washington, D.C.) "Matches and Lighters in Flammable Fabric Incidents: The Magnitude of the Problem," *National Bureau of Standards Final Report TN-750* (December 1972)

Subjects: Fabric fires; Fire injuries; Flammable fabrics; Ignition sources; Lighters; Matches

Authors' Abstract

Matches and lighters were a major factor in the 1,838 flammable fabric incidents studied for which ignition sources are known. They accounted for 430, almost one-fourth, of the ignitions and led to 375 injuries, of which 57 were fatal. Children and the elderly were the groups most frequently involved in fires started by matches or lighters. Nearly half the incidents involved children under age 11, and two-thirds of these were children under age 6. Forty-four of the 57 fatalities were children under age 11 or adults over 65. The highest fatality rate, 57 percent, was experienced by persons over age 65. The home was the predominant location of fires involving matches and lighters. Of the fabric items ignited by matches and lighters,

garments were first to ignite four times as frequently as non-apparel items such as furnishings and bedding. Over one-third of the incidents involved intermediary materials in the ignition sequence. Match ignitions outnumbered lighter ignitions by 6 to 1. Among the 430 match and lighter incidents, fires involving children were overwhelmingly the result of playing with matches and lighters, whereas for persons over age 16, smoking was the single most prevalent activity at the time of ignition.

Slater, J. A. (National Bureau of Standards, Washington, D.C.) "Fire Incidents Involving Sleepwear Worn by Children Ages 6 - 12," *National Bureau of Standards Final Report TN* - 810 (December 1973)

Subjects: Clothing fires; Burns; Fire deaths; Flammable fabrics; Standards

Author's Abstract

Sleepwear was the first fabric item ignited more frequently than any other item in over 1,900 fire incidents reported to the National Bureau of Standards Flammable Fabrics Accident Case and Testing System (FFACTS). Information acquired since promulgation of the current sleepwear flammability standard protecting children of ages 0-5 indicates a problem of comparable magnitude exists for children of ages 6-12. Of 316 incidents involving non-contaminated sleepwear that was first to ignite, about one-fourth involved children 0-5 years old and one-fourth involved children 6-12 years old. For the 6-12 group, sleepwear ignited first more often than all other garment items combined. Females outnumbered males 4-to-1 in the 6-12 group, due mostly to the involvement of nightgowns and kitchen ranges, the most common ignition source for this age group. Five of the 6-12 year old children died and 52 of 74 victims were hospitalized. Almost all of the first-to-ignite sleepwear in this group was cotton. Data from Shriners Burns Institute and the National Burn Information Exchange provide further evidence of the involvement of children ages 6-12 in garment fires. It is recommended that a new standard be issued covering sleepwear sizes 7 through 14 to effectively protect 6-12 year old children.

Vickers, A. K. (National Bureau of Standards, Washington, D.C.) "Drapery and Curtain Fires - Data Element Summary of Case Histories," *National Bureau of Standards Interim Report No. NBSIR 73-234* (July 1973)

Subjects: Burns, case histories; Curtain and drapery fires; Fires; Fire deaths; Flammable fabrics; Statistical fire data; FFACTS

Author's Abstract

A preliminary examination of 1,567 computerized case histories from the NBS Flammable Fabric Accident Case and Testing System has found 77 incidents in which curtains and draperies were involved in fires. This report is a summary of information relating to these 77 incidents, and includes the location of incidents,

ignition sources, personal injury, fabrics involved and personal characteristics of victims. Fifteen people died from these fires and 32 others were injured. Curtains or draperies were the first fabric item to ignite in 28 of 55 curtain and drapery incidents in which the ignition source is known.

Yasuno, K. (Kyoto University, Kyoto, Japan) "Study on the Fire Spread Formula for Forest Fires," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 88 (English translation by Trans. Sec., Brit. Lend. Lib. Div., Boston Spa Wetherby, Yorkshire, U.K.)

Subjects: Forest fires; Fire spread in forests

Author's Conclusions

The results of the present investigations are summarized as follows:

(a) The fire-spread formula adaptable for forest fires in Kure city has been presented in formula (1); the formula of adequate number of firemen required for forest fire fighting has been presented in formula (6); and the formula for adequate number of fire engines required for forest fire fighting has been presented in formula (7). The author considers that these formulae may provide a criterion for determining fire fighting power against forest fires, and the accuracy of these formulae can be improved by adding data from other cities.

(b) It has been found that insufficient fire fighting activity at the early stage of the fire permitted the fire to spread. Accordingly, the most effective fire defense system against building fires and forest fires should be established as early as possible.

(c) The author considers that inadequate fire-fighting power level determined by the local administration contributes to big fires; therefore, such unscientific determination should be replaced and renovated.

M. Model Studies and Scaling Laws

Fernandez-Pello, A. and Williams, F. A. (University of California, San Diego, La Jolla, California) "Laminar Flame Spread Over PMMA Surfaces," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 217 (1975). See Section D.

Kung, H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "The Burning of Vertical Wood Slabs," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 243 (1975). See Section D.

Lee, S. L. and Otto, F. W. (State University of New York, Stony Brook, New York) "Gross Vortex Activities in a Simple Simulated Urban Fire," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 157 (1975). See Section I.

Handa, T., Suzuki, H., Takahashi, A., Ikeda, Y., and Saito, M. (Science University of Tokyo) "Characterization of Factors in Estimating Fire Hazard by Furnace Test Based on Patterns in the Modelling of Fire for the Classification of Organic Interior Building Materials. Part II. Checks on Factors Concerning the Surface Flame Spread Rate and Smoke Evolution of Organic Building Materials by Small Inclined Type Test Furnace," *Bulletin of the Fire Prevention Society of Japan 21* (1) 1971 (2) 1972 44 (English translation by Trans. Sec., Brit. Lib. Div., Boston Spa, Wetherby, Yorkshire, U.K.). See Section A.

Harris, G. W. (Safety in Mines Research Establishment, Sheffield, England) "A Sandbox Model Used to Examine the Stress Distribution Around a Simulated Longwall Coal - Face," *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 11* 325-335, Pergamon Press, Great Britain (1974)

Subjects: Longwall coal-mine face; Sandbox model; Stress distribution

Authors' Abstract

A box containing sand is used to examine the possible distribution of stress in the region of coal-mine face workings; the floor of the box represents the top of a coal seam, and strips of the floor can be lowered successively through a distance equivalent to the seam thickness to represent an advancing longwall face. The effects of depth, seam thickness, and two types of sand are also considered.

In the model, the results show that, as the "face" advances, the weight of the overlying sand is carried by a vault, the larger abutments of which are in the "rib-side" areas (rib-side abutments) with smaller abutments ahead of the "face" (front abutment) and behind the "face starting-line". A minor arch, an abutment of which is in the "goaf" (rear abutment), is thought to span the "face", its span distance being a function of depth and its load a function of seam thickness, sand cohesion, and depth.

The traditional view postulates a plane strain condition in which the weight is carried by arching from the front to the rear of the face.

The relevance of these model results to practical longwall mining conditions is discussed and some evidence is reviewed.

Kanury, A. Murty (Stanford Research Institute, Menlo Park, California) "Modeling of Pool Fires with a Variety of Polymers," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 193 (1975)

Subjects: Modeling pool fires; Polymer fires; Diffusion flames; B-numbers; Smoke measurement

Author's Abstract

The experiments reported in this paper deal with steady turbulent free convective diffusional burning of eight different polymeric solids in the geometry of horizontal circular pools. The measurements include the burning rate, the history, and the thermal radiation emitted by these fires under various ambient air pressures up to about 40 atm.

A simple one-dimensional diffusion flame theory is used to correlate the mass transfer rates, history of burning, and radiant-emission rates. The theory leads to determination of *B*-numbers for the simulated, realistically large, polymer fires that involve radiation effects in *B*. These *B*-numbers are in excellent accord with other measurements available in the literature.

The tested materials are rated for their flammability (burning intensity) on the basis of the *B*-number. They are also rated for their smokiness on the basis of the radiation measurements. As may be expected, a desirable material on the basis of flammability is not necessarily so desirable on the basis of smoke potential.

Parker, W. J., and Lee, B. T. (National Bureau of Standards, Washington, D.C.) "Fire Build Up in Reduced Size Enclosures," *National Bureau of Standards Special Publication 411* 139 (August 1973). See Section G.

Rothermel, R. C. (Northern Forest Fire Laboratory, Missoula, Montana) "A Mathematical Model for Predicting Fire Spread in Wildland Fuels," *U.S. Department of Agriculture Forest Service Research Paper INT - 115* (1972)

Subjects: Mathematical fire model; Fire spread; Wildland fuels

Author's Abstract

A mathematical fire model for predicting rate of spread and intensity that is applicable to a wide range of wildland fuels and environment is presented. Methods of incorporating mixtures of fuel sizes are introduced by weighting input parameters by surface area. The input parameters do not require a prior knowledge of the burning characteristics of the fuel.

Rothermel, R. C. and Philpot, C. W. (Intermountain Forest and Range Experimental Station, Northern Forest Fire Laboratory, Missoula, Montana) "Fire in Wildland Management Predicting Changes in Chaparral Flammability," *Journal of Forestry 71* (10), (1973). See Section L.

Stevenson, A. E., Schermerhorn, D. A., and Miller, S. C. (The Aerospace Corporation, El Segundo, California) "Simulation of Southern California Forest Fires," *Fifteenth Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, Pennsylvania, 147 (1975)

Subjects: Forest fires; Simulation of forest fires; California wildland fires; Meteorology; Model of forest fires

Authors' Abstract

Wildland fire spread has been simulated using a computer model. Reasonable

success has been achieved in matching computed results with the observed fire perimeters. The model for this effort was based upon existing Forest Service submodels augmented with ancillary programs to process the fuel, terrain, and meteorological data collected from the selected fires. Refinements to the model were made based upon sensitivity studies of the numerous input parameters. The simulation runs performed during this study gave insight into the improvements required to employ the model operationally.

N. Instrumentation and Fire Equipment

Alger, R. S. and Nichols, J. R. (Naval Ordnance Laboratory, Silver Spring, Maryland) "A Mobile Field Laboratory for Fires of Opportunity," *Naval Ordnance Laboratory Technical Report 73-87,* 105 (October 1973)

Subjects: Mobile field laboratory; Fire measurement sensors; Fire portraits

Authors' Abstract

Techniques for preventing and suppressing large fires can be improved with a better understanding of fire characteristics and their relationship to the fuel and environment. The Fires of Opportunities program was designed to provide some of this information by generating portraits of large fires in both planned and unplanned circumstances. Part of the program involved the procurement or development of sensors to measure the appropriate fire parameters and the assembly of an instrument trailer to serve as a mobile field laboratory. This report describes the present field facilities and some of the techniques developed while acquiring portraits of large Class A and B fires.

Benson, S. P. and Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts, England) "A Calorimeter for Measuring the Heat Flux from Experimental Fires," *Fire Research Note No. 1005, Joint Fire Research Organization* (April 1974)

Subjects: Calorimeter; Flammable liquid fires; Radiation; Convection

Authors' Summary

The calorimeter will be useful for measuring heat flux in the range 0.1 - 10 W cm^{-2} from such sources as flammable liquid fires.

Shortcomings of existing methods are considered, and desirable characteristics for the new instrument are enumerated. Descriptions of the new calorimeter design and its advantages are given, together with its construction, performance under fire-test conditions, and its principal characteristics.

A further possible development is described which will permit the heat retained by the calorimeter to be determined in its two component parts - radiation and convection.

Boyes, J. H., Kennedy, M. P., and Wilton, C. (URS Research Company, San Mateo, California) "Development of a Long Duration Flow Facility for Studies of Blast Fire Interaction," Final Report No. URS 7239-6, Contract DAHC20-73-C-0195, *Defense Civil Preparedness Agency* (June 1974)

Subjects: Airburst long range; Blast; Fires; Suppression; Interactions; Test facilities; Civil Defense

Authors' Abstract

The study reports on the conversion of an underground complex into a Long Duration Flow Facility (LDFF), the calibration of the facility, and a limited test program to study the effect of long duration pressure pulses on extinguishing materials simulated to have been ignited by the coincident thermal pulse (so-called "blast-fire" interaction). The LDFF is composed of a compression chamber with a volume of approximately 40,000 cubic feet separated by a mechanical diaphragm from a test room approximately twelve feet by fifteen feet by nine feet high. In operation, the compression chamber is filled; the diaphragm is then opened and the flow vents through the test room producing a flow of up to 5 psi and with a duration of up to 4,000 milliseconds to provide correlation with the long duration pressure pulse of megaton nuclear weapons.

High speed photographic cameras and pressure sensing gauges instrument the test room. Three blast-fire interaction tests were conducted and it was found that the blast wave extinguished initial fires, but would not extinguish smoldering fires in upholstered materials such as mattresses. These tests demonstrated the usefulness of the facility.

Brenden, J. J. (Forest Products Laboratory, Madison, Wisconsin) "An Apparatus Developed to Measure Rate of Heat Release from Building Materials," *U.S. Department of Agriculture Forest Service Research Paper FPL 217* (1973)

Subjects: Furnace, auxiliary equipment; Rate of heat release; Heat of combustion; Flaming conditions

Author's Abstract

Describes a gas-fired, water-jacketed furnace and auxiliary equipment designed to expose one face of a specimen to controlled flaming conditions.

Chigier, N. A. and Dvorak, K. (University of Sheffield, Sheffield, England) "Laser Anemometer Measurements in Flames with Swirl," *Fifteenth Symposium (International) on Combustion,* The Combustion Institute, Pittsburgh, Pennsylvania, 573 (1975)

Subjects: Anemometer, laser; Laser anemometer; Velocity measurement; Swirl; Doppler velocitimetry

Authors' Abstract

An experimental study has been made of flow fields in turbulent swirling jets under flame and no-flame conditions. Natural gas was supplied separately to a burner with a divergent exit of 20°. The recirculation zone penetrated into the diffuser at a swirl number of 0.3. Time mean axial, radial and circumferential components of velocity, and rms velocity fluctuations were measured. The laser anemometer operated in the double Doppler mode and frequency shifting was obtained with a rotating diffraction grating. Signal processing was carried out by an electronic single particle pulse counter. Substantial changes in flow patterns were detected as a consequence of combustion, and the kinetic energy of turbulence per unit mass under flame conditions was higher than in the corresponding cold conditions, in almost all regions of the flame.

Courtney-Pratt, J. S. "Advances in High Speed Photography," *Journal of the Society of Motion Picture and Television Engineers 82* (3), 167-175 (1973)

Subject: High speed photography

Safety in Mines Abstracts 22 No. 569
Safety in Mines Research Establishment

Paper presented at the opening of the Tenth International Congress on High-Speed Photography, Nice, 25-30 Sept. 1972. Describes advances up to the date of the conference. Among the subjects discussed are the characteristics of streak cameras, experimental arrangements to photograph laser light pulses in flight, photography showing the rupture of test specimens, rotating mirror cameras, image dissection cameras, flash X-ray photography, etc.

Elmer, C. H. and Endelman, L. L. "A Report on the Tenth International Congress on High Speed Photography, Nice, 25-30 September, 1972," *Journal of the Society of Motion Picture and Television Engineers 82* (3), 176-187 (1973)

Subject: High speed photography, Tenth International Congress

Safety in Mines Abstracts 22 No. 570
Safety in Mines Research Establishment

Summary of proceedings. The papers covered the subjects of cameras (ultra-high speed, mechano-optical camera giving 10 million images per second, high-speed rotating mirror with gas bearings, possibilities of rotating drums), picosecond cameras, lenticular plate cameras, holography, time resolution, spectrography, strobe light sources, propagation of shock waves in fluids, studies of materials and explosive phenomena (studies of initiation of explosives using HS photography, visualization of the shape and symmetry of detonation waves by means of a slit camera, high-speed camera study of shock-wave propagation, 3-dimentional detonation wave analysis using a multi-slit streak camera, automatic accurate full-range synchronization of a light strobe with shutter opening of a fast-framing camera, etc.

