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Fourth Annual Conference on Fire Research

Ileana M. Martinez and Sonya M. Cherry, Editors

Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

December 1980

Final Report

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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FOURTH ANNUAL CONFERENCE ON FIRE RESEARCH

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U.S. DEPARTMENT OF COMMERCE, Philip M. Klutznick, *Secretary*
Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

FOREWORD

When we began these Annual Conferences three years ago, it was with the intent that they provide fire researchers with a focus for discussion and a forum for new ideas. We think it is working well on both counts.

Conference attendance has expanded dramatically. What began as a domestic affair now involves fire researchers the world over. For the first time this year, those attending include a delegation of distinguished visitors from Japan, members of the 5th meeting of the United States - Japan Panel on Fire Research.

The technical challenges of the fire problem are the same in every country; the approaches taken to meet those challenges can be quite different. We look forward to enriching our own approaches with the views and ideas of our colleagues from abroad.

Frederic B. Clarke
Director
Center for Fire Research

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FOURTH ANNUAL CONFERENCE ON FIRE RESEARCH

Ileana M. Martinez and Sonya M. Cherry
Editors

ABSTRACT

This report contains descriptions of the internal programs of the Center for Fire Research as well as extended abstracts of grants and contracts sponsored by the Center for Fire Research, National Bureau of Standards.

Key words: Chemistry of fire; combustion products; detection; fire hazards; fire modeling; fire protection; fire suppression; fire research; human behavior in fires; physics of fire; toxicity of combustion products.

NOTE: The Annual Conference on Fire Research held October 22-24, 1980, marks the fourth time the Center for Fire Research has sponsored such an event. In 1980 the Conference stresses the more applied aspects of fire research. Topics discussed include toxicology, fire tests, detection and suppression, hazard analysis, and human behavior in fires. The Conference is devoted in alternate years to the basic and applied aspects of fire research.

CENTER FOR FIRE RESEARCH PROGRAMS

Exploratory Fire Research
Center for Fire Research

Professional Personnel

Richard G. Gann, Head
Michael J. Drews, Guest Worker
William L. Earl, Research Chemist
Takao Kashiwagi, Guest Worker
Takashi Kashiwagi, Materials Research Engineer
Thomas G. K. Lee, Guest Worker
W. Gary Mallard, Research Chemist
Michael J. Manka, Chemist
Bernard J. McCaffrey, Mechanical Engineer
Robert J. McCarter, Research Chemist
George W. Mulholland, Research Chemist
Thomas J. Ohlemiller, General Engineer
Russell Schmidt, Physicist
Kermit C. Smyth, Research Chemist

Program Objectives

(1) Understand the physical and chemical processes which underlie macroscopic fire phenomena, including chemical processes in burning solids and flames, and the formation and properties of smoke particulates and toxic gases, mass and energy transport in flames, the mechanism of action of fire retardants, and ignition, flame spread and flame extinguishment processes.

(2) Devise new techniques for studying these phenomena.

(3) Furnish fundamental scientific information to support the activities of the Fire Safety Engineering Division and the Fire Performance Evaluation Division.

Project Areas

1. Radiative Ignition

Before a liquid or solid fuel can ignite, it must absorb a significant quantity of energy. In many circumstances, radiation is the dominant transfer mechanism supplying this energy. Work to date has involved exposing samples of n-decane, PMMA and red oak to a CO_2 laser, with and without a pilot heat source present. It has been shown that significant absorption takes place in the gas phase above the fuel, presumably by the vapors from the fuel. The effect of sample orientation on this type of ignition has been determined. High speed motion pictures of the liquid fuel surface have shown complex surface motions between the beginning of irradiation and ignition. We are now replacing the laser with a high intensity black body source, determining the absorptivity and nature of the pyrolyzate, and characterizing the pyrolyzate temperature and concentration field using a two-line holographic technique.

2. NMR Studies of Combustion of Solids

Jointly with the NBS Center for Materials Science, we are developing a capability in magic angle spinning, high resolution nuclear magnetic resonance (NMR) of solids. Our intent is to follow the degradation of natural and synthetic polymers using the ^{13}C nuclide. Studies of both polyethylene and cellulose have shown that conformational differences can be observed between chemically similar samples. Preliminary spectra of wood and the different crystalline forms of pure cellulose have been obtained as a prelude to detailed studies on wood decomposition and smoldering combustion. In addition, detailed studies have begun on the magnitudes of line-broadening in the NMR spectra. These will determine the limits of information available in the planned decomposition experiments.