Kinns, R. "Calibration of a Hot-Wire Anemometer for Velocity Perturbation Measurements," *Scientific Instruments 6* (3), 253-256 (1973)

Subjects: Hot-wire anemometer; Anemometer calibration; Velocity perturbation measurements

Safety in Mines Abstracts 22, No. 207
Safety in Mines Research Establishment

Many workers have formulated empirical cooling laws to describe hot-wire anemometer response, but the highly non-linear response of the anemometer makes curve-fitting a difficult exercise which has led to large errors in velocity perturbation measurements. Recently, it has been suggested that a dynamic calibration is therefore necessary. In this paper, it is shown how the rate of change of anemometer voltage with windspeed can be accurately computed from coarsely spaced static calibration data. The calibration of an approximately linearized anemometer is then discussed and appropriate formats for data presentation are described. Experimental results from cylinder wakes at the same Reynolds number demonstrate the validity of the calibration procedure when an analogue linearizer is used.

McQuaid, J. and Wright, W. "The Response of a Hot-Wire Anemometer in Flows of Gas Mixtures," *International Journal of Heat and Mass Transfer 16* (4), 819-827 (1973)

Subjects: Anemometer response; Hot-wire anemometer; Turbulent flow measurement

Safety in Mines Abstracts 22 No. 206
Safety in Mines Research Establishment

An investigation of the problem of measuring turbulence quantities in flows of gas mixtures by means of hot-wire anemometry is described. In view of the lack of a reliable heat-transfer law for fine wires in flows with variable gas properties, an entirely empirical approach is adopted. Attention is paid initially to the air/carbon dioxide system and it is shown that a simple calibration procedure is possible. An assessment is made to determine a suitable gas as a marker for flows in which turbulence measurements are to be made, and it is concluded that argon is to be preferred to carbon dioxide. The procedure for measuring turbulence quantities in air/argon mixtures is discussed; the optimum arrangement is a large-diameter wire operated at low overheat ratio combined with a small-diameter wire operated at high overheat ratio.

Parker, W. J. and Long, M. E. (National Bureau of Standards, Washington, D.C.) "Development of a Heat Release Rate Calorimeter at NBS." Ignition, Heat Release, and Noncombustibility of Materials, *ASTM STP 502, American Society for Testing and Materials*, 135-151 (1972)

Subjects: Heat flux; Calorimeters; Thermal radiation; Radiant heating;; Fire tests; Construction materials; Combustion

Authors' Abstract

The heat release rate calorimeter being developed at the National Bureau of Standards measures the rate of heat release for building materials exposed to radiant fluxes up to 10 W/cm^2 with a response time of a few seconds. The calorimeter and its operation are described and preliminary results are presented on the maximum one minute average heat release rates for a variety of building materials. Also given is the effect of irradiance on the maximum one minute average heat release rate of a wood fiber insulating board. The total heat generated by a pine specimen is compared with its heat of combustion measured with an oxygen bomb calorimeter. This heat release rate calorimeter has adequate sensitivity, accuracy, and time response to provide useful information on the heat release characteristics of building materials in a fire environment.

Tonkin, P. S. and Berlemont, C. F. J. (Joint Fire Research Organization, Borehamwood, Herts, England) "Gas Explosions in Buildings, Part I. Experimental Explosion Chamber," *Fire Research Note No. 984, Joint Fire Research Organization* (February 1974)

Subjects: Explosions; Gas explosions; Building explosions; Tests; Explosion chamber; Pressure of explosions; Chromatography; Strain measurement

Authors' Summary

An explosion chamber of volume 28.4 m^3 (1002 ft^3) has been built of 4.8 mm (3/16 in) thick steel plates in which explosions with natural gas/air mixtures can be carried out.

Provision has been made for the measurement of all relevant explosion parameters as necessary to obtain information on the effects of gas explosions in buildings.

Satisfactory operating and safety procedures have been established and used and are described herein.

O. Miscellaneous

Bibliography of RANN-Supported Fire Research Literature, The Johns Hopkins University Applied Physics Laboratory Report FPP TR18, compiled by **B. W. Kuvshinoff and J. Jernigan** (January 1975)

Subjects: Bibliography on fire research; Fire research, RANN-NSF; RANN (Research Applied to National Needs) fire program; NSF (National Science Foundation) RANN fire program

PREFACE*

The entries in this bibliography represent the formal fire research documentation produced at 19 institutions under the NSF RANN sponsorship. This includes journal articles, symposium and conference papers, technical reports, theses and dissertations, and action picture films. Progress reports, talks, and informal memoranda are not included. Entries are arranged alphabetically by author under these general headings for each institution. A list of principal investigators and their affiliations is included as an appendix.

This bibliography was prepared with the aid of an IBM 360-91 computer, using INFC-36C document writing program prepared by APL. Each bibliography entry is a unit record in the file. A brief description of the file design, coding, and the indexing technique used in the preparation of this bibliography is available from the compilers.

*Extracted by the editor FRAR

INTRODUCTION

The National Science Foundation's fire research effort within the Research Applied to National Needs (RANN) Program is in its fourth year, and many useful results have been determined. This bibliography has been assembled at the request of NSF and gives evidence of the research findings and the accumulated knowledge.

The NSF/RANN fire research effort has the objective to reduce deaths and losses due to hostile fires, and to improve the effectiveness of fire control. One measure of magnitude is the level of financial support. Currently, the budget for fiscal year 1975 (beginning July 1, 1974) is $1,000,000. Past expenditures were $1,455,000; $2,000,000; and $1,647,000 for fiscal years 1972, 1973, and 1974, respectively. The projects are in various stages of completion and vary considerably in size. There are four multidisciplinary projects (Harvard University, University of California/Berkeley, University of Utah, and The Johns Hopkins University/Applied Physics Laboratory) which are much larger than the others.

Another document has been printed which should complement the bibliography, as it contains brief progress reports on each project. It is the proceedings from the recent "NSF/RANN Conference on Fire Research," which was held at Georgia Institute of Technology in May 1974 and will be available from the National Technical Information Service, Department of Commerce. The NSF/RANN Document Center, Washington, D.C. 20550, may be contacted for acquisition information.

These documents represent a means of disseminating information from the projects to various performers concerned with fire protection and control. It is hoped that this bibliography will find wide use. The Foundation welcomes comments on the fire research program and related needs.

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COMMENTS

This cumulative bibliography of the National Science Foundation RANN Fire program is an impressive document. It covers a span of just over three years and the results of some twenty research institutions of broad interests. Some of the programs are specialized in scientific discipline, some in engineering, some in practical problems; other programs are multidisciplinary and cover a spectrum of basic and applied fire problems. All contribute to the understanding of the fire program. Dr. Long is to be congratulated for having assembled this diverse array of scientific and engineering talent into a meaningful attack on the fire problem. The reader will find this a guide to a rich literature on fire problems well worth his study.

Christian, W. J. (Underwriters' Laboratories Inc., Northbrook, Illinois) "The Effect of Structural Characteristics on Dwelling Fire Statistics," *Fire Journal 68*, 22-28 (1974)

Subjects: Dwelling fires; Structural characteristics; Statistics of dwelling fires

Review by W. J. Christian

Estimates by the National Fire Protection Association indicate that over 500,000 fires occur yearly in one- and two-family dwellings, and it is known that these fires are responsible for a large percentage of the fire fatalities. This paper examines the role played by structural characteristics, although it is recognized that various sociological, psychological, and technological factors contribute to these fatalities. Based on published fire statistics, as well as information available from fire testing and research activities, a number of conclusions can be made.

1. Vulnerability of dwellings to exposure fires is not a significant weakness in the United States, since the national exposure fire frequency is low[1], although local areas of high conflagration risk may exist because of inadequate exposure protection. Dwelling owners who wish to take measures to make dwellings extra safe from exposure fires have available a number of options. These are: limitation of the amount of combustible material surrounding the dwelling; maintenance of adequate separation distances between buildings; and provision of as much fire resistance as is feasible in the exterior of the dwelling. Inadequate building separation distances and combustible roof coverings, such as represented by wood shingle or shake roofs, were contributing factors in a large percentage of the conflagrations which have occurred in the United States and Canada in this century[2], thus these deserve most attention. Information on recommended building separation distances[3,4], and on fire resistance of roof coverings[5] is available.

2. It is combustible contents rather than combustible structural materials that are the first ignited materials in dwelling fires which cause about 90 percent of the fatalities[6], thus the role of dwelling structural characteristics in fire fatalities has to do mainly with the effect that the structure will have on burning contents. The structural characteristics having the greatest effect on life safety during fire are: fire resistance of interior walls, floors, and ceilings; fire stopping of concealed spaces;

interior compartmentation; and thermal properties and flame spread charcteristics of wall, floor, and ceiling materials.

3. Statistics show that, on the average, the basic fire resistance of dwelling walls, floors, and supporting structure is such that structural collapse or penetration by fire is not a significant direct or indirect cause of death[7,8,9]. This conclusion is supported by the observation that modern dwelling construction entails relatively open interiors so that fire may spread extensively through a dwelling without penetration of walls, floors, or ceilings. This indicates that construction practice predominant in this country does provide adequate protection against collapse and leads to the suggestion that the standard fire resistance required of interior walls, floors, and ceilings in dwellings is perhaps 20 min. Experimental data on the maximum severity of fire in rooms characteristic of dwelling occupancies reinforce this conclusion[10,11,12,13].

4. The presence of open doors and stairways, plus the lack of fire stopping in concealed spaces, is responsible for spread of fire and smoke in a high percentage of dwelling fires involving fatalities[9]. Fire stopping within wall or floor-ceiling cavities or within concealed spaces formed by other construction features is apparently absent in many dwelling structures. The trend toward relatively open interiors in dwellings has all but eliminated the use of doors in many living areas, and most of the doors provided are customarily left open by occupants for convenience. For this reason it is practical to consider that the only interior doors that can be counted on for significant effect on life safety are those separating bedrooms, basements, and perhaps attached garages from the remainder of the house, or separating individual dwelling units. Experimental information shows that a substantial increase in survival time during a dwelling fire is provided by a closed door, even one of minor fire resistance, as compared to the same situation with an open doorway[14,15].

5. Combustible finish material contributes to death by fire spread in more than half of all fatal dwelling fires[9]. The ultimate in interior finish safety would be associated with the use of relatively-dense noncombustible interior finish materials, that is, those whose standard flame spread indices would place them within NFPA Class A. However, it is probable that the fire hazard associated with interior finished materials of Class B would not usually be excessive[16,17]. The use of large amounts of Class C materials in a dwelling ought to be discouraged, especially in areas used as exitways and areas particularly subject to rapid development of hot fires. Other than through fire spread, interior finish materials may also contribute to the hazard through generation smoke and toxic gases. Since there is presently insufficient experience upon which to base judgments of acceptable materials in this regard, it appears that limitation of smoke and toxic gas hazards must rely on measures to control the amount of material that may become involved in the fire.

6. A large percentage of fatal dwelling fires involve victims who would have been unable to escape even if warned in time[8]. This suggests that to improve the chances for survival of such occupants, it would be necessary to limit the rate of generation and transmission of toxic fire products within the dwelling, rather than to provide earlier warning times.

Items 4 and 5 above identify the principal weaknesses of existing structures relative to overall dwelling fire deaths in this country—open doors, stairways, and concealed spaces; and combustible interior finish. A purely structural approach to widespread improvement of life safety in dwellings would have to address these aspects first. It does appear that the level of fire safety connected with other structural features that are now incorporated in most dwellings is sufficient in comparison with these weaknesses.

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Directory of Fire Research in the United States 1971-1973, 7th ed., M. Kalas, editor, Committee on Fire Research, Division of Engineering, National Research Council, National Academy of Sciences, 2101 Constitution Avenue, Washington, D.C. 20418, 361 pages (1975)

Subjects: Directory U.S., fire research; U.S. fire research directory; Fire research directory

Abstracted by R. Fristrom

This biannual directory is an indispensable guide to the multifaceted regime of Fire Research. As indicated in the introduction, it is intended to be a comprehensive listing of fire research projects in this country. Somewhat over a hundred different laboratories are represented. This is the only national summary of the field and provides one of the few measures of the efforts in this country. It is cross indexed according to sponsor and subject.

The chairman of the Committee on Fire Research, Dr. C. Walters, indicated in his forward to the volume "the mission of the Committee on Fire Research to advise, recommend, and identify areas of research and development needed for fire prevention and control and the alleviation of fire damage" led to the cataloging of current research as a basis for its deliberations. The Directory of Fire Research in the United States is thus a by-product that has established itself as a general reference and resource for interchange of information for a diffuse and worldwide endeavor to understand the destructive action of fire.

The Directory is indispensable for an understanding of the present direction of fire research and the location of the groups working in the area.

Fire Problems Program: Annual Summary Report, 1 July 1973 - 30 June 1974, Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland, under a grant from the National Science Foundation (RANN program GI-34288x) Program Director: A. G. Schulz; Principal Investigators: R. M. Fristrom and W. G. Berl

Subjects: Education; Systems analysis; Combustion; Fatalities; Casualties; Toxic gases; SCORE project; Fire prevention and control hearings; Fire problems exhibit

Report Summary

AREA I
Education and Information

The Education and Information programs have a threefold objective: (a) to strengthen the academic training and resource materials of fire specialists; (b) to contribute to the development of an effective Fire Information Center; and (c) to bring fire safety information to the attention of the public.

The unusually rapid expansion of fire science instruction in community colleges has made it important to assist in strengthening the framework for career education in the fire sciences, in fire prevention, and in the preparation and enforcement of adequate codes. The rapid transfer of research information into practice and the feedback of practical needs into additional research and development are dependent on the availability of an effective information exchange system that spans the entire field in detail and breadth of coverage.

The following tasks contribute to this program:

A. *Symposia/Workshops/Colloquia on Fire Problems*

This long-established series has been continued and extended to cover topics in depth. Berl, W. G., Halpin, B. M., Ordway, G. L., Smith, E. G., and Tuve, R. L.

B. *The Teaching of the Fire Sciences*

A 2-day seminar and workshop with particular emphasis on course content, teaching objectives, and innovative teaching methods was held. Berl, W. G. and Tuve, R. L.

C. *Conference on Fireground Command, Control, and Communications*

A 2½-day conference and workshop with emphasis on fire service problems was organized and held. Berl, W. G., Halpin, B. M., and Ordway, G. L.

D. *Fire Sciences Dictionary and Source Book (Revision)*

The text of the book, to be published by Wiley interscience, has been essentially completed. Kuvshinoff, B. W.

E. *Fire Safety Films*

Arrangements for wide distribution of the film *Don't Get Burned* have been concluded with the National Fire Protection Association. A second film, directed toward inner city problems, is in production. Berl. W. G., Brubaker, J., Halpin, B. M., Mandella, M. C., and Walter, B. S.

F. *Fire Information Center*

Several projects were continued to clarify the objectives of a Fire Information Center. Berl, W. G. and Kuvshinoff, B. W.

G. *Advances in Fire Sciences*

Four reviews and bibliographies have been published. Fristrom, R. M., Kuvshinoff, B. W., and Robison, M. M.

AREA II
Systems Analysis and Development

One goal of the NSF/RANN Fire Program is to improve the effectiveness of methods of preventing or controlling fires. The Systems Analysis and Development area of the APL Fire Problems Program is addressing this problem by the design and evaluation of devices that will improve the fireground effectiveness of fire departments (Task A) and by analysis of the frequency and nature of fire incidents (Tasks B and C).

A. *Fireground Command and Control System*

An economical and workable fireground command and control system has evolved from previously developed components. To record the status and location of fire-service units or of fire-suppression aids a Tactics Display Case has been designed consisting of a box the size of an attaché case containing aerial photographs and magnetically attachable markers to designate apparatus and other mobile equipment. The case can be used for preplanning operations, training, or actual fireground command and control. When the Tactics Display Case is used in conjunction with a microfiche viewer for retrieving stored prefire planning information, the configuration is called a Tactics Console. The most fully developed configuration is a Mobile Tactical Unit, which consists of the previously described control aids plus communications and other equipment, all installed in a mobile van.

In a cooperative project with the Hillandale (Maryland) Volunteer Fire Department, which supplied the vehicle, APL has designed and outfitted such a van. It was formally turned over to Hillandale in March 1974 and put in active service to evaluate its effectiveness and utility as a tactical aid on the fireground. Halpin, B. M., Hickey, H. E., and Shapiro, D. O.

B. *Communications in an Urban Fire Department*

Previous studies of alarm rates and communications procedures in the Baltimore City Fire Department have been extended to include analysis of false-alarm activity on street boxes and a consideration of various criteria of false-alarm activity. The dependence of alarm rate on box type was investigated, and the hypothesis that quick-pull boxes might be associated with a higher alarm rate was found to be unsubstantiated. Ordway, G. L.

C. *Fire Incident Analysis*

Data on fire incidents have been gathered in Alexandria, Virginia, since December 1971. The Uniform Fire Incident Reporting System (UFIRS) has been extended to include additional variables of possible interest and significance. A cumulative frequency analysis has been made for fire incident types, actions taken, property grouping, property types, construction types, and socio-economic factors, gross accumulations of events by location on a grid, false alarms, and time analysis. The data have been reduced to a computer-plottable form and can be displayed on a street map of Alexandria. Hickey, H. E.

AREA III
Combustion Research

The ignition, propagation, and extinction of fires are physico-chemical processes that are amenable to quantitative understanding. The technology of fire prevention and suppression has much to gain from an awareness of the basic principles involved.

The suppression of fires by chemical inhibitors generally involves interference with a few key reaction steps in such a way that a stable reaction cannot be sustained and the reaction ceases. The combustion of hydrogen-containing substances (such as hydrocarbons, cellulose, and plastics) is sensitive to halogens which in relatively small amounts are able to suppress flame propagation. To understand the mechanisms by which these powerful extinguishing agents exert their influence is the objective of the ongoing research effort.

A. Premixed Flame Model

A simple model for the prediction of flame velocities and reaction zone conditions in both the absence and the presence of inhibitors has been developed. It is assumed that the major rate-determining reactions take place in a narrow reaction zone, preceded and followed by slow events whose influence on the primary zone is negligible. Predicted and observed effects of hydrogen bromide on the flame speed of hydrogen-oxygen mixtures are in fairly good agreement. Brown, N. J. and Fristrom, R. M.

B. *Flame Inhibition Chemistry*

A novel technique has been developed to measure relative reaction rates of potential flame inhibitors at elevated temperatures. Small quantities of inhibitors are injected into a low-pressure flat flame, and concentration changes due to diffusion and reaction are measured. From this, reaction rates of the inhibitor with a predominant flame component are deduced. Hart, L. W., Grunfelder, C., and Fristrom, R. M.

AREA IV
Fire Casualty Studies

Loss of life is one of the major disasters in fires. In order to find ways to reduce the number of fatalities an understanding of the factors that cause fire deaths is critically important. Information available at the present time is surprisingly sparse and unreliable. Therefore, a program to investigate the medical and physical causes of fire casualties is being carried out with the cooperation of the State of Maryland Medical Examiner's Office and The Johns Hopkins University School of Hygiene and Public Health. The program includes detailed autopsies, blood and urine analyses, studies of lung tissue of fire victims. and analysis of the physical factors relating to the fire.

The effects of exposure to toxic atmospheres of survivors of a fire is another problem area in which very little information is available. A program to obtain definitive data through studies of surviving victims exposed to toxic gases was implemented.

A. *Fire Fatalities Study*

To establish the cause of fire fatalities, a systematic study of the causes of such deaths in Maryland has been carried out. Cooperation among the State of Maryland Medical Examiner's Office, The Johns Hopkins University School of Hygiene and Public Health, the Maryland State Fire Marshal's Office, and local fire authorities allowed a program of autopsies, case studies, and analyses to be undertaken. Halpin, B. M., Fisher, R. A., Caplan, Y. H., and Radford, E. P.

B. *Biochemical Studies of Tissues and Fluids of Fire Victims*

In support of the fire fatality studies, laboratory programs are making special studies for poisons and other causes of death not ordinarily considered in standard autopsies. These studies include methods for examining the tracheal-bronchial tree and the lung for the presence of heavy metals, oranic vapors, and other toxic materials. Fristrom, G. A., Fristrom, R. M., Shapiro, D. O., Frazier, J. M., and Halpin, B. M.

C. *Nonfatal Fire Injury Study*

To understand the consequences of exposures to toxic gases and smoke from fires, a program was implemented to investigate such effects on people with non-fatal injuries ("overcome" victims) and fire department personnel. Blood samples were taken from civilians and firemen for analysis, and follow-up medical histories were documented. This program is in cooperation with The Johns Hopkins University School of Hygiene and Public Health and the Baltimore City Fire Department. Halpin, B. M. and Radford, E. P.

AREA V
Miscellaneous Studies and Activities

A. *SCORE (Student Competitions on Relevant Engineering, Inc.)*

A competition was sponsored in 1973/1974 by SCORE on the topic "Students Against Fires." A project was submitted by the Student Chapter of the Society of Fire Protection Engineers (sponsored under the Fire Protection Curriculum, College of Engineering, University of Maryland) dealing with the design, testing, and installation of an automatic sprinkler system with novel features. This project was under the direction of Professor H. E. Hickey. B. M. Halpin served as a judge.

B. *Hearings, Subcommittee on Science, Research, and Development, U.S. Hours of Representatives, on Fire Prevention and Control (July 25, 26, 31; August 1, 2, 1973)*

Professor H. E. Hickey, accompanied by Dr. W. G. Berl, presented an invited statement on the provisions for fire education incorporated in various proposed legislations and on the established or projected educational programs. A statement was submitted for the record by Dr. Berl.

C. *NSF/APL Exhibit*

An exhibit illustrating the fire research activities of the NSF/RANN program was shown at the First Symposium on RANN: Research Applied to National Needs, Washington, D.C., 18-20 November 1973. Berl, W. G., Halpin, B. M., and Simmons, R. R.

Fowler, L. C. (Joint Fire Research Organization, Borehamwood, Herts, England) "Collected Summaries of Fire Research Notes 1973," Fire Research Note No. 1009, *Joint Fire Research Organization* (April 1974)

Subject: Fire research, review

Giles, K. and Powell, P., Editors (National Bureau of Standards, Washington, D.C.) "Attacking the Fire Problem; A Plan for Action," *Final Report No. NBS SP 416, National Bureau of Standards* (May 1975)

Subjects: Building design; Consumer protection; Fire control; Fire detection; Fire research; Fire spread; Flammability

Editors' Abstract

The mission of the Center for Fire Research is to insure the development of the technical base for the standards and specifications needed in support of the National goal to reduce fire losses by 50% over the next generation. A systems approach to accomplish this mission is described. The Center consists of three basic programs in the area of Fire Science and five applied research programs in the area of Fire Safety Engineering. Each applied program addresses an aspect of the Fire Problem, using fundamental information supplied by the basic research function. Active participation by staff members in voluntary standards organizations is the principal means of making this technology available for codes and standards needed to reduce the Nation's fire loss.

"Consequences of LNG Spills on Land," *Liquid Natural Gas Safety Program: Interim Report on Phase II Work, American Gas Association Project IS-3-1, Battelle Columbus Laboratories* (July 1974)

The American Gas Association sponsored the "LNG Safety Program, Phase II, Consequences of LNG Spills on Land" (designated A.G.A. Project IS-3-1), with objectives of developing models capable of predicting the dispersive and the radiative hazards associated with large spills on land and of obtaining data on means to reduce the hazards. This large experimental and analytical program involved research personnel at Battelle Columbus Laboratories, Arthur D. Little, Inc., University Engineers, Inc., TRW Systems, Inc.; Professors R. C. Reid and R. O. Parker as consultants; and advisors from the LNG and the cryogenics industries.

The objectives of Phase I of this program were to define the circumstances of possible spills, to estimate quantities and rates of possible spills, and to identify areas of further research. It was found that a very high level of safety and reliability exists for LNG facilities constructed by present techniques; that if an LNG spill from a large storage tank were to occur it would most likely be caused by some very improbable event. The Phase I report recommended the Phase II research program.

The Phase II program was planned to obtain data on dispersion of vapor clouds, on radiation intensities near LNG fires, and on methods of LNG fire control and vapor suppression. LNG was spilled into dikes up to 80 feet in diameter. Some experiments gave data on the dispersion benefits of high dikes and of insulated dike floors. An effort was made to obtain data for a range of wind velocities and weather classes—the classes ranged from neutral to slightly unstable.

Most experimental data were recorded on magnetic tape at several bits per second from each sensor channel. Dispersion data included gas concentrations and temperatures in the vapor cloud, LNG depth, dike soil temperatures, weather data, and others. In fire experiments the data included weather variables, LNG depth, dike soil temperatures, radiation intensities from narrow angle and wide angle radiometers, etc. Fire control and vapor suppression experiments were done with several dikes up to 30 feet by 40 feet. These tests included fire control with high expansion foams and with dry chemicals, reduction of radiation by water sprays, and vapor suppression with high expansion foam.

Analytical models for dispersion and radiation were developed which fit these data for the 80-foot spills satisfactorily and will predict the hazards for spills into dikes up to 400-500-feet-diameter. It is possible that the models can be used to predict the hazards for spills in stable weather conditions, although data were not obtained for this condition in this program. Experiments verified very significant reduction of dispersion hazards by insulated dike floors and by high dikes. The report presents background material, analysis of data, and conclusions. The latter include predictions of downwind distances of travel of flammable vapors and radiation intensities on targets near fires on soil, in low dikes up to 500-feet-diameter, and in neutral weather.

CONTENTS

SECTION A. SUMMARY
SECTION B. BACKGROUND (Battelle)
SECTION C. DISPERSION AND RADIATION EXPERIMENTS (Battelle)
SECTION D. ANALYSIS OF VAPOR DISPERSION EXPERIMENTS (A.D.L.)
SECTION E. VAPOR DISPERSIONS FROM LNG SPILLS (U.E.)
SECTION F. RADIANT HEATING FROM LNG FIRES (U.E.)
SECTION G. RADIATION FROM LNG FIRES (A.D.L.)
SECTION H. SPECTROSCOPIC RADIATION MEASUREMENTS ON LNG DIFFUSION FLAMES (TRW)
SECTION I. FIRE CONTROL AND VAPOR SUPPRESSION (U.E.)
SECTION J. A VAPOR DISPERSION DATA CORRELATION COM— PARED TO A VAPOR DISPERSION MODEL (Parker)

Obukhov, F. "UdSSR; Die Atemschutz - Ausbildunj von Feuerwehrleuten": "Fire Protection Abroad; USSR; Respiration Training of Firemen," Brandschutz, *Deutsche Feuerwehr-Zeitung 26* (2) 54 (1972)

Subjects: Firemen training; Respiration training; Fire protection of personnel

Translated by L. Holtslag

In order to assure the safety of fire-protection personnel in an unbreathable ambient atmosphere, respiration teams are being set up in fire brigades in the USSR with a permanent watch of more than five men. In such brigades each man is equipped with a closed system respirator that is independent of the surrounding air. Such teams are physically capable of fighting fires under difficult breathing conditions.

Oxygen circulators are used for the most part at the present time in the Soviet fire-fighting system. At a number of sites, however, especially in petrochemical plants, where a respirator may become contaminated with oil, compressed-air respirators are also used.

As demonstrated by the experience of the Leningrad Fire Department, almost every fourth or fifth fire requires the respirators. These are usually fires in basements, storehouses, cable conduits, etc., in industrial areas. But also the increasing use of synthetic polymers as covering material in the interior design of buildings as well as in the manufacture of modern furniture increases the danger that toxic products may appear when these materials decompose in a fire.

For example, polyurethane foam decomposition is significant even at relatively low temperatures (180 to 300°C). In this temperature range polyurethane foam loses 40 to 50% in weight as a result of formation of gaseous decomposition products: the principal decomposition products of polyurethane foam are carbon dioxide, carbon monoxide, various hydrocarbon compounds, hydrogen cyanide, and vaporous toluene diisocyanate (up to 0.233 mg/ l). Near the center of the fire the concentration of the last-named decomposition product exceeds the limit concentrations permissible under the Soviet labor-protection regulations by a factor greater than 10.

As a rule, it is necessary to work under respirator conditions in fire fighting only a short time, on the average only about 10% of the total time. But such work is almost always strenuous and involves staying in rooms in which temperatures and relative humidity are high.

During moderately heavy and very heavy work, O_2 consumption can rise to 2.5 l/ min and the pulse rate from 90 to 100 to 140 to 160. At the same time the temperature at the point where the fireman is working can, at times, exceed 50 to 60°C at a relative humidity of 100%. Therefore, every fireman assigned to a respirator team must be given systematic, special training for work with a respirator under various conditions in order to gain the necessary experience for work and to prevent accidents.

The experience accumulated in the course of thirty years of respirator use in fire departments, as well as analysis of some experimental results of laboratories for industrial hygiene and physiology make it possible to set up a number of requirements relating to the organization and methods of respirator training and to develop some recommendations.

All command personnel are already schooled in breathing apparatus during their training at technical schools. The leading fire protection experts of the Republics, Regions, and Administrative Districts as well as the commanders of large fire departments are recruited from people who have graduated from an institute in the department of fire fighting technology and safety.

Before they are sent out on calls, all firemen are especially trained for work wearing oxygen respirators. This training course lasts forty-one hours and supplements the general basic training program.

Further schooling of personnel is carried out at the stations during duty hours. Every individual equipped with a respirator goes through a refresher exercise at least once every quarter year in an ambient atmosphere not suitable for breathing (smoke chambers) and at least twice a month in the open air (once within the framework of a fire-extinguishing exercise).

Also, fire-fighting personnel not directly employed in such service and command personnel of the respirator service (insofar as the personnel are physically fit for work wearing breathing apparatus) are trained at least once a month in a smoke chamber or in the open air.

Command personnel of the fire department are given training sessions with respirators in a smoke chamber once every quarter year.

A special smoke chamber must be available in every fire department region for training respirator teams. As a rule it consists of the following sections:

- a main room with room dividers (moveable partitions and rotatable walls), making it possible to modify the room as desired;
- a heating plant;
- a smoke chamber; and
- a control panel for the safety guard.

According to the most recent designs, provisions are being made for heating chambers for exercises at very high temperatures (up to 50°C).

Depending on the particular demands of the region in which the fire department operates, some training areas are additionally equipped with special structures and installations (ship superstructures, tunnels, aircraft cabins, et al.), in order to permit training for special tasks. The smoke chamber is filled with smoke and heated by means of a heating plant in the basement of the chamber. The heating system is a hot-air furnace. The smoke chamber has at least two exits and an emergency ventilation system which, if necessary, can clear the interior within one to two minutes. In order to ensure the team safety during practice, all smoke chamber doors and partitions are equipped with electrical signal transmitters connected to the control panel of the safety guard.

Supervision of training in respiration is the responsibility of the respiration chiefs of the fire department involved and on the fire department chiefs themselves.

A universally binding plan for scheduling the training time has been established for respiration exercises in the Soviet Union.