3. Smoldering Combustion of Cellulosics

According to current statistics, at least one-fourth of all fire deaths result from scenarios that involve a non-flaming step. The increasing use of shredded paper as home insulation threatens to increase that fraction. As a result, a major effort is underway to understand the ignition, propagation and inhibition of smoldering.

Experiments on the thermal ignition of cellulosic insulation have been completed. For several heat source configurations, minimum ignition temperatures have been determined. Using fundamental physics and global chemical kinetics, a model has been constructed that quite accurately reproduces these values. This has led to a suggested configuration for an ignition test method.

Earlier experiments in CFR have shown that sulfur is an effective smoldering inhibitor in some systems. We have now demonstrated that it operates primarily by poisoning the active sites in the pyrolyzed cellulose where oxidation and the accompanying energy release take place.

Concurrently, nearly two hundred inorganic salts have been subjected to a screening test for effectiveness as flaming and smoldering inhibitors. About one-half stopped the smoldering front, and about forty were effective on flaming as well. Using the results of the physical study mentioned above, we are now designing a larger-scale experiment to more closely simulate loose-fill insulation usage.

4. Fire Plume Characterization

Traditionally, a fire has been treated as a thermodynamic energy source with a spatially uniform heat release. Measurements show significant differences, however, between measurements of plume parameters near the base of a buoyant diffusion flame and predictions based on current, far field models. We are now preparing to measure the time-averaged flow, temperature and concentration fields in order to determine the validity of the classical representation and to refine these models.

It is realized that the plume is not well-mixed, and that it is highly likely that the flame-determining physics and chemistry are dominated by the local fuel-air ratio. Thus we are in the process of determining the fluctuation magnitudes and frequency distribution of the temperature and reactant concentrations in turbulent plumes. This is being done jointly with co-workers in the NBS Center for Thermodynamics and Molecular Science and the NBS Continuous Processes Technology Program.

5. Soot Formation and Evolution

Smoke from fires dominates the flame radiation process, is a major factor in hindered egress from the fire vicinity, and is the prime basis for early detection. We have two studies of the fundamentals of smoke and its evolution.

We are in the early stages of a long-term study of the basic chemistry carried out jointly with the NBS Continuous Processes Technology Program. Using the opto-galvanic effect in flames, we have observed an enhanced ionization signal with long time delays. This corresponds to either small particles or macromolecules. This phenomenon only occurs in a narrow stoichiometric range near the sooting limit. Further work is in progress. Concurrently we will be characterizing the radical pool in various flames to determine the relevance of premixed flame data to diffusion flames.

If a realistic test method for a material's sooting tendency is to be developed, it must be based on the smoke properties that determine the eventual hazard and on the dynamic processes controlling the growth and movement of the smoke as it moves from the source. We have recently compared the various instruments for measuring these properties, cooperated in a study of coagulation of particles in a buoyant plume, and studied the smoke-filling process in a room. Further work will lead to the documentation of the conditions that can lead to the desirable, or undesirable, values of smoke parameters. This in turn will define the early smoke properties to be measured in the test method.

6. Wood Combustion Chemistry

The degradation of wood during a fire occurs by a complex mechanism, yielding a vastly distorted solid and a large number of gaseous and condensed species. These evolve to fill the upper portion of the fire room, impede the escape of occupants and perhaps cause their disability or death. Similar processes occur in stoves when wood or wood products are the fuel. There, they lead to creosote formation chimney fires and environmentally unacceptable emissions. We are beginning a study on the degradation of the wood solids, the generic classification of products under fire pyrolytic conditions, and the chemical transformation of these products under various conditions of temperature, oxygen availability, etc. We will be using high resolution NMR, liquid chromatography, gas chromatography/mass spectrometry and a variety of other analytical techniques. The end product will be a general predictability of the products of wood combustion as a function of ambient conditions. This effort is closely coordinated with several other laboratories such as Argonne, TBA, Batelle and Ga. Tech.

Associated Grants and Contracts

1. Clemson University, Michael J. Drews - "Antimony Oxide-Organohalogen-Polymer Substrate Interactions in the Solid Phase."

2. SRI International, Sharon K. Brauman - "Polymer Degradation During Combustion."

3. University of Montana, Fred Shafizadeh - "Ignition and Fire Spread of Cellulosic Materials."

4. Princeton University, Irvin Glassman - "An Experimental Investigation of Flame Spread Over Condensed Combustibles: Gas Phase Interactions."