- Testing of respirators, instruction in the training problem, donning the respirators: 5 to 10 mins.
- Accommodation exercises in the open air: time required - 5 to 10 mins.
- Execution of exercise according to a fixed training plan in smoke chamber or in the open air: time required - 45 to 50 mins.
- Removing the respirator, inspection and critique of the exercise: time required - 5 to 10 mins.
- Inspection, cleaning, and readjustment of respirators after use: time required - 60 mins.

The operation problems to be mastered by the respirator teams during training simulate essentially the tasks that come up in actual fire fighting.

- Negotiating narrow corridors;
- Climbing down through manholes;
- Handling a play pipe under pressure in restricted areas and working with the pipe;
- Climbing stairs;
- Handling foam pipes and finding foam-covered pockets of fire;
- Finding a fire source in the smoke chamber;

- Finding and carrying a "smoke-inhalation casualty" (a dummy);
- Self-rescue and rescue using a grapple and rope;
- Transportation of casualties on the level and up and down stairs;
- First aid for a fireman, victim of a respiration accident;
- Learning signal codes, the use of transmitters, the duties of a safety guard;
- Emplacement of smoke ejectors and construction of air ducts;
- Dismantling of components;
- Changing the oxygen flask of a respirator while in the smoke chamber.

This respiration training is scheduled in the training plan of the fire brigade. Before carrying out each exercise the trainer determines how well the accident regulations are known, the level of first-aid skills, and the capability of the men carrying respirators to recognize and eliminate possible troubles in the respirator itself. The exercises are carried out in such a way that physical exertion is gradually increased.

Practice for already-trained teams in the solution of tactical problems is carried out at plants where strong formation or the liberation of toxic gases and vapors can occur during a fire. But training in the smoke chamber is also adapted as much as possible to severe-case conditions. Such training is carried out only if the trainee has firmly mastered handling of the respirator and the basic accident-prevention rules. The physical condition of the participants in the exercises is continuously checked by the respiration trainer.

After all practice sessions the behavior of the participants is discussed thoroughly. During this discussion the trainee is to be indoctrinated with the importance of the rules for working with respirators. A "training critique" is held immediately in the training area or in the classroom following each training exercise.

Pelouch, J. J., Jr., and Hacker, P. T. (Aerospace Safety Research and Data Institute, Lewis Research Center, Cleveland, Ohio) "Bibliography on Aircraft Fire Hazards and Safety," Volume I - Hazards, Part 1, Preliminary Form, 267 pages, *National Aeronautics and Space Administration NASA TMX 71553*

Subjects: Aircraft fire hazards; Fire hazards of aircraft

Publications of the Rocky Mountain Forest and Range Experimental Station 1953 - 1973, *U.S. Department of Agriculture, Forest Service General Technical Report RM - 6,* compiled by **M. F. Nickerson and G. E. Brink** (September 1974): Available Rocky Mountain Forest and Range Experimental Station, Forest Service, U.S. Department of Agriculture, Fort Collins, Colorado 80521.

References to Scientific Literature on Fire, Department of the Environment and Fire Offices, *Joint Fire Research Organization,* Borehamwood, Herts, England, compiled by **P. Mealing,** Part 24A January - June 1973, 132 pages (published April 1974) and Part 24B July - December 1973, 188 pages (published July 1974)

Bibliography Topics

A. Occurrence of fire: Fire losses and statistics; arson; incidents
B. Fire hazards and fire precautions: Industries and materials
C. Initiation and development of combustion: Theory and experimental studies; flammability tests
D. Fire resistance: (including structural protection) Structures; building materials; fire retardant treatments and coatings
E. Fire detection and extinction: Appliances; equipment, including technique; extinguishing media; personnel protection; flammable gas detectors; salvage
F. Nuclear energy
G. General

The Home Fire Project: Semi Annual Progress Reports, June 1974 and December 1974, Harvard University, Cambridge, Massachusetts, and Factory Mutual Research Corporation, Norwood, Massachusetts, under a grant from the National Science Foundation (RANN program GI - 34734) Program Directors; **H. W. Emmons and R. Friedman**

Subjects: Fire dynamics; Pyrolysis; Ignition; Extinguishment; Fire destruction rate

Contents June 1974

This program, currently consisting of thirteen tasks, is directed toward developing an understanding of the fire dynamics of pyrolysis, ignition, fire growth, extinguishment, and value destruction rate in fires.

Some highlights of the past six months work are:

1. Preliminary comparison of radiance and transmittance for arrays of laminar and turbulent diffusion flames shows lower effective radiative temperatures for the latter.
2. The data from last year's bedroom fire have been analyzed, using data from some of the laboratory studies.
3. Vertical plastic wall and cylinder fire development and characteristic burning rate have been modeled over a range of pressures.
4. Some useful but limited fire spread and value destruction data can be obtained by the careful inspection of burned properties after a fire.
5. The extinguishment of burning vertical woodslabs and wood cribs follows an inverse 1.5 power law with water application rate. This empirical result agrees with the empirical interpretation of a simple theory. There is a lower limit water rate which is completely ineffective.

Contents December 1974

This program currently consists of twelve tasks of which only ten are active. These tasks are directed to the development of a sufficient understanding of fire and its control, so as to decrease the loss of lives and property by fire in the home.

Some highlights of the past six months work are:

1. The second bedroom fire was accomplished. (It does not model.)
2. The feasibility of pressure modeling has been extended to transient wood crib fires.

3. Radiative properties of multiple turbulent flames was measured. The total radiation from a single flame is directly proportional to flow rate over a wide range.
4. Two fan anemometers went through the bedroom fire including flashover without difficulty.
5. Some pyrolysis products of cellulose can diffuse and condense and then further pyrolyze with char deposit on later heating.
6. The experimental difficulties of burning an analyzable charcoal fire have been overcome.
7. The fire value destruction rate requires improved quantitative fire investigation methods and instruments.
8. The equipment for testing by radiative ignition of a vertical wall is ready for calibration.

Each of the tasks are briefly summarized below and a more extensive summary is attached as an appendix.

I. Dr. Kun Min has made further progress with the study of pyrolysis of cellulose and wood. It has been verified that a significant fraction of the pyrolysis products are condensible at room temperature and that on reheating these products further pyrolyze to carbon and flammable gases and that such condensation may occur in coolerparts of a porous fuel. A report on these qualitative results is in preparation and what further testing is needed to make them quantitative is under study.

II. Dr. Francesco Tamanini has completed the study of the extinguishment of crib and flat plate fires, has received his Ph.D. and is now working at Facrory Mutual. His study used a single droplet size water spray. Although inactive at present, this work needs to be extended to include other drop sizes and other extinguishing agents.

III. Mr. David Evans has completed the development and analysis of the one dimensional burning of charcoal after considerable effort to control heat losses, to get consistent surface temperatures, and to measure and correlate surface heat and mass transfers. The effect of small amounts of ash accumulated on the surface is very important. The measured ratio of CO to CO_2 differs considerably from various values reported in the literature for reasons not yet understood. Mr. Evans expects to receive his Ph.D. in June and is currently seeking employment.

IV. Professor Joseph Prahl and Professor H. Emmons are completing a report on the theory and measurement of the flow of hot buoyant gases through an opening. The report will be submitted for publication. The attempt by Professor Thomas Shen to measure the flow coefficients in a hot gas apparatus proved to be very difficult. After trying water-air and salt water-fresh water flows, kerosene-water proved to be most effective. Although flow coefficients were measured, it was found that a fixed flow coefficient of C = .68 was adequate for all present fire purposes.

V. Dr. Charles Knight has prepared a large report on the two dimensional convective flows in an enclosure which will be published as a project report soon. He has left the project for employment at Avco Research Labs. This convective study will be temporarily discontinued.

VI. The fan anemometer developed earlier on this project by Mr. Richard Land measured velocities reliably throughout the full scale test and a manufacturer is being sought to make and distribute them for general fire research and other velocity measurements.

VII. Professor Neville Fowkes has made fair progress with the prediction of the growth of fire in an enclosure and in particular the fire growth observed for the bedroom fire. A report is in preparation.

VIII. Mr. Paul Croce directed most of his effort during the last report period of study of Froude Number Modeling toward obtaining supplementary information on quasi-steady crib burns. Free burning rates were obtained for all cribs used in this study, and additional tests were performed to assess the effects of crib porosity, crib geometry, and enclosure wall materials. The hypothesis is now being applied to the transient burning of plastic slab (pool) fires.

IX. Dr. Ronald Alpert has initiated and nearly completed in the last six months a study which has proven the feasibility of pressure modeling the important transient processes of fire growth and decay in pine-wood cribs. Two crib geometries are being considered, one having a fuel surface-controlled burning rate at full-scale and at one atmosphere ambient pressure while the second has a ventilation controlled burning rate under the same conditions. Experiments performed over a wide range of crib length scales (7.6 to 76 cm width) and ambient pressures (1 to 40 atm) have shown that the rate of weight loss, beginning with a point ignition and ending with the fuel nearly consumed, behaves exactly as predicted by the pressure modeling theory. Preliminary analysis of data on crib fires in enclosures from 24.4 cm to 2.44 m wide has shown that the effect of these (well ventilated) enclosures on the crib burning rate can also be pressure modeled.

X. Dr. George Markstein has used carefully developed and calibrated radiation instrumentation to study the absorptance and radiance of laminar and turbulent diffusion flames. Turbulent flames radiate a nearly fixed fraction of the fuel energy (1/4 to 1/5) independent of the fuel flow rate. Furthermore, the effective radiation temperature is 5 to 10% less for turbulent flames than for the laminar flame with the same gaseous fuel.

The radiation measurement techniques and instrumentation were used in the last full scale bedroom fire and showed that most of the radiation on the floor of the room originates in the hot gases (and smoke) above and not from the ceiling.

XI. Mr. Paul Croce has issued a project report on the analysis of the 1973 full scale bedroom fire. A second "identical" bedroom was burned with considerable difference in behavior. In particular, one fire took 17.5 minutes to flashover while the other took only 7 minutes. The data have been partially analyzed and show fairly good internal self consistency. The use of full scale tests cannot serve to properly evaluate fire safety of materials if the reproducibility of "identical" room fires is so bad. A full scale test is planned for each of the next several years to resolve this problem of reproducibility.

XII. Mr. Manny Ratafia has started the study of the burning of vertical slabs in a radiative field. Apparatus to accomplish this is nearing completion and will be used in the next contract period.

BOOKS

Fire Fighting Hydraulics R. Purington, Lawrence Livermore Laboratories, Livermore. California, McGraw Hill, New York (1974) 428 pages

Reviewed by J. W. Kerr
Dunn Loring VFD, Virginia
International Association of Fire Chiefs
Defense Civil Preparedness Agency

How many fire chiefs ever write books? Answer: Very few. How many of those few books are *text* books? Answer: Even fewer. How many of the total are really *good* books? Answer: Few indeed.

In fact, one of the big problems with books written for the fire service by somebody else is the fact that the authors do not see things in our light. And one of the problems with most books written by fire chiefs is that they are long on the "war stories" and short on the solid meat we crave.

So here we have a book by a practicing fire chief (Lawrence Livermore Laboratories, Livermore, California) that is credible, readable, qualifies as a first-class textbook, and gives any fire service student of hydraulics the material he needs, in or out of class.

Bob Purington is a member of the Research Committee of the International Association of Fire Chiefs, heads a number of professional groups in his state of California and serves with the faculty of Chabot College, Hayward, California. He thus brings to the study of hydraulics many years of line experience plus his solid technical know-how.

Technical folk will like this book because it addresses practical problems in a relatively rigorous fashion, stressing basic concepts, giving some basic proofs, and forcing the user to think things through step by step.

Instructors will like this book because it lays out the subject in a pattern of relationships, giving enough solutions to lead the student up to the problems he has to solve on his own. We start with water and its properties, get into dynamics, and move on to equipment.

Students will like this book because it's all right there, with enough hard work to keep them on their toes, but no stupid over-tough "problems" that some poor instructors throw in to show their superiority.

Fire service poeple in general will like this book because it refreshes us on our old skills and reminds us of things we need to be aware of.

One appendix gives derivations, and another nomenclature. A useful bibliography, a good index, and a table of conversion factors round out the text, with a dozen or so blank pages inside the soft cloth binding for notes. We now await Chief Purington's promised study on metric conversion for the fire service.

Heat Transfer in Fires: Thermophysics, Social Aspects, Economic Impact P. L. Blackshear, Editor. Halsted Press Division, J. Wiley and Sons, Inc. New York (1974)

Subjects: Heat transfer; Fires; Economics; Social aspects of fires

Reviewed by R. M. Fristrom

This collection of papers in the fire area has been organized to cover a very wide field in fire technology, including the social and economic aspects. The subject material is very broad and coverage inevitably cannot be complete or uniform. The volume comprises a very useful collection of reviews as can be seen from the table of contents reproduced below. The reader's attention is directed to the companion volume **Heat Transfer in Flames** edited by N. H. Afgan and J. M. Beer which is reviewed in this issue of FRAR.

Contents

List of Contributors
Preface

I **Social and Economic Aspects of Fire**
1 The Fire Problem in the United States, *E. R. G. Eckert*
2 The Forest Fire Problem, *E. A. Brun*
3 Social & Economic Impact of Fire, *P. H. Thomas*

II **Geometric Parameters for Classifying Full-scale Fires**
1 Effects of Fuel Geometry on Fires in Solid Fuel Arrays., *P. H. Thomas*
2 Fires in Enclosures, *P. H. Thomas*
3 On the Combustion and Heat Transfer in Fires of Liquid Fuels in Tanks, *P. G. Seeger*

III **Heat and Mass Transfer in Gaseous and Condensed Phases**
1 Interactions Between Flames and Condensed Phase Matter, *R. C. Corlett*
2 Concentration and Temperature Similarity, *R. C. Corlett*
3 Condensed-Phase Mass and Energy Balances, *F. Williams*
4 Chemical Kinetics of Pyrolysis, *F. Williams*
5 Velocity Distributions in Fires, *R. C. Corlett*
6 Fire Violence and Modeling, *R. C. Corlett*

IV **Radiative Heat Transfer Associated with Fire Problems**
Introduction
1 Basic Principles of Radiative Transfer, *F. R. Steward*
2 Fire Spread through a Fuel Bed, *F. R. Steward*
3 Ignition Characteristics of Cellulosic Materials, *F. R. Steward*

Appendix I Black Body View Factors
Appendix II Direct Interchange Areas with Absorbing and Emitting Material Present
Appendix III Example of Total Surface to Surface Radiative Interchange in an Enclosure
Appendix IV Emissivities of Combustion Product Gases
Appendix V Example of Total Gas to Surface Radiative Interchange in an Enclosure
Appendix VI Nomenclature

V Radiative Transfer Parameters

1 Band Models of Infrared Radiation, *R. Goulard*
2 Introduction to the Use of the NASA Handbook SP-3080, *R. Goulard*
3 Carbon Particle Radiation, *R. Goulard*

Index

Heat Transfer in Flames N. H. Afgan and J. M. Beer, Editors, Halsted Press Division, J. Wiley and Sons, Inc., New York (1974)

Subjects: Heat transfer; Flames; Radiant transfer; Convective transfer

Reviewed by R. M. Fristrom

This is a collection of papers presented at a meeting in 1973 by a distinguished group of contributors. The subjects range from theory to practical engineering of furnaces. As is to be expected in such collections, the treatment is varied in approach and quality. The coverage of the subject is not complete, however the volume represents a significant contribution to the literature. The coverage can best be appreciated by considering the table of contents reproduced below. The volume is recommended as a reference work, but not as an introduction to the subject. The reader is also referred to the companion volume **Heat Transfer in Fires** (ed. P. Blackshear) reviewed in this issue.

Contents

Foreword

Part I: Heat Transfer in Steady Confined Flames

Section I: Method of Calculation

1 First Estimates of Industrial Furnace Performance—The One-Gas-Zone Model Reexamined, *Hoyt C. Hottel*
2 Methods for Calculating Radiative Heat Transfer from Flames in Combustors and Furnaces, *János M. Beér*
3 Mathematical Simulation of an Industrial Boiler by the Zone Method of Analysis, *F. R. Steward and H. K. Güruz*
4 Simultaneous Predictions of Flow Patterns and Radiation for Three-Dimensional Flames, *Suhas Patankar and Brian Spalding*
5 A Mathematical Model of a Low-Volatile Pulverized Fuel Flame, *W. Richter and R. Quack*

6 The Problem of Flame as a Disperse System, *A. Blokh*
7 Solid/Gas Phase Heat Exchange in Combustion of Powdered Fuel, *V. I. Babiy*
8 Geometrical-Optical Characteristics and Calculation of Radiant Heat Transfer Between a Flame and a Wall, *I. Mikk*
9 Flame as a Problem of the General Theory of Furnaces, *M. A. Glinkov*
10 Prediction of Radiant Heat Flux Distribution, *T. M. Lowes, H. Bartelds, M. P. Heap, S. Michelfelder, and B. R. Pai*
11 The Application of Flux Methods to Prediction of the Behavior of a Process Gas Heater, *Richard G. Siddall and Nevin Selcuk*
12 A New Formula for Determining the Effective Beam Length of Gas Layer of Flame, *Milos Gulic*
13 The Intensification of the Heat Exchange Process in Industrial Flame Furnaces and the Choice of Rational Regimes, *A. E. Erinov*
14 Method of Approximate Calculation of Radiant Heat Transfer Between Gas and Surface, *S. P. Detkov*

Section II: Radiative Properties

15 Infrared Gaseous Radiation, *Robert D. Cess*
16 Experimental and Theoretical Results with Infrared Radiating Gases, *Ralph Greif*
17 The Effect of Pressure on Heat Transfer in Radiating Gases, *J. L. Novotny*
18 Luminous Flame Emission Under Pressure up to 20 atm, *Takeshi Kunitomo*
19 Spatial Distribution of Spectral Radiant Energy in a Pressure Jet Oil Flame, *E. G. Hammond and J. M. Beér*

Section III: Experimental Methods

20 Nonlinear Inversion Techniques in Flame Temperature Measurements, *C. M. Chao and R. Goulard*
21 Steady and Unsteady Radiant Heat Flux Measurement on the Screen Tube of a Power Boiler Furnace, *P. Pavlović, L. Jović, Lj. Jovanović, N. Afgan*
22 Temperature Field Measurement in Flames by External Means, *N. N. Kondic*
23 An Experimental and Analytical Determination of Heat and Mass Transfer in a Diffusion Flame, *S. Abdel-Khalik, T. Tamaru, and M. M. El-Wakil*

Part II: Heat Transfer in Unsteady Confined Flames

24 Heat Transfer from Flames in Internal-Combustion Engines, *W. J. D. Annad*
25 A Method for Calculating the Formation and Combustion of Soot in Diesel Engines, *I. M. Khan and G. Greeves*
26 Flame Radiation in High Speed Diesel Engines, *G. Sitkei*

Part III: Open Flame Heat Transfer

27 Radiation From Pool Flames, *D. Burgess and M. Hertzberg*
28 Heat Transfer by Radiation From Fires of Liquid Fuels in Tanks, *P. G. Seeger*
29 Flame Radiation as a Mechanism of Fire Spread in Forests, *H. P. Telisin*
30 Fabric Ignition and the Burn Injury Hazard, *Wolfgang Wulff and Pandeli Durbetaki*

31 Heat Transfer from Turbulent Free-Jet Flames to Plane Surfaces, *H. Kremer, E. Buhr, and R. Haupt*
32 Heat and Mass Transfer Considerations in Super-Critical Bipropellant Droplet Combustion, *R. Natarajan*
33 Soot Oxidation in Laminar Hydrocarbon Flames, *A. Feugier*
34 The Extinction of Spherical Dissusion Flames, *G. I. Sivashinsky and C. Gutfinger*

Index

Problems in Combustion and Extinguishment, Collection of Articles, edited by I. V. Ryabov, A. N. Baratov, and I. I. Petrov, All Union Scientific Research and Experimental Construction Institute of Fire Prevention Service, MOOP of the USSR, TsNIIPO MOOP Publishers, Moscow 1968. Translated from Russian, Published for the National Bureau of Standards and the National Science Foundation by Amerind Publishing Co., Pvt. Ltd., New Delhi (1974)

Contents

Foreword

Fundamentals of Automatic Local-Fire Extinction Devices, *A. I. Veselov*

The Development of Means and Methods of Extinguishing Fires on Oil Products in Reservoirs, *I. I. Petrov*

A Review of Investigations on the Chemical Inhibition of Flames, *A. N. Baratov*

The Chemical and Thermophysical Effect of Halogenated Hydrocarbons on the Concentration Limits of Flame Propagation for Hydrocarbons, *V. M. Kucher*

The Effect of Tetrafluorodibromoethane on the Flame Velocity of a Hydrogen-Air Mixture, *A. N. Baratov, F. A. Karagulov, and V. I. Makev*

The Minimum Ignition Energies of Finely-Dispersed Solid Combustible Materials, *G. I. Smelkov, P. A. Fetisov, and B. G. Popov*

The Pyrological Properties of Some Combustible Forest Materials, *A. V. Filippov*

The Structure Effect of Combustible Forest Materials on Their Rate of Combustion, *M. A. Sofronov*

Some Characteristic Features of Combustion with Low Oxygen Content, *M. V. Kolyshenko, A. U. Naumchik, and A. D. Orel*

The Electric Charging of Free-Flowing Material in Gas Conveyors, *V. I. Gorshkov, B. G. Popov, and V. N. Verevkin*

The Discharges of Static Electricity, *V. N. Verevkin, V. I. Gorshkov, and V. A. Bondar'*

The Extinguishment of Experimental Fire by Steam-Gas Mixtures, *V. P. Rudchenko, M. V. Kolyshenko, and A. M. Kushnarev*

A Study of the Conditions of Feeding Fire Extinguishing Liquids and Gas-Liquid Mixtures from Cylinders through Pipelines, *A. A. Rode*

Thermophysical Processes during the Localization of Underground Fires, *A. I. Kozlyuk, V. Ya. Baltaitis, V. D. Guguchkin, P. P. Petrov, B. I. Lumer, and E. A. Savon*

A Study of Stationary Apparatus for Fire-Extinguishment with Powder, *M. N. Isaev*

Design and Calculations for Fire Ladder Extensions, *I. I. Ozherel'ev*

PERIODICALS

Flammability News Bulletin 3 (1) 19 pages (July-August 1974), E. E. Stahly (Consultant) U.S. Editor, S. B. Sello (J.P. Stevens and Co.) Co-editor, J. DiPietro (Milan, Italy) International editor

This new journal is published bimonthly and may be obtained from Flammability News Bulletin, Inc., PO Box 13085, Washington, D.C. 20009.

MEETINGS

Symposium on Fire Detection for Life Safety, March 31-April 1, 1975, Committee on Fire Research, National Research Council, National Academy of Sciences, Washington, D.C.; Chairman W. J. Christian

Program

Session I: Chairman C. W. Walter, Harvard University Medical School

"Status and Problems of Fire Detection for Life Safety in United States" - R. Bright (Programmatic Center for Fire Research, National Bureau of Standards)

"Human Behavior" A Critical Variable in Fire Detection Systems" - J. L. Bryan (Fire Protection Curriculum, University of Maryland)

"Emergencies: Arousal from Sleep" - E. Bixler (Hershey School of Medicine, Pennsylvania State University)

"Warning and Survival in Fire" - J. H. Petajan (School of Medicine, University of Utah)

Session II: Chairman R. M. Fristrom, Applied Physics Laboratory, The Johns Hopkins University

"Aerosol Technology in Fire Research and Detection" - B. H. Y. Liu (Particle Technology Laboratory, University of Minnesota)

"Measuring Techniques for the Response Threshold Value of Smoke Detectors" - F. J. Kraus (I.E.N.T., Gesamthochshule, Duisberg, Germany)

"The Separated Ionization Chamber - A New Aerosol Measuring Technique" - P. E. Burry (Fire Research Station, Borehamwood, England)

"Large Scale Laboratory Fire Tests of Smoke Detectors" - R. W. Bukowski (Underwriters Laboratories, Inc.)

"Large Scale Laboratory Fire Tests of Smoke Detectors" - R. W. Bukowski (Underwriters Laboratories, Inc.)

Session III: J. W. Kerr, Defense Civil Preparedness Agency, Department of Defense

"Generalized Characterization of Smoke Entry and Response for Products of Combustion Detectors" - G. Heskestad (Applied Mechanics Section, Factory Mutual Research Corporation)
"The Response of Smoke Detectors to Pyrolysis and Combustion Products from Aircraft Interior Materials" - N. J. Alvarez (Stanford Research Institute)
"A Survey of Non Fire Environments" - P. E. Burry (Fire Research Station, Borehamwood, England)
"The Application of Thermal and Flame Sensors to Fire Detection Systems" - G. J. Grabowski (Fenwal Incorporated)
"Optical Smoke Detectors - Concepts, Design, Performance, and Reliability" - C. Zimmerman (Electro Signal Laboratory)

Session IV: Chairman W. J. Christian, Underwriters Laboratories, Inc.

"Physical Aspects of Ionization Chamber Measuring Techniques (unipolar and bipolar chambers)" - A. Scheidweiler (Cerberus, Ltd., Maennedorf, Switzerland)
"Ionization Smoke Detection, Its Application to Life Safety in Dwellings" - D. Pearsall (Statitrol Corporation)
"Development of a Quartz Crystal Incipient Fire Detector for Aerospace Vehicles" - L. G. Barr (Celesco Industries)
"Application of Cloud Chamber Techniques to Fire Detection" - F. A. Ludewig (Environment One Corporation)

Symposium on Flammability and Burning Characteristics of Materials and Fuels, Central and Western States Sections, The Combustion Institute, April 21-22, 1975, San Antonio, Texas; Meeting Chairman: W. McLain (Southwest Research Institute); Program Chairmen: F. A. Williams (University of California, San Diego) and R. A. Strehlow (University of Illinois, Urbana-Champaign); Papers Chairmen: A. S. Gordon (Naval Weapons Center, China Lake) and W. D. Weatherford, Jr. (Southwest Research Institute)

Session I: Chairman R. A. Strehlow, University of Illinois

"An Experimental Investigation of the Height of Gaseous Diffusion Flames in a Concentric Stream of Air or Pre-Mixed Air and Fuel" - Karim and Mohindra (University of Calgary, Southern Alberta Institute of Technology)
"Flame Stability in Combusting Turbulent Jets" - Nelson, Kushida, and England (Jet Propulsion Laboratory, California Institute of Technology)
"A Numerical Model of a Turbulent Fuel Jet" - Tamanini (Factory Mutual Research Corporation)
"Statistical Model for Pre-Mixed Turbulent Flames" - Gouldin (Cornell University)

"Turbulent Diffusion Flame Structure" - Bilger (University of California, San Diego)
"Flame Stabilization by Leading Edge Vortex Breakdown Above a Delta Shape" - Sweat and Panton (University of Texas, Austin)
"Combustion of Hydrocarbons in an Adiabatic Flow Reactor: Overall Correlations of Reaction Rate" - Cohen, Dryer, and Glassman (Princeton University)

Session II: Chairman N. W. Ryan, University of Utah

"Properties of Smoke Produced by Burning Wood, Urethane, and PVC Samples Under Different Conditions" - Bankston, Cassanova, Powell, and Zinn (Georgia Institute of Technology)
"Polymer Flame Retardant Mechanisms" - Holve and Sawyer (University of California, Berkeley)
"Limiting Oxygen Index Measurement and Interpretation in an Opposed Flow Diffusion Flame Apparatus" - Matthews and Sawyer (University of California, Berkeley)
"Pyrolysis and Ignition of Polymer Films at Heating Rates from 1° to 100°K/Second" - Baer, Hedges, and Ryan (University of Utah)
"Flammability Study of Polymer Fuels Using Counter Flow Diffusion Flame Technique" - Singhal and T'ien (Case Western Reserve University)
"The Gasification Combustion of Solid Polymeric Particles in Reactive Environment" - Massoudi (Arya Mehr University of Technology)
"The Burning Behavior of a Solid Polymeric Slab in Oxidizing Atmospheres" - Massoudi (Arya Mehr University of Technology)
"Development of Fire Performance Specifications for Carbon Impregnated Polyurethane Foams" - Tatem and Williams (Naval Research Laboratory)

Session III: Chairman A. M. Mellor, Purdue University

"A Theoretical and Experimental Investigation of the Ignition of Fuel Droplets" - Sangiovanni and Kesten (United Aircraft Research Laboratories)
"A Preliminary Analysis of Transient Convective Droplet Burning" - Prakash and Sirignano (Princeton University)
"Fundamental Concepts on the Use of Emulsions as Fuels" - Dryer (Princeton University)
"Alternative Automotive Fuels - Some Prospects and Problems" - McLean (Cornell University)
"Measurement and Analysis of Particles Emitted from a Diesel Combustion Process" - Vuk and Johnson (Michigan Technological University)
"Temperatures, Pressures and Compositions Developed in Fast Exothermic Reactions" - Adams and Adams (University of Cincinnati)
"Studies of Fuel Volatility Effects on Turbine Combustor Performance" - Moses (Southwest Research Institute)
"Theoretical and Practical Concepts Governing Production of Power Gas from Coal" - Laurendeau (Purdue University)

Session IV: Chairman T. P. Torda, Illinois Institute of Technology

"The Mechanism of Ignition of Organic Compounds and It Catalysis by Asbestos Type Materials" - Benbow and Cullis (The City University, London)
"Hydrogen Flammability and Burning Characteristics in a Closed Vessel" - Slifer (General Electric Company, San Jose)
"Correlation of Burning Rates for Thin Materials with Piloted Ignition Data" - Rooks, Sliepcevich and Welker (University of Oklahoma)
"Flammability of Treated Cotton Fabric" - Ambs and Aggarwal (University of Massachusetts)
"Ignition of Single Fabrics Subject to Normal Impinging Flames" - Annamalai and Durbetaki (Georgia Institute of Technology)
"Ignition of Fabric Assemblies Subject to Radiative Heating" - Acree, Durbetaki and Wulff (Georgia Institute of Technology)
"An Experimental and Mechanistic Study of the Reactions of COF_2 with H_2 and with CO" - Gangloff, Milks, Maloney, Adams, and Matula (Drexel University)
"Research on Antimist Aircraft and Diesel Engine Fuels" - Weatherford and Wright (Southwest Research Institute)

Session V: Chairman R. M. Fristrom, Applied Physics Laboratory, The Johns Hopkins University

"On the Burning of a Large Flammable Vapor Cloud" - Raj and Emmons (Arthur D. Little, Inc.; Harvard University)
"Vapor Dispersion, Fire Control, and Fire Extinguishment for LNG Spills" - West, Brown, and Welker (University Engineers, Inc.)
"Modeling Sub-surface Foam Fire Protection for Crude Oil Storage Tanks" - Brzustowski, Sullivan, and Kaptein (University of Waterloo, Canada)
"Prediction of Ignition Conditions for Flammable Mixtures Drifting Over Heated Planar Surfaces" - Thiyagarajan and Hermance (University of Waterloo, Canada)
"A Minimum Effective Length Criterion for Flame Arrestors" - Wilson and Atallah (A. D. Little, Inc.)
"The Formation of Toxic Products During the Combustion of Halogen Containing Polymers" - Benbow and Cullis (The City University, London)
"Safe Hypergolic Ignition of TNT" - Tulis, Keith, Sumida, Heberlein, and Beveridge (IIT Research Institute, U.S. Army MERDC)
"Fire Endurance of Soldered Copper Joints Used in Copper Tube Sprinkler Systems" - Alvares (Stanford Research Institute)