5. Lawrence Berkeley Laboratory, Patrick Pagni - "Fire Modeling."

6. Johns Hopkins University, Applied Physics Lab, Robert Fristrom - "Polymer Flammability and Flame Inhibition."

7. Lawrence Berkeley Laboratory, C. L. Tien - "Thermal Radiation of Luminous Flames and Smoke."

8. AeroChem Research Laboratories, Hartwell F. Calcote, "Soot Nucleation Mechanisms in Flames."

CONSTRUCTION AND MATERIALS RESEARCH
FIRE PERFORMANCE EVALUATION DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

Sanford Davis, Head
Jin B. Fang, Chemical Engineer
Lionel A. Issen, General Engineer
David P. Klein, Fire Protection Engineer
Billy T. Lee, Fire Protection Engineer
James S. Steel, Physicist
William H. Bailey, Supervisory Engineering Technician
David C. Jeanes, Research Associate

Program Objectives

The objectives of the Construction and Materials Research Program are to conduct research and development studies to evaluate the fire and high temperature performance of materials and products used in construction assemblies and transportation systems and to develop test procedures and performance criteria for improving fire safety. In addition, the Program manages the Center's large-scale experimental fire test facility.

Project Areas

1. Fire Endurance of Floor Constructions

The objectives of this project are to develop a test procedure for evaluating the fire endurance of floor assemblies in residences and to recommend rational performance criteria for protected and unprotected load-bearing constructions. The approach has been to conduct full-scale fire tests in a simulated basement recreation room using modern furniture with a typical fire load for that type of room. Based on the temperatures, heat fluxes, and pressures recorded during these tests, a new time-temperature curve was developed for evaluation in the gas-fired pilot furnace. Because of temperature, pressure, and oxygen constraints with the existing furnace, some modifications in furnace design and operation are being implemented. Once this has been accomplished, several types of floor constructions will be tested and the failure times will be compared to those obtained by the present ASTM E119 test. An analytical prediction capability for fire growth is being developed along with the experimental testing.

2. Fire Safety in Mobile Homes

The objective of this project is to determine the effect of interior finish materials on fire growth and spread on the attainment of untenable conditions in mobile homes in order to provide a rational basis for regulating these materials. Full-scale fire tests have been conducted in a single-wide mobile home using upholstered chairs and wood cribs as ignition sources. Work has been carried out to duplicate the essential features of the full-scale test results using reduced-scale modeling in order to provide a viable testing procedure for predicting fire performance.

3. Structural Fire Endurance

The objective of this project is to predict the fire endurance of structural building components under typical fire exposure conditions. In cooperation with the American Iron and Steel Institute, a restrained steel structure (having a reinforced concrete deck) typical of that found on the 10th floor of a 20-story building has been constructed and instrumented. One-quarter of the structure will be exposed to fires of increasing intensity to provide the data needed to validate an analytical model which has been developed for predicting such behavior.

4. Prison Cell Room Fire Study

The objective of this project is to determine the rate of heat production of a prison cell with a representative fire loading under different ventilation conditions. The approach has been to determine the total rate of heat released by the fire from the measurement of the oxygen content and volume flow rate of the exhaust gases. A series of four room fire tests have been carried out to determine the burning behavior of the combustible contents as a function of different sized doorway openings. The individual fuel items also were burned on a weight loss platform positioned directly under the exhaust collector hood in order to provide the input data on the rate of heat release for an analytical model which will be used to predict the total rate of heat production in the cell.

5. Shipboard Fire Research

The objectives of this project are to evaluate the potential fire hazard of shipboard and submarine hull insulations and to improve the application of laboratory fire tests for screening compartment lining materials. The approach is to subject the variety of shipboard and submarine hull insulations, some of which are protected with fire resistant materials, to laboratory fire tests on ignitability, flame spread, rate of heat release, and potential heat. The performance of these insulations are then examined in quarter and full-scale compartment fires. By comparing the time to flashover or the maximum temperature reached in the full sized compartment with the results of the laboratory fire test methods, improved acceptance criteria for materials can be derived. By comparing the performance of the material between the full and reduced scale fire test, the usefulness of the quarter-scale model as a screening tool can be evaluated. At the same time analytical and experimental studies are being carried out to improve the ability of the quarter-scale model to predict full-scale fire behavior. A standard test procedure based on the quarter-scale model will be developed.