Session VI: Chairman A. Broido, U.S. Forest Service

"Dynamics of Pyrolysis of Cellulosic Materials" - Kun Min (Harvard University)
"The Pyrolysis of Natural Fuels" - Duvvuri, Muhlenkamp, Igbal, and Welker (University of Oklahoma)
"Extinction of Wood Crib and Pallet Fires" - Kung and Hill (Factory Mutual Research Corporation)
"Rate of Heat Release Calorimetry as a Method for Evaluating the Fire Per-

formance of Construction Materials" - Chamberlain (National Bureau of Standards)
"Evaluation of NO_x Emission Characteristics of Alcohol Fuels in Stationary Combustion Systems" - Martin (Environmental Protection Agency, Research Triangle Park)
"Sampling Systems for the Collection of Particulate and Polycrylic Organic Matter from Combustion Effluents" - Giammar (Battelle, Columbus Laboratories)
"An Analysis of Fire Hazard to Pulverized Coal Fired Burners for Steam Generating Plants" - Biswas and Bryers (Foster Wheeler Energy Corporation)
"The Combustion of Low Calorific Value Waste Gas" - Dahmen and Syred (Continental Carbon Company; University College, Cardiff)

Symposium on Physiological and Toxicological Aspects of Combustion Products, Committee on Fire Research, Division of Engineering, National Research Council, National Academy of Sciences and the Flammability Research Center, University of Utah, Salt Lake City, Utah, March 18-20, 1974, Chairman I. N. Einhorn

Subjects: Smoke problems during fires; Smoke and fire casualties; Physiological aspects of fire exposure; Toxicological aspects of fire exposure; Smoke development; Smoke characterization

Program

Introduction - Professor I. N. Einhorn, Symposium Chairman, Flammability Research Center and Division of Materials Science and Engineering, University of Utah
Welcoming Address - Dr. P. D. Gardner, Vice President for Academic Affairs, University of Utah
Keynote Address - Dr. C. W. Walter, Chairman, Committee on Fire Research, National Academy of Science

Session I: Smoke Problems Encountered During Fires

Moderator: Dr. W. J. Christian, Underwriters' Laboratories, Inc., Northbrook, Illinois

Smoke Problems in Urban Fire Control - Chief L. DeKorver, Salt Lake City Fire Department, Salt Lake City, Utah
Smoke Control During Fires in High-Rise Buildings - Chief J. O-Hagan, New York City Fire Department, New York City, New York
Methods for Combating Smoke - H. W. Brice, Fire Marshal, Miami Fire Department, Miami, Florida

Session II: Smoke and Fire Casualties

Moderator: Dr. M. M. Birky, National Bureau of Standards, Visiting Professor, University of Utah

Fire Deaths and Casualties - Dr. E. P. Radford, Department of Environmental Medicine, The Johns Hopkins University, Baltimore, Maryland

What is Clinical Smoke Poisoning? - Dr. B. A. Zikria, Department of Surgery, Columbia-Presbyterian Hospital, New York, New York

Medical Aspects of Toxicity Resulting from Fire Exposure - Professor J. Autian, College of Pharmacy, University of Tennessee, Memphis, Tennessee

Session III: Phsiological and Toxicological Aspects Resulting from Fire Exposure

Moderator: Professor I. N. Einhorn,Flammability Research Center and Division of Materials Science and Engineering, University of Utah

Fires, Toxicity, and Plastics - Dr. J. Zapp, Haskell Laboratory for Toxicology and Environmental Medicine, E. I. du Pont de Nemours and Company, Inc., Wilmington, Delaware

Effects of Exposure to Carbon Monoxide and Hydrogen Cyanide - Dr. P. W. Smith Aviation Toxicology Institute, Federal Aviation Administration, Oklahoma City, Oklahoma

Synergistic Effects of Combustion Products - G. Armstrong, Southwest Research Institute, San Antonio, Texas

Effects of Brief Single Exposure to HCl and NO_x - Dr. K. C. Back, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio

Toxicology Associated with Flame-Retarded Plastics - Dr. V. Carter, Johnson Spacecraft Center, Houston, Texas

Survival Response During Fire Exposure - Professor J. H. Petajan, Department of Neurology and Flammability Research Center, University of Utah Medical Center, Salt Lake City, Utah

Long-Term Nervous System Effects Resulting from Carbon Monoxide Exposure - Professor M. L. Grunnet, Departments of Neurology and Pathology and Flammability Research Center, University of Utah Medical School, Salt Lake City, Utah

Kinetics of Uptake and Elimination of Carbon Monoxide - Dr. J. A. MacGregor, Stanford Oil Company of California, San Francisco, California

Methodology for Analyses of Combustion Products - Dr. G. Kimmerle, Bayer Institute for Industrial Toxicology, Wuppertal, Germany

Use of Animals in Experiments to Predict Human Response - Dr. F. Coulston, Institute for Comparative and Human Toxicology, Albany Medical Center, Albany, New York

Session IV: Smoke: Its Development and Characterization

Moderator: Dr. R. M. Fristrom, Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

Factors Affecting Smoke Development and Measurement - Professor S. D. Seader, Flammability Research Center and Department of Chemical Engineering, University of Utah

Analysis of Products of Combustion: A Computerized Analytical System - Professor I. N. Einhorn, Flammability Research Center and Division of Materials Science and Engineering, University of Utah

Session V: General Discussion

Panel Discussion: Government and Industry Programs for Smoke Control

Moderator: Dr. J. J. Lyons, Chief Fire Programs, National Bureau of Standards, Washington, D.C.

Panelists:

Mr. B. Andrus, Fire Marshal
Salt Lake City Fire Department
Salt Lake City, Utah

Mr. J. Carroll
Director of Safety and Loss Prevention
Society for the Plastics Industry, Inc.
New York, New York

Dr. W. J. Christian
Underwriters' Laboratories, Inc.
Northbrook, Illinois

Professor I. N. Einhorn
Flammability Research Center and
Division of Materials Science and Engineering
University of Utah

Mr. J. W. Kerr
Support Systems Research
Defense Civil Preparedness Agency
Washington, D. C.

Mr. G. W. Shorter
Fire Section
National Research Council of Canada
Ottawa, Ontario

Mr. R. Riddell, Fire Marshal
State of Utah
Salt Lake City, Utah

Panel Discussion: Early Treatment at the Fire Scene

Moderator: Professor J. H. Petajan, Department of Neurology and Flammability Research Center, University of Utah

Panelists:

Professor F. Chang
Department of Surgery
University of Utah Medical School
Salt Lake City, Utah

Mr. B. Finkle
Center for Human Toxicology and
Flammability Research Center
University of Utah

Dr. G. Kimmerle
Bayer Institute for Industrial
Toxicology
Wuppertal, Germany

Dr. E. P. Radford
Department of Environmental Medicine
The Johns Hopkins University
Baltimore, Maryland

Dr. J. Zapp
Haskell Laboratory for Toxicology
and Environmental Medicine
E. I. du Pont de Nemours and
Company, Inc.
Wilmington, Delaware

Dr. B. Zikria
Department of Surgery
Columbia-Presbyterian Hospital
New York, New York

Proceedings will be published by the National Academy of Sciences.

Symposium on Products of Combustion of (Plastics) Building Materials, March 25-26, 1973, Research and Development Center, Armstrong Cork Company, Lancaster, Pennsylvania, 87, H. J. Roux Chairman, G. E. Graham Co-Chairman, A. R. McGarvey Coordinator (1974)

Contents

Estimation of Smoke Load from Building Materials, *H. E. Nelson*
Smoke Hazards and Their Measurement—A Researcher's Viewpoint, *J. R. Gaskill*
Can We Control the Toxic Products of Combustion of Building Fires? If not, Why Not?, *J. E. Smariga*
Toxicity of Thermal Degradation Products of Plastics, *H. Cornish*
Fire-Department Concern with Respect to Products of Combustion of Plastic Materials, *S. Ifshin*
The Problems of Smoke and Toxic Compounds in Building Fires, *A. Tewarson*
Products of Combustion of Building Materials, *J. E. Bihr*
Analysis of the Combustion Products from Wood and Synthetic Polymers, *M. O'Mara*
Firesafety at GSA, *L. Roush*

Fire Prevention and Control, *R. E. Bland*
The Fire-Protection Engineer's View of Plastics, *J. M. Rhodes*
Chemical and Physical Factors Affecting Smoke Evolution from Polymers, *C. J. Hilado*
Firesafety in Urban Housing—A Description of the NSF-RANN Program at the University of California, Berkeley, *R. B. Williamson*

Second Seminar and Workshop on the Teaching of Fire Sciences, April 27-28, 1974, Northern Virginia Community College, Annandale, Virginia, Report No. FPP B74-2 Applied Physics Laboratory, The Johns Hopkins University, Proceedings editor R. L. Tuve, 72 pages (December 1974)

Program

Welcome and Introduction

Robert L. Smith
Program Head, Fire Science
Northern Virginia Community College
Annandale, Virginia

Address of Welcome

Edward J. Fredericks
Division Chairman
Northern Virginia Community College
Annandale, Virginia

Session Host's Remarks

Robert L. Smith
Northern Virginia Community College
Annandale, Virginia

Objectives of This Seminar

Seminar Moderator: Walter G. Berl
Co-Principal Investigator
Fire Problems Program
Applied Physics Laboratory
The Johns Hopkins University

Qualification Standards

John L. Bryan, Director
Fire Protection Engineering Curriculum
University of Maryland
College Park, Maryland

Panel Subject: Basic Fire Sciences Curriculum Content and Teaching Objectives

(Organized by Francis L. Brannigan, Coordinator, Fire Science Curriculum, Montgomery College)

Panel Moderator: Richard L. Tuve
Consultant, Fire Problems Program
Applied Physics Laboratory
The Johns Hopkins University

Experience with the "Two Plus Two" Program

R. Wayne Powell
Office of Fire/Rescue Services
Montgomery County, Maryland

Panel Discussion: Articulation with Four-Year Courses

Panel Moderator: Sylvan P. Stern
Coordinator, Fire Science Program
New York City Community College

Joseph J. Carroll
Fire Science Program Liaison Officer
New York City Fire Department

Eugene J. Fortrell
National Ass'n. of Fire Science Administration
New York, N. Y.

F. J. Ronan
New York City Community College

Innovative Teaching Methods

Professor Joseph A. O'Keefe
Fire Sciences
Bunker Hill Community College
Charlestown, Massachusetts

Assistant Professor Robert Carlson
Department of Mathematics
Bunker Hill Community College
Charlestown, Massachusetts

National Science Foundation, Research Applied to National Needs Conference on Fire Research, May 28-29, 1974, Georgia Institute of Technology, Atlanta, Georgia, 218 pages

Subjects: Flame spread; Fire systems studies; Physico-chemical aspects of fires; Combustion products behavior

General Chairman: Dr. S. Peter Kezios, Director, School of Mechanical Engineering, Georgia Institute of Technology
Program Chairman: Dr. Ben T. Zinn, Regents Professor, School of Aerospace Engineering, Georgia Institute of Technology
Local Arrangements Chairman: Dr. W. Denney Freeston, Director, School of Textile Engineering

Foreword

Dr. R. H. Long, Jr., Program Manager, Division of Advanced Technology Applications, National Science Foundation, Washington, D.C.

Foreword

This document is a record of the fire research projects, supported by NSF, that were discussed at a conference on May 28 and 29, 1974, at the Georgia Institute of Technology. There is a brief progress report for each project. The report is not intended to provide all features of the research. Reports and publications are listed so that interested persons can obtain more information.

The NSF/RANN fire research effort has the objective to reduce deaths and losses due to hostile fires, and to improve the effectiveness of fire control. It has been in operation for three years, and currently the expenditure level is about two million dollars per year. At this time, the future of the effort is uncertain, because it is dependent on actions to be taken by Congress and the administration.

When one looks at the cumulative results, I believe progress is evident and significant. The projects are in various stages of completeness. There are four comprehensive projects (Harvard, Johns Hopkins University/Applied Physics Laboratory, University of Utah, and University of California-Berkeley) which are much larger than the others. Thus, the reports reflect such differences.

In addition to research performers, representatives of the fire protection community also attended the conference and participated in discussions. While the open and at times spirited interchanges were not recorded, they will surely be reflected in a strengthening of future research and thus meet a goal of the conference.

The Foundation welcomes comments on the fire research program and related needs. The dissemination of information from the projects to the various performers concerned with fire protection and control continues to be a matter of concern and suggestions for improvement are solicited.

Program

Opening Session

Chairman: Dr. S. P. Kezios, Georgia Institute of Technology

Welcoming Address: Dr. T. E. Stelson, Vice-President for Research, Georgia Institute of Technology

Introductory Comments: Dr. Ralph H. Long, Program Manager, National Science Foundation

Session I: Flame Spread

Chairman: Professor Howard W. Emmons, Harvard University

Fire Propagation Along Solid Surfaces, *Professor F. A. Williams, Department of Applied Mechanics and Engineering Sciences, University of California, San Diego*

Flame Spreading Over Solid Surfaces, *Professor Merwin Silbulkin, Division of Engineering, Brown University*

Mechanism of Fire Propagation on Polymer Surfaces, *Professor Norman W. Ryan, Department of Chemical Engineering, University of Utah*

Fire Rate of Spread in Paper Arrays, *Professor Ashley S. Campbell, Department of Mechanical Engineering, University of Maine*

Flame Spreading Across Liquid Fuels, *Professor Irvin Glassman, Guggenheim Laboratories, Princeton University*

Flame Spread over Liquid Fuels, *Professor Kenneth E. Torrance, Department of Thermal Engineering, Cornell University*

Session II: Fire Systems Studies

Chairman: Dr. John W. Lyons, National Bureau of Standards

Firesafety in Urban Housing, *Professor R. B. Williamson, Department of Civil Engineering, University of California, Berkeley*

The Home Fire Project, *Professor Howard W. Emmons, Harvard University, and Dr. Raymond Friedman, Factory Mutual Research Corporation*

Education and the Fire Services, *Dr. Robert M. Fristrom, Applies Physics Laboratory, Johns Hopkins University*

Session III: Physico-Chemical Aspects of Fires

Chairman: Professor Irvin Glassman, Princeton University

Ignition of Fabrics, *Professor Wolfgang Wulff, School of Mechanical Engineering, Georgia Institute of Technology*

Thermal and Flammability Behavior of Multicomponent Fibrous Polymer Systems, *Dr. Bernard Miller, Textile Research Institute*

Chemistry of Cellulosic Fires, *Professor Fred Shafizadeh, Wood Chemistry Laboratory, University of Montana*

Extinction of Flames by Metal Powders, *Professor Walter E. Kaskan, Department of Chemistry, SUNY at Binghamton*

Flame Inhibition Studies, *Dr. Robert M. Fristrom, Applied Physics Laboratory, Johns Hopkins University*

Behavior of Water Droplets in Fire Plume, *Professor M. C. Yuen, Department of Mechanical Engineering, Northwestern University*

Mechanisms of Wildland Fire Suppression, *Professor R. C. Corlett, Department of Mechanical Engineering, University of Washington*

Fire Whirl and Firebrand in Mass Fires, *Professor S. L. Lee, Department of Mechanics, SUNY at Stony Brook*

Forest Fire Statistical Problems, *Professor F. N. David, Statistics Department, University of California at Riverside*

Session IV: Combustion Products Behavior

Chairman: Dr. Raymond Friedman, Factory Mutual Research Corporation

NBS Fire Safety Program, *Dr. John W. Lyons, Director of Fire Programs, National Bureau of Standards*

Convective Flows of Building Fires, *Professor Edward E. Zukoski, California Institute of Technology*
Fire and Smoke Spread in Corridors, *Professor J. L. Novotny, Department of Aerospace and Mechanical Engineering, University of Notre Dame*
Properties of Combustion Products from Building Fires, *Professor Ben T. Zinn, Department of Aerospace Engineering, Georgia Institute of Technology*
Physiological and Toxicological Aspects of Smoke Produced During the Combustion of Polymeric Materials, *Professor Irving Einhorn, Flammability Research Center, University of Utah*
Smoke Injury Studies, *Dr. Robert M. Fristrom, Applied Physics Laboratory, Johns Hopkins University*
Fire Research Needs and Priorities, *Dr. Edward H. Blum, New York City-RAND Institute*

Symposium on Fire Safety Research, National Bureau of Standards, Gaithersburg, Maryland, August 22, 1973, edited by M. J. Butler and J. A. Slater, Programmatic Center for Fire Research, Institute for Applied Technology, National Bureau of Standards Special Publication 411 (November 1974) 239 pages

Subjects: Fire safety; Fire research; Detection; Firefighting; Inhibition; Retardants; Fire hazard; Modeling

A Symposium on Fire Safety Research was held at the National Bureau of Standards (NBS), on August 22, 1973. The Symposium's participants were NBS staff as well as outside contributors affiliated with the NBS fire program, including representatives from private industries, universities, government agencies, and the National Fire Protection Association. The papers covered topics in hazard analysis, standards development, flame chemistry, fire modeling, fire detection, physiological effects of fire, fire services, effect of fire on building materials, and field investigation methods for firefighters. Specifically included were papers dealing with the development of the Children's Sleepwear Flammability Standards and mandatory sampling plans, mechanisms of flame retardants, flame spread, and radiant panel test methods, contribution of interior finish materials to fire growth, a field study of non fire-resistive multiple dwelling fires. the Research Applied to National Needs (RANN) Program of NSF, and other related topics.

Contents

Welcome: Richard W. Roberts, National Bureau of Standards
Introduction: F. Karl Willenbrock, National Bureau of Standards
A Comparison Between Potential Hazard Reduction from Fabric Flammability Standards, Ignition Source Improvement, and Public Education, *Benjamin Buchbinder and Allan Vickers, National Bureau of Standards*
Development of the Standards for the Flammability of Children's Sleepwear, *Emil Braun, James H. Winger, and James A. Slater, National Bureau of Standards*

Sampling Plans in Mandatory Standards, *Paul Gottfried, Consumer Product Safety Commission*

Human Activity Patterns and Injury Severity in Fire Incidents Involving Apparel, *Laura Baker Buchbinder, The Cotton Foundation*

Chemical Aspects of Flame Inhibition, *John W. Hastie, National Bureau of Standards*

Mechanism of Flame Retardant Action in Textiles, *Robert H. Barker, Clemson University*

Additional Studies of the Transfer of Flame Retardant Effects with Cellulosic Fabrics, *Bernard Miller, Textile Research Institute*

An Evaluation of Flame Spread Test Methods for Floor Covering Materials, *James Quintiere and Clayton Huggett, National Bureau of Standards*

Mathematical Modeling of Radiant Panel Test Methods, *J. A. Rockett, National Bureau of Standards*

Flame Spread over a Porous Surface under an External Radiation Field, *Takashi Kashiwagi, National Bureau of Standards*

Physiological and Toxicological Effects of the Products of Thermal Decomposition from Polymeric Materials, *M. M. Birky, National Bureau of Standards, I. N. Einhorn, M. L. Grunnett, S. C. Packham, J. H. Petajan, and J. D. Seader, University of Utah*

Contribution of Interior Finish Materials to Fire Growth in a Room, *J. B. Fang and D. Gross, National Bureau of Standards*

Fire Build-up in Reduced Size Enclosures, *W. J. Parker and B. T. Lee, National Bureau of Standards*

An Analytic Model for Calculating the Fire Resistance of Simply Supported Prestressed and Reinforced Concrete Beams, *Lionel A. Issen, National Bureau of Standards*

Smoke and Carbon Monoxide Generation from Burning Selected Plastics and Red Oak, *Thomas Y. King, Armstrong Cork Company*

A Field Study of Non Fire-Resistive Multiple Dwelling Fires, *Frances L. Brannigan, Montgomery College*

The Current Status of Fire Detection, *George Sinnott, National Bureau of Standards*

Sequencing the Purchase and Retirement of Fire Engines, *Patsy B. Saunders and Richard Ku, National Bureau of Standards*

Fifi—Fire Information Field Investigation, *F. James Kauffman and Martin E. Grimes, National Fire Protection Association*

National Science Foundation RANN Program, *Ralph H. Long, Jr., National Science Foundation*

Appendix - Contributing Author Index

CUMULATIVE INDEX OF AUTHORS FOR VOLUME 16

YEAR 1974

Abdel-Khalik, S. I., 187
Afgan, N. H., 263
Alger, R. S., 178, 239
Allen, D. E., 188
Alvares, N. J., 178
Amaro, A. J., 178
Ames, S. A., 188, 190
Apin, A. Ya., 206
Autian, J., 230

Babrauskas, V., 233
Ballal, D. R., 162
Baratov, A. N., 265
Barstad, J., 145
Bauer, A. N., 181
Beck, R. E., 189
Beer, J. M., 204, 263
Benson, S. P., 189, 239
Berl, W. G., 248
Berlemont, C. F. J., 190, 243
Bevan, P. R., 189
Bilger, R. W., 189
Biordi, J. C., 179, 214
Birky, M. M., 230
Blackshear, P. L., 262
Blakely, A. D., 220
Boler, J. B., 145
Bovsunovskaya, A. Ya., 155
Boyes, J. H., 239
Brannigan, F. L., 145
Bredo, M. A., 214
Brenden, J. J., 190, 240
Bridge, N. W., 146
Bright, R. G., 169
Brink, G. E., 257
Bröll, R., 190
Brzustowski, T. A., 193
Buchbinder, B., 146, 234
Bullen, M. L., 186
Burdett, N. A., 215
Burgess, D., 146, 162, 166, 170
Bürkholz, A., 224
Burnett, J. C., 182
Butler, M. J., 278
Butlin, R. N., 190

Campbell, A. S., 172
Carhart, H. W., 222
Cato, R., 166
Cernansky, N. P., 216
Chandler, S. E., 233
Chigier, N. A., 240
Christian, W. J., 245
Clodfelter, R. G., 148
Corrie, J. G., 189, 239
Courtney-Pratt, J. S., 241
Custer, R. L. P., 169

Daizo, M., 222
Delbourgo, R., 167, 205
Demske, D., 161
de Ris, J., 176, 191
De Soete, G. G., 191
DiPietro, J., 266
Dixon-Lewis, G., 162, 216
Donaldson, W. F., 170
Doyle, W. H., 147
Dvorak, K., 240

Edmonds-Brown, H., 147
Eickner, H. W., 192

Elmer, C. H., 241
Elovskaya, T. P., 175
El-Wakil, M. M., 187
Emmons, H. W., 168, 258
Endelman, L. L., 241

Fang, J. B., 192, 193
Fernandez-Pello, A., 172
Field, P., 207
Firth, J. G., 218
Fowler, L. C., 252
Frandsen, W. H., 163, 172
Friedman, R., 258
Fristrom, R. M., 109, 248
Fujii, K., 222

Gandee, G. W., 148
George, C. W., 220
Geyer, G. B., 180
Gibbs, B., 204
Giles, K., 252
Goldsworthy, F. A., 216
Gollahalli, S. R., 193
Gorb, V. Yu., 155
Greenberg, J. B., 216
Greuer, R. E., 224
Gross, D., 193
Grumer, J., 180
Guillaume, P. J., 214
Gurevich, M. A., 163

Hacker, P. T., 156, 165, 257
Hallman, J. R., 194
Handa, T., 148, 164, 173, 195, 211
Harmathy, T. Z.,, 149, 150, 152, 196
Harmel, M. H., 232
Harris, G. W., 237
Harrison, G. A., 150
Hartzell, L. G., 196
Hayashi, T., 151
Hayhurst, A. N. 215
Haynes, B. S., 196
Hedley, A. B., 204
Hertzberg, M., 166, 170
Heselden, A. J. M., 158
Hibbard, R. R., 165
Hinds, W., 225
Hirano, T., 174, 197
Hjorteland, O., 145
Holmes, C. A., 151, 198
Holve, D. J., 198
Hopkinson, J. S., 186
Howard, J. B., 212
Huggett, C., 205

Ikeda, Y., 148, 211
Iverach, D., 196

Jernigan, J., 18, 243
Jin, T., 226
Johnson, G. M., 220
Jones, A., 218
Jones, T. A., 218

Kaimakov, A. A., 181
Kalas, M., 247
Kamra, A. K., 226
Kanury, A. Murty, 237
Kashiwagi, T., 165, 174, 175
Kaskan, W. E., 185
Katz, B. S., 161
Kennedy, M. P., 239
Kent, J. H., 181
King, M. K., 199
Kinns, R., 241
Kirov, N. Y., 196
Kolesnikov, B. Ya., 175
Konoshita, M., 197
Krucke, W., 152
Ksandopulo, G. E., 175
Kuchta, J. M., 166
Kung, H., 175
Kuvshinoff, B. W., 18, 243

Lazzara, C. P., 179, 214
Lee, B. T., 202
Lee., S. L., 227
Lefebvre, A. H., 162
Leonard, J. T., 182
Leschonski, K., 227
Levy, A., 219
Lie, T. T., 152, 188

Liebman, I., 229
Lipska, A. E., 178
Litton, C. D., 166, 170
Long, M. E., 242
Loomis, R. M., 233
Luck, H., 170
Lunn, G. A., 183
Lyle, A. R., 153
Lynch, J. R., 153

MacArthur, J. D., 231
Magee, R. S., 183
Mahajan, R. L., 177
Mallet, M., 153
Manheim, J. R., 154
Markstein, G. H., 176, 200, 227
Martin, S. B., 160
McDonald, G. H., 157
McQuaid, J., 242
Mealing, P., 257
Melvin, A., 218
Merryman, E. L., 219
Miller, S. C., 238
Modak, A. T., 228
Moore, F. D., 231
Morgan, H. P., 186
Morita, M., 164
Morris, W. A., 186
Moss, J. B., 218
Mulvihill, J. N., 200
Murphy, J. N., 146, 162

Naruse, I., 220
Nicholas, E. B., 154
Nichols, J. R., 239
Nickerson, M. F., 257

Oda, N., 220
Odnorog, D. S., 175
Ogasawara, M., 202, 222
O'Neill, J. H., 154
Onuma, Y., 202
Oppenheim, A. K., 228
Orloff, L., 176, 191
Orlov, N. V., 155
Osipov, S. N., 155
Otto, F. W., 227
Ozerova, G. E., 163

Pandya, T. P., 202
Papp, J. F., 179, 214
Parker, W. J., 202, 242
Pearson, F. K., 159
Peeters, J., 203, 223
Pelouch, J. J., Jr., 156, 257
Pepekin, V. I., 206
Pereira, F. J., 204
Perlee, H. E., 146, 162
Peters, 204
Petrov, I. I., 265
Phillips, H., 183, 184, 204
Phillips, L. F., 200
Philpot, C. W., 221, 234
Pickard, R. W., 170
Pitt, A. I., 156
Pokhil, P. F., 206
Powell, J. H., 156
Powell, P., 252
Purington, R., 261

Quintiere, J. 157, 205

Rae, D., 167
Rattenborg, C. C., 232
Reist, P. C., 225
Reitz, R. D., 183
Richard, J. R., 167, 205
Richmond, J. K., 229
Roberts, A. F., 184, 206
Romodanova, L. D., 206
Rothermel, R. C., 234, 238
Rousseau, J., 157
Ryabov, I. V., 265

Saito, F., 187
Saito, M., 148, 211
Sato, K., 174
Sawyer, R. F., 198, 216
Schermerhorn, D. A., 238
Schulz, A. G., 248
Schwenker, H., 158
Sello, S. B., 266
Senior, M., 206

Shepherd, I. G., 162
Shivadev, U. K., 168
Sibulkin, M., 207
Sjolin, V., 99
Slater, J. A., 234, 235, 278
Sliepcevich, C. M., 194
Soloukin, R. I., 228
Solum, E., 145
Sommers, D. E., 154
Spratt, D., 158
Sridhar, Iya, K., 185
Srivastava, N. K., 202
Stahly, E. E., 266
Stark, G. W. V., 207
Stevenson, A. E., 238
Stone, J. P., 222
Strawson, H., 153
Strömdahl, I., 208
Stysanov, A. M., 163
Sullivan, J. J., 158
Sumi, K., 212, 232
Suzuki, H., 148, 164, 195, 211

Takagi, T., 222
Takahashi, A., 148, 164, 173, 195
Takemoto, A., 171
Tamaru, T., 187
Tarumi, H., 151
Thomas, P. H., 212
Tonkin, P. S., 243
Torrance, K. E., 177
Tovey, H., 234
Tsuchiya, Y., 212, 232
Tuve, R. L., 274

Van Dolah, R. W., 166
Vandooren, J., 223
Van Tiggelen, P. J., 214, 223
Vickers, A., 146, 235
Vinckier, C., 203
Virr, L. E., 159
Vovelle, C., 167, 205

Wallace, W. H., 220
Watanabe, Y., 159, 171
Waterman, T. E., 177
Welker, J. R., 194
Wersborg, B. L., 212
Westley, F., 223
Whitehouse, R. B., 171
Wiersma, S. J., 160
Williams, F. A., 172, 181
Williams, F. W., 222
Wilson, D. M., 161
Wilton, C., 239
Wollowitz, S., 185
Wraight, H. G. H., 161, 168
Wright, W., 242

Yamao, S., 213
Yasuno, K., 236
Yeung, A. C., 212
Young, R. A., 146

Zabetakis, M. G., 146, 162
Zarem, H. A., 232
Zavadskii, V. A., 175

CUMULATIVE INDEX OF SUBJECTS FOR VOLUME 16

YEAR 1974

Adsorption, 200
Aerosols, 225
Aerospace vehicle fires, 154
Airburst long range, 240
Aircraft crashes, 180
Aircraft fire hazards, 257
Aircraft fire safety, 156
Aircraft safety, 154
Alarm systems, 170
Ammonium sulfate retardant, 220
Anemometer calibration, 242
Anemometer, laser, 240
Anemometer response, 242
Aqueous film forming foams (AFFF), 180
Aqueous fire fighting foams, 182
Aviation fuel, 148, 154
Aviation safety, 148

Bibliography on fire research, 243
Blast, 240
B-numbers, 237
Boron flames, 199
Brands, 227
Brush fires, 234
BS 2773, 1945, 156
Building codes, 145
Building design, 145, 149, 252
Building explosions, 243
Building fires, 149, 150, 157, 192
Building materials, 148, 173, 187, 193, 207
Building materials tests, 211
Burn-back, 189
Burning rate, 206
Burn-prone patients, 231
Burns, 235
Burns, case histories, 235
Burns, epidemiology of, 231