6. Flame Retardant Permanency of Cellulose Insulation

The objective of this project is to study the effect of temperature and humidity cycling on the flammability characteristics of cellulosic loose-fill insulation. Based on the analysis of climatological data for regions of the country having widely differing weather conditions, various test cycles (time, temperature, humidity, number) will be imposed on cellulose insulation having different flame retardant compositions. Performance will be based on measurement of the critical radiant flux and the resistance to ignition by a smoldering cigarette. A proposed test method for inclusion in the Residential Conservation Service standard for cellulosic insulation will be written with recommended acceptance criteria.

7. Fire Safety of Amtrak Furnishings

The objective of this project is to develop and test cost beneficial concepts for reducing fire hazards in passenger rail vehicles. Specimens of passenger rail vehicle interior components will be obtained and assembled into sectional mock-ups for full-scale testing. Taking into account fire scenarios, usage geometry, and specific applications in railroad cars, mock-ups will be tested. An attempt will be made to predict the mock-up performance on the basis of small-scale laboratory tests. NBS will assist the Federal Railroad Administration in the conduct of full-sized burn experiments in actual rail vehicles by recommending "improved" materials and appropriate instrumentation of the test facility and recommending appropriate ways of analyzing and interpreting the resultant data.

8. VA Hospital Evaluation

The objectives of this project are to examine the smoke penetration problem of lay-in ceiling tile in hospital patient rooms, under various fire exposure conditions, and to determine if smoke from the fire in a patient's room will penetrate to adjacent room spaces. A fire test building having an 8-ft. clear ceiling with a 5-ft. high interstitial space above it will be built in a larger building. The plan will be typical of that found in a hospital with patient rooms opening on a corridor; the ceiling will be lay-in tile. Both smoldering and flaming fire experiments under different ventilation conditions will be conducted in one of the rooms and observations will be made in the interstitial space, the corridor, and the other rooms to identify the smoke leakage paths. Temperature, gas, and smoke measurements will be made in the various locations.

9. Large Scale Fire Research Facilities

The following large-scale testing facilities are available at the Gaithersburg site for use by CFR programs as needed:

Building 205

This is a 60-ft. by 120-ft. test building with controlled environmental conditions; a large smoke collection hood serves the individual experimental facilities and is connected to a large stack with afterburner. The following facilities are contained within the building:

> A room burn and smoke test facility. This is a two-story structure, 20 ft. by 20 ft. in plain view, which may be used for fire growth studies and for examining fire and smoke spread through ducts, dampers, doors, etc.
>
> A corridor test facility. This is a 12-ft. wide, 30-ft. long corridor with several burn rooms attached which can be used for a variety of studies, including the contribution of furnishings and interior finish as well as sprinkler performance.
>
> A research fire resistance furnace. This furnace is designed to meet the essential requirements of ASTM E 119 as well as to provide for more rapid heating of walls (10 ft. by 8 ft.), floor-ceilings (10 ft. by 8 ft.) and columns (8 ft. high). Structural loads up to 30 tons may be applied and furnace pressure may be adjusted from -0.05 in. to +0.15 in. water gage. The furnace may be used to test components, innovative constructions, and the effects of joints in wall-floor assemblies.

Building 205 also houses rooms for specialized calorimeters, small furnaces, and model enclosures. Laboratories are available for keeping and testing rats for toxicology studies in conjunction with large-scale fire experiments. Shops, instrument rooms, and service areas are also located in the building.

Mobile homes specially instrumented and outfitted to permit repetitive tests of fire growth and smoke movement and detection are adjacent to Building 205.

NBS Annex

This is a former DOD facility adjacent to the NBS site which is available for special tests. It has a 3-story stair tower which can be used for smoke spread and sprinkler studies; a dormitory building containing a 60-ft. long loaded corridor with lobbies at each end; a large laboratory designed for smoke detector testing; and an electrical testing laboratory.

Instrumentation and Staff

Each of the facilities is equipped with automatic data recording systems to collect a wide variety of information from the large-scale tests. A staff of 6 technicians and an instrumentation specialist are available to support CFR research programs. An instrumented van is available for field testing at distant sites.

Associated Grants

University of Michigan, George S. Springer - "Degradation of Mechanical Properties of Wood During Fire"

Portland Cement Association, Michael Gillen - "Extension of Short-Term Creep Tests at Elevated Temperatures"

FIRE TEST METHODS RESEARCH
FIRE PERFORMANCE EVALUATION DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

William J. Parker, Head
Vytenis Babrauskas, Fire Protection Engineer
William D. Walton, Fire Protection Engineer
Gerald D. Mitchell, Research Chemist
James R. Lawson, General Physical Scientist
David L. Chamberlain,, Research Associate
Monica Cavell, Co-op student

Program Objectives

The objective of the Fire Test Methods Research Group is to reduce the probability of the growth and spread of fire and its combustion products in a building by developing fire test methods and acceptance criteria for furnishings and construction materials and their assemblies.

Project Areas

1. Fire Test Standards

The objective of this project is to develop laboratory test methods for the ignitability, flame spread rate, and rates of heat release and smoke production of construction and furnishing materials. These tests are intended to supply the input data on the fire properties of a material needed by the analytical models being developed for fire growth and spread in buildings. The tests must meet the criteria for ASTM Fire Test Standards and their precision and accuracy must be demonstrated. The current fire test methods used in CFR will be maintained and improved in conjunction with the ASTM task group activities.

Work will continue on the development of the ease of ignition test which measures the time to ignition for vertically oriented interior finishing and furnishing materials by flame impingement. Some important improvements have been suggested as a result of preliminary round robin tests carried out on this test method.

Test methods for measuring the lateral and downward flame spread rates along a vertical surface as a function of the surface temperature ahead of the flame will be developed. In addition, a test method is needed to characterize the flame spread rate in the direction of air flow up a wall or across a ceiling. Some experiments are planned in this area which involve measuring the flame heights above vertical specimens as a function of their heat release rate.

Work will continue on the development of the heat release rate calorimeters. An internal round robin will be run on a range of materials on all of the calorimeters at NBS in each of their modes of operation. A test procedure is also being developed for measuring the heat release rate of assemblies in the ASTM E119 furnace using the oxygen consumption technique. In addition, a furniture calorimeter has been built which can measure the heat release rate of full size couches by this technique. The project leader is J. R. Lawson. The other professional investigator is D. L. Chamberlain.

2. Fire Test Criteria

The objective of this project is to develop acceptance criteria for materials and assemblies which wlll provide an acceptable level of fire safety in specific applications. This involves the selection of a suitable set of test methods and setting limits on the fire performance of the materials or assemblies in these tests. The acceptance criteria will be derived from a correlation between the results of the fire tests on the materials and assemblies and their full scale burning behavior. The output of this project will be used by building code officials and the government regulatory agencies to reduce the incidence and severity of unwanted fires within their jurisdiction.

The analytical models being developed for room fire growth will be modified to take into account the spread of flame over the combustible interior finish materials and their heat release rates. Well instrumented reduced-scale and full scale room fire tests will be run with interior finish materials whose fire properties have been measured in order to validate or upgrade the computer models for predicting the contribution of interior finish materials to fire growth. The acceptance criteria for these materials can then be based on their predicted performance in a standard room fire test or other enclosure fire of concern. The analytical model serves as a guide for correlating the results of the laboratory tests with the full scale burning behavior.

This project is also responsive to other applications which may arise due to the incidence of or recognized potential for serious fires in the field. Through investigation and/or analysis of these real or potential fires, scenarios are developed which can form the basis for (1) an analytical model which can predict the hazard based on small scale laboratory tests or (2) a mockup test which captures the essential features of the real life hazard. The project leader is W. D. Walton.

3. Plastics Flammability Research

The objective of this project is to provide a means of predicting the full scale burning behavior of upholstered furniture based on the ignitability, flame spread rates, and heat release rates of the materials of construction along with a geometrical description of the furniture including the area, thickness, and orientation of the various materials. The results of this project could be used as a basis for selecting test methods and acceptance criteria for the regulation of upholstered furniture for fire safety.

A systematic study of the geometrical and material effects on the burning behavior of upholstered furniture will be undertaken using mockups. The mockups will be an idealization of the actual piece of furniture maintaining the same area and average thickness in so far as possible but with simpler and more easily describable geometry. These are intended to be amenable to rapid construction. The similarity between the mockups and the actual furniture must be close enough to provide essentially the same heat release rate history. When this has been established, the thickness, area and type of padding material along with the covering fabric will be systematically varied in the mockups to establish their effects on the total rate of heat release. The project leader is Vyto Babrauskas.