California wildland fires, 238
Calorimeter, 239, 242
Calorimetric bead systems, 218
Carbon monoxide toxicity, 232
Carboxyhemoglobin, 232
Cardboard, 168
Carpet flammability, 165
Carpets, 174, 175
Casualties, 248
Catalytic fuel oxidation, 157
Ceiling smoke, 159
Cellulose retardants, 178
CF_3Br inhibition, 179
Char limits, 167
Chemical kinetics, 223
Chemical plants, 147
Chemical structure and burning fuels, 206
Chemionization, 203, 214
Chlorine, 223
Chlorine oxides, 223
CH_4-O_2 flames, 179
Chromatographic analysis, 187
Chromatography, 243
Civil Defense, 240
Cl^- formation, 215
Clothing fires, 235
C_2N_2 breakdown, 200
CN species, 197
Coal, 166, 220, 229

Coal combustion, 204
Coal dust explosions, 167
Coal mine locomotives, 159
Code requirements, for fire detection, 169
Columns, supports, 152
Combustibility of furnishings, 192
Combustible materials, 159
Combustion, 212, 230, 242, 248
Combustion instability, 204
Combustion phenomenon, 153
Combustion products behavior, 275
Combustion properties, 167
Commensurability in fire testing, 196
Compartment fires, 149, 212
Computer programs, 233
Concrete, 152
Concrete columns, stress under fire load, 188
Construction materials, 242
Consumer protection, 252
Convection, 174, 239
Convection, natural, 176
Convective transfer, 163
CO + OH reaction, 223
Cooling by water spray, 161
Corridor fires, 157, 205
Corrosion, 186
Counterflow diffusion flames, 202
Crib fires, 212, 220
Critical fire load of concrete columns, 188
Critical ignition conditions, 163
Curtain and drapery fires, 235

Decomposition of PVC, 186
Defoaming agents, 178
Detection, 278
Detection of earth fault, 159
Detectors, 154, 171
Detectors for fire and explosion, 170
Diammonium phosphate retardant, 220
Diffusion controlled combustion, 198
Diffusion flames, 172, 181, 187, 189, 191, 193, 197, 200, 202, 216, 218, 227, 228, 237
Directory U.S., fire research, 248
Dispersed particles, 175
Dispersion of spills, 146
Distillation, 147
Doppler sizing of particles, 225
Doppler velocitimetry, 240
Droplet burning, 193
Droplet flames, 187
Droplets, holography, 224
Dry chemicals, 185
Durability of wood, 198
Dust dispersed systems, 227
Dust electrification, 226
Dust flames, 199
Dwelling fires, 245
Dynamic behavior of fires, 160

Earth fault detection, 159
Economics, 262
Education, 146, 248
Effects of forest fire, 234
Electrical apparatus dangers, 147
Electrical equipment, 158
Electrostatic hazards, 153
Electrostatics, 226
Elementary reactions, 217, 223
Emission, 200
Energy conservation, 172
Energy transport, 200
Entrainment of smoke, 186
Environmental factors in building fires, 177
Equal area compartment fires, 149
Ethylene flames, 215
Ethylene-oxygen flame, 203
Evaporation, 182
Evaporation suppression, 182
Explosion, 147, 243
Explosion chamber, 243
Explosion detectors, 170
Explosion gasdynamics, 228
Explosion interruption, 151
Explosion limit hydrocarbon-air mixtures, 145
Explosion of gas in buildings, 188, 191, 207

Explosion, physical model of, in mines, 229
Explosion pressures, 188
Explosion prevention, by nitrogen atmospheres, 155
Explosion suppression, 184
Extinction, 181, 184
Extinguishants, 180
Extinguishment, 183, 258

Fabric fires, 146, 234
Fatalities, 248
FFACTS, 235
Fibreboard, 168
Fire, 145, 147, 150, 235, 240
Fire behavior, 163, 206
Fire-blast interaction, 160
Fire brands, 227
Fire brigade reports, 233
Fire cell, 208
Fire control, 252
Fire deaths, 235
Fire destruction rate, 258
Fire detection, 169, 252
Fire detector, 169, 170, 171
Fire detector response, 171
Fire detector testing and standards, 169
Fire dynamics, 258
Fire endurance testing, 196
Fire extinguishers in Germany, requirements, 190
Fire extinguishment by nitrogen, 156
Fire fighting foam, 178
Fire gases and temperature toxicity, 232
Fire hazard, 148, 161, 165, 211, 278
Fire hazards of aircraft, 257
Fire hazards of fuels, 165
Fire injuries, 234
Fire interaction, 224
Fire load, 149, 208
Fire measurement sensors, 239
Fire modelling, 148
Fire point, 184
Fire portraits, 239
Fire prevention and control hearings, 248
Fire problems exhibit, 248
Fire protection, 233
Fire protection of personnel, 254
Fire reports 1973, 233
Fire research, 252, 278
Fire research directory, 248
Fire research, RANN-NSF, 243
Fire research, review, 252
Fire resistance, 149, 152, 233
Fire resistance of concrete columns, 188
Fire-resistant hydraulic oil, 158
Fire resistant wood doors, 192
Fire retardant ASTM exposure test, 198
Fire retardant paints, 190
Fire retardant synthetics, 153
Fire retardants, 178, 220
Fire safety, 147, 149, 278
Fire safety of aircraft, 156
Fire severity, 149
Fire signatures, 169
Fire smoke, 226
Fire spread, 150, 172, 176, 177, 238, 252
Fire spread in buildings, 177
Fire spread in debris, 160
Fire spread in forests, 236
Fire spread model, 163
Fire structure, 204
Fire systems design, 171
Fire systems studies, 275
Fire testing, 196
Fire test methods, 205
Fire test, motor vehicle safety standard no. 302, 152
Fire tests, 152, 157, 196, 202, 207, 233, 242
Fire toxicology, 230
Fire, underground, 156
Fire victim carbon monoxide levels, 232
Fire walls, 145

Firefighting, 278
Firemen training, 254
Fires in aerospace vehicles, 154
Fires in shopping malls, 161
Flame arresters, 151
Flame deflectors, 150
Flame inhibition, 181
Flameproof enclosures, 205
Flame propagation rate, 165
Flame quenching, 181
Flame radiation, 227
Flames, 263
Flame size effect on radiation, 207
Flame speed, 199
Flame spread, 165, 172, 173, 174, 175, 193, 205, 275
Flame structure, 162, 167, 174, 179, 181, 185, 187, 191, 193, 197, 198, 200, 202, 203, 204, 213, 214, 215, 216, 217, 218, 219, 222, 223
Flaming and nonflaming conditions, 190
Flaming conditions, 240
Flammability, 146, 167, 196, 252
Flammability index, 229
Flammability limits, 148, 154
Flammability of materials, 154
Flammability of wildland brush, 234
Flammability testing, 153
Flammability tests, 205
Flammable fabrics, 234, 235
Flammable liquid fires, 239
Flammable mixtures, 146
Flammables, 147
Flashover, 202
Floor covering flammability, 205
Flooring, 196
Flow effects on ignition, 162
Fluidized bed, 204
Fluorchemical, 189
Fluorprotein, 189
Foam, 180, 189
Forest fire, 163, 236, 238
Forest fire damage appraisal, 234
Fuel crib heating, 163
Fuel ignition, 165
Fuel model, 234
Fuel nitrogen, 191
Fuel rich flames, 200
Fuel spills, 146
Fuel systems vulnerability, 148, 154
Fuel tank filling hazard, 153
Fuel tank inerting, 157
Fuel vulnerability, 154
Full-scale building burns, 177
Furnace, auxiliary equipment, 240
Furnace design, 196
Furnace tests, 148, 211

Gaps for flame quenching, 181
Gas analysis system, 191
Gas detection, 147, 158
Gasdynamic experiments of explosions, 228
Gas explosions, 145, 188, 191, 207, 243
Gas phase reactions, 223
Gas solid kinetics, 218
Gas velocity, 174
Gunfire, 148, 154

H atom profiles, 162
H_2 flames, 215
Halogen extinguishing agents, 190
Hazard analysis, 157
H_2-C_2N_2 flames, 214
HCl in flames, 215
Heat flux, 172, 242
Heat of combustion, 240
Heat radiation, 208
Heat release, 193
Heat release rate, 202
Heat transfer, 262, 263
High expansion foam, 178
High racked storages, 146
High rise, 150
High rise fires, 150
High speed photography, 241
High speed photography, Tenth International Congress, 241
High voltage equipment, for flammable atmospheres, 158

H_2-N_2-O_2 flames, 200
Hot-wire anemometer, 242
Hydrocarbon-air concentrations, 145
Hydrocarbon-air flames, 175
Hydrocarbon flames, 197, 216
Hydrocarbon fuels, 182
Hydrocarbon liquids, 182
Hydrocarbon oil, fire-resistant, 158
Hydrogen chloride, 223
Hydrogen chloride adsorption, 222
Hydrogen flames, 217

Ignitability, 165
Ignition, 163, 164, 165, 167, 168, 192, 196, 205, 258
Ignition energy, 162
Ignition hazard, 146
Ignition,, localized, 162
Ignition of particles, 163
Ignition sources, 146, 234
Incipient combustion, 166
Industrial hazards, 147
Infrared detectors for fire, 170
Inhibited flames, 179
Inhibition, 185, 278
Inhibition mechanism, 175
Instabilities, 204
Interactions, 240
Interferometry, 187
Ionization detector, 169
Ions, 215
Ions in flames, 213, 214
Irradiation energy level, 190
Irradiation of paper sheets, 168

Jet fuels, 165
JP-4, 148
JP-8, 148

Kinetics, 179, 215
Kinetics of gas solid reactions, 218

Laboratory fire test, 189
Laminar burning, 176
Laminar flames on polymers, 172
Laser anemometer, 240
Laser Doppler spectroscopy, 225
Leaks of fuel, 146
Lean hydrocarbon flames, 217
Length of light path, 190
Lethal fire gases, 232
Light transmission, 190
Lighters, 234
Liquid fires, 177, 184
Liquid fuel flames, 181
Long gallery coal dust explosions, 167
Longwall coal-mine face, 237
LPG, 156

Margolis effect, 177
Matches, 234
Material ignitability, 193
Mathematical fire model, 238
Maximum safe experimental gap (M.S.E.G.), 205
Metal oxides as gas detectors, 158
Meteorology, 238
Methane-oxygen flames, 203, 218
Mine fire prevention, 155
Mine fires, 224
Mines, 159, 166, 206, 213, 229
Minimum ignition energy, 162
Mobile field laboratory, 239
Model for urban fires, 227
Model of forest fires, 238
Modeling, 278
Modeling flame structure, 172
Modeling pool fires, 237
Molecular beam sampling, 213
M.S.E.G., 205

Narrow gap theory, 184
NFPA 231C, 146
NH species, 197
Nitrogen as fire extinguishing agent, 156
Nitrogenous fuels, 219
Nitrous oxide, 197
Non-flammable elastomeric materials, 152

Nonluminous radiation, 228
NO_x formation, 191, 216, 219, 222
Noxious gas concentrations, 177
NSF (National Science Foundation) RANN fire program, 243
Nuclear fire threat, 160
Nuclear weapons effects, 161

Odors, 220
OH concentrations, 185
Opposed flow diffusion flames, 198
Opposed jet diffusion flames, 202
Optical detectors, 170
Oscillations, 204
Oxygen index, 167

Pallet storage, 146
Paper, 174
Particle combustion, 204
Particle ignition, 163
Particle production, 220
Particles, 195, 226, 227
Particles, sizing of, 224, 225
Pedestrian precincts, 161
Petroleum industry safety, 147
Physico-chemical aspects of fires, 275
Plastic fires, 183
PMMA (Polymethyl Methacrylate), 172
Pollution, 191, 216, 219, 222
Polymer combustion, 198
Polymer combustion, toxicology of, 230
Polymer fires, 176, 237
Polymeric materials, 212
Polymeric materials, radiant heating, 194
Polymers, 172, 206, 230
Polyolefin polymers, 167
Polystyrene, 167
Polyvinyl chloride fires, 222
Polyvinyl chloride soot, 222
Pool fires, 180
Porosity in crib fires, 212
Porous fuels, 172
Porous materials, 175
Powdered inhibitors, 175
Pressure dependence of flame structure, 193
Pressure of explosions, 243
Protective equipment failure, 156
Protein, 189
PVC fires, 186
Pyrolysis, 167, 230, 258
Pyrolysis of cotton wood, 221
Pyrolysis of PVC, 186
Pyrolysis products, 178
Pyrolysis rate, 221

Quenching ability of sintered metals, 151
Quenching distance, 162, 183

Radiant heating, 242
Radiant heating of polymers, 194
Radiant panel, 196
Radiant transfer, 263
Radiation, 168, 174, 175, 191, 200, 239
Radiation, analytical solutions, 228
Radiation augmented flames, 183
Radiation form fires, 207
Radiative ignition, 165
Radical reactions, 217
RANN (Research Applied to National Needs) fire program, 243
Rate constants, 223
Recombination reactions, 217
Reflectance-absorptance of polymer surface, 194
Regression rate, 198
Respiration training, 254
Respirators, design, 231
Respirators, law requirements, need, development, 153
Retardants, 159, 278
Retardants, "self-help", 178
Room fires, 193

Safe gaps, 183

Safety engineering, 233
Safety scheme deficiencies, 156
Sandbox model, 237
Scale models, 202
Scaling of wood burning, 176
SCORE project, 248
Self ignition, 163, 164
Ship structures, 161
Shopping complexes, 161
Simulation of forest fires, 238
Sintered metals as flame quenchers, 151
Sizing of particles, 227
Smoke, 192, 193, 195, 207, 213, 220, 230
Smoke detector, 171
Smoke extraction, 159, 186
Smoke generation, 187, 212
Smoke measurement, 237
Smoke products, 178
Smoke, visibility through, 226
Social aspects of fires, 262
Sodium salts, 185
Solid fuel ignition, 165
"Solid-core" doors, 192
Soot, 195, 222
Soot characterization, 222
Sooting flames, 213
Space heater, 156
Spark ignition, 162
Specific optical density, 230
Spontaneous combustion, 166, 220
Spontaneous ignition, 164
Spontaneous ignition of paper, 168
Spray extraction of smoke, 186
Spray flames, 202
Sprinklers, 146
Standards, 146, 235
Statistical fire data, 235
Statistics of dwelling fires, 245
Steels, 152
Strain measurement, 243
Strain measurement in explosion, 207
Stress distribution, 237
Structural characteristics, 245
Structural concrete, 186
Structural design, 152
Structural fires, 177
Structural fires, response to blast waves, 160
Structure and burning, 206
Supertanker cleaning hazard, 145
Suppression, 180, 240
Surface burning, 172
Surface combustion, 176
Swirl, 240
Systems Analysis, 248

Temperature curve, 208
Temperature profiles, 174, 197
Test facilities, 240
Testing of respirators, 231
Tests, 146, 156, 211, 213, 243
Tests on smoke, 187
TGA (thermogravimetric analysis), 167
Thermal degradation of paper, 168
Thermal model of flameproof enclosures, 205
Thermal radiation, 192, 202, 242
Timber structure fire, 208
Time dependence of explosion pressure, 167
Toxic gas transport, 222
Toxic gases, 207, 230, 248
Toxicity, 230
Toxicity by carbon monoxide, 232
Toxicity of polymer combustion products, 230
Treated cotton wood, 221
Tunnels, 159, 206
Turbulence, 162
Turbulent diffusion flames, 222
Turbulent fires, 176
Turbulent flames, 191, 216
Turbulent flow measurement, 242
Turbulent jet flames, 189

U.K. fire reports, 233
U.S. fire research directory, 248

Velocity measurement, 240
Velocity of gas, 197

Velocity perturbation
measurements, 242
Ventilation, 149
Ventilation flow, 224
Venting, 159
Vertical wood slabs, 176
Vinyl Chloride (poly), 186
Vortex urban fire model, 227
Water flow cooling, 161
Water spray extraction of smoke, 186
Water sprays, 183
Wildland fuels, 238
Wood, 164, 206
Wood burning, 176
Wood doors, 192
Wood flammability, 152