4. Oxygen Consumption Calorimetry

The objective of this project is to improve the instrumentation used to determine the heat release rates by oxygen consumption for the various applications encountered in CFR, to establish the accuracy of the method and its sensitivity to the test variables, and to make recommendations as to the optimum instrumentation for a particular application in order to achieve an acceptable balance of simplicity, accuracy, time response, etc. The output of this work will be to refine the oxygen consumption calorimeter and the measurement of heat release rate in the full and reduced scale room fire tests, the fuel contribution in the ASTM E84 tunnel, and the heat release rate of assemblies in the ASTM E119 furnace.

A systematic study will be made on the accuracy, sensitivity and time response of the oxygen consumption calorimetry technique by burning solids, liquids and gases of known chemical composition and heat of combustion at various heat release rates in the oxygen consumption calorimeter. The effect of gas pressure, temperature, chemical composition, and flow rate through the analyzer on the measured concentration of O_2, CO_2, and CO will be determined for the different types of analyzers available. Leakage through the sampling lines and chemical reactions with the interior surface of the lines will be considered. The effect of different types of trapping systems on the time response will be investigated. A comparison of different types of volume flow rate measurements in the exhaust duct such as orifice plates, bidirectional probes, and pitot tubes will be made. The project leader is G. D. Mitchell.

Associated Grants

University of California (Berkeley), R. Brady Williamson "Intralaboratory Evaluation of a Standard Room Fire Test"

SRI International, Stanley B. Martin "Effect of Retardants on the Heat Release Rate of Building Materials"

Northwestern University, A. C. Fernandez Pello "Fire Propagation in Concurrent Flows"

Illinois Institute of Technology, Research Institute, R. Pape/ T. Waterman "Preflashover Room Fire Model"

Factory Mutual Research Corporation, A. Tewarson "Determination of Fuel Parameters for Fire Modeling"

PRODUCT FLAMMABILITY RESEARCH
FIRE PERFORMANCE EVALUATION DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

James H. Winger, Head
Emil Braun, Physicist
John F. Krasny, Textile Technologist
Joseph J. Loftus, Research Chemist
David J. Mitchell, Mechanical Engineer
Richard D. Peacock, Chemical Engineer
Catherine J. Morin, Research Associate

Program Objectives

The program objective is to develop and apply technology to reduce fire losses associated with the use of products by working through regulatory agencies and voluntary standards and codes.

Project Areas

1. Mine Fire Safety

The objective is to develop effective test methods, standards, and operating procedures to reduce fire losses in underground coal mines. The accident data have been reviewed and analyzed and fire scenarios developed for several products and systems. The existing fire tests for hydraulic fluids and conveyor belts have been reviewed, and appropriate tests are under development. Review of fire tests for explosion containment and brattice cloth has started. Recommended procedures and supporting documentation will be prepared for each product area and submitted to the Bureau of Mines and the Mine Safety and Health Administration.

2. Fuelwood Fire Safety

The objective is to develop methods and procedures to assure adequate fire safety when wood is used as a fuel in residences and small industries. The literature, model codes, and tests for the fire safety of wood-burning appliances have been reviewed, and a report has been published. An experimental program based on the review has been started. Recommended code changes and test procedures will be provided to the Department of Energy and the model code organizations.

3. Textiles

The Upholstered Furniture Action Council voluntary program to reduce the incidence of cigarette ignition of upholstered furniture is under evaluation and concepts for improvement are under development.

A standard for the flammability of flight crew uniforms has been recommended to the Federal Aviation Administration (FAA). Technical support is being provided to the FAA as they prepare a proposed rule.

The capabilities for apparel fabrics to provide some protection from an existing fire are under investigation. Various test concepts and procedures are under evaluation as well as the performance of various fabrics in these procedures.

Grants

1. Auburn University

"Investigation of Safety Problems Associated With Fireplace Inserts"

2. Underwriters Laboratories, Incorporated

"Investigation of Fire Hazards of Fireplace Inserts in Factory-Built and Masonry Fireplaces"

DESIGN CONCEPTS RESEARCH
FIRE SAFETY ENGINEERING DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

Harold E. Nelson, Head
Bernard M. Levin, Research Psychologist
A. Jeffrey Shibe, Operations Research Analyst
Leonard Y. Cooper, Research Fire Protection Engineer
Norman E. Groner, Research Psychologist
Daniel M. Alvord, Math/Programmer
Roseanne L. Paulsen, Social Scientist

Program Objectives

The objectives of the Program are to synthesize and integrate research and technology to develop technically based rational approaches toward providing safety from fire in buildings of various types of usage; and to provide operating mechanisms for using these approaches in setting fire safety requirements in these facilities.

Project Areas

1. Rational Approach to Fire Safety in Health Care Facilities

A multi-faceted program to extend the ongoing program on health care facilities. Major areas include the extension of the decision analysis and evaluation system approaches to those facilities that involve the developmentally disabled and boarding care for the elderly; to investigate and provide technical improvement allowing better or expanded values in specific subsystem parameters of the existing Fire Safety Evaluation System; to continue work on a fundamental modeling basis of fire development and smoke and heat propagation in health care facilities; to improve emergency preparedness criteria; and to initiate major investigations in fire safety through control of building contents.

The approach includes operations research application particularly as relates to decision analysis and emergency preparedness. These approaches are being directed at combining technical information, statistics and other historical information with the consensus of professional experts. The improvement of subsystem parameters and the development of predictive calculations on fire threat development will extensively use established engineering technology and the most current math modeling techniques and research developed data with emphasis on the development of engineering and design tools. Developments in the furnishing area will concentrate on use of oxygen calorimetry and bench tests to establish rates of heat release, total energy, and companion measurements on smoke and toxic species.

2. Fire Safety for the Developmentally Disabled

A recent development in the care of the mentally retarded (and other developmentally disabled persons) is to provide for their custodial care in small home-like facilities in the community rather than in large remote institutions. Life/fire safety requirements have not been specifically developed for these types of facilities so the responsible authorities are using regulations designed for other purposes including the NFPA Life Safety Code standards for private homes, boarding houses and hospitals. The objective of this project is to develop life/fire safety performance criteria specifically geared for these group homes.

This 39-month project started in July 1977. During the familiarization phase of the project, over 50 group homes were visited; detailed information about the facilities and the residents was obtained for 9 of them. A report has been published on the "Behavioral and Physical Characteristics of Developmentally Disabled Individuals." (NBS-GCR-79-167).

The approach is to develop a variation and modification of the Fire Safety Evaluation System. This system will permit flexibility in the selection of fire safety features, and the fire protection requirements will depend, in part, on the level of capabilities of the residents. The criteria will be developed with the advice of experts throughout the country.

A preliminary version of the evaluation system is now developed. Review and testing of subsystems started in 1979 and the system is being modified as needed based on these field tests and on the comments of the reviewers.

3. Means of Egress Study

The objective of this project is to investigate the state-of-the-art; to conduct experiments to establish an improved data base, providing a basis for hazard assessment approaches; and to determine specific engineering solutions relevant to yielding emergency escape criteria for means of egress arrangements. The effort includes: 1) an assessment of the state-of-the-art literature on the human factors relating to emergency egress in buildings; 2) a review and analysis of the current state of technology theories and test data involved in the growth of fire, controlling factors, and the speed and distribution of effects that interfere with or terminate the ability to escape from fire; and 3) investigations toward the development of procedures to determine the smoke restricting capability of various qualities of stairwell doors.

The program, initially intended for two years, has been extended an additional year. The literature analysis of emergency egress has been completed and a report entitled "A Critical Assessment of the Technical Literature on Emergency Egress From Buildings" has been authored by Dr. Fred Stahl of the NBS Center for Building Technology. Tests have been conducted on a full sized open stairwell test facility at NBS and in cooperation with Underwriters Laboratories, tests have been initiated to evaluate a shroud method (ISO approach) for using the standard door furnace in a positive mode to determine leakage rate through fire doors during the course of fire exposure.

Continue the development of the time available for egress model based on smoke filling as a function of heat and mass transfer. The approach consists of the theoretical transfer of the fire growth model, two room model, smoke migration models, and experimental data to develop an applied engineering technology useful in the design or evaluation of conditions as occur in actual or proposed buildings or building renovations.

4. Multi-Family Housing Life/Fire Safety Evaluation System

The objective of this project is the development of a fire safety evaluation system applicable to existing multi-family housing. The system will be designed to evaluate equivalency of alternative fire safety approaches as compared to the normal requirements of the Department of Housing and Urban Development Minimum Property Standards.

The 18-month project was initiated in FY 1979. The evaluation system will be based on the relevance of the various elements of building design to the performance objectives of fire safety (e.g., prevention of ignition, litigation of fire development capability, confinement of fire, detection and extinguishment, and escape and rescue). A working evaluation system that may be used as an alternative to the existing explicit requirements has been developed and is now being tested.

5. Life/Fire Safety Evaluation Manual-Inmate Housing and Confinement Facilities in Penal Occupancies

The purpose of this project is to develop a fire safety evaluation system and supporting manuals to determine the relative level of safety in inmate housing facilities in prisons and similar penal institutions. The approach will be modeled after the other types of fire safety evaluation systems prepared or underway by the program. The project, scheduled for 1 and 1/2 years' duration, was initiated in mid 1979. The project has been extended to include full scale test of the rate-of-energy release of fully involved prison cells. The tests have been completed. The data has been used to develop a smoke removal criteria for prison cell blocks. This criteria is planned for inclusion in the 1980 Life Safety Code.

6. Coal Mine Fire Safety Evaluation

This is a three-year project to develop a methodology for determining alternative means for providing fire safety in coal mines. The objectives are both to protect the lives and health of the miners and to preserve the national resources involved. Phase 1 (FY 81) is directed at the development of an event logic tree and other descriptions of the overall organization of elements and interrelationships involved in fire safety in coal mines.

The approach in Phase 1 consists of joint analysis by NBS and the Bureau of Mines of the fire histories, available statistics, experience of

Bureau of Mines in coal and coal mining activities, and the experience and knowledge of NBS in fire protection and fire safety system principles to develop the resultant tree and supporting documentation.

7. Fire Safety for Handicapped Persons

To initiate important programs on providing needed fire safety for handicapped persons to enable broadening of their activity and more full entry into the world of business, commerce and independent living. Initial emphasis will be on general concepts and on the development of fire safety aspects of the use of elevators as a means of emergency egress. A parallel effort will be directed to the development of acceptable design criteria for safe refuge for handicapped persons.

8. Extra-CFR Activities

A major portion of the activities of Design Concepts Research are conducted outside of Center for Fire Research. These include:

Center for Building Technology, NBS

1. "Simulation of Human Behavior in Fires: a Computer Model", Fred I. Stahl.

2. "System for Cost Comparison of Fire Safety Alternatives", Robert Chapman.

3. "The Evacuation of Nonambulatory Patients From Hospital and Nursing Home Fires", John Archea.

4. "Time-based Provisions for Emergency Escape in Public Occupancy Buildings", Fred I. Stahl.

Center for Consumer Product Technology, NBS

1. "Safe Environments--Anthropometric, Biomechanical, and Activity Considerations", Clarke Jones and John Fechter.

Associated Grants

1. University of Maryland, John Bryan - "The Determination of Behavior Response Patterns in Fire Situations - Project People II"

2. North Carolina State University, Richard Pearson - "Occupant Response Variability in Escape from Residential Fires."

3. University of Florida, Richard L. Francis - "Network Models of Building Evacuation."

4. University of North Carolina, Marc Waller and Robert Vreeland - "Guidelines for Preparing Fire Plan for Group Homes."

5. University of Washington, John Keating and Elizabeth Loftus - "Human Behavior in Fire Situations: A study of Post-Fire Interviews."

FIRE HAZARD ANALYSIS
FIRE SAFETY ENGINEERING DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

Benjamin Buchbinder, Head
Alan Gomberg, Fire Prevention Engineer
Susan Helzer, Mathematician
James Slater, Mathematician
Vickie Shaw, Programmer

Program Objectives

The work carried on in this program is based on two major objectives. The first is to characterize fire hazards by analytical means and to evaluate strategies for reducing fire losses on a cost/benefit basis, both to help establish research priorities and to guide the development of test methods for codes and standards. The second objective is to provide access to fire loss data for CFR.

Project Areas

1. Decision Analysis

   Decisions on the choice between strategic alternatives for reducing fire losses should be based on a systematic consideration of all benefits, risks and costs. However, because of the complexity of safety problems and the uncertainties inherent in the evaluation of strategies for reducing accidental losses, the choice among strategies is difficult. We have developed analytical techniques for assessing the risks and avoided damages associated with different fire safety alternatives, and the economic costs of these alternatives. Decision analysis provides the analytical framework for the combination of these loss and cost assessments in choosing the most cost effective strategy for addressing a particular fire problem. The initial decision analysis study of alternatives for the reduction of upholstered furniture fire losses served to establish the utility of this approach for fire hazard applications. A major decision analysis study is underway on the residential fire problem. Decision analysis is also being applied in other fire safety areas including transformer fluids and rail transportation.

2. Special Studies

   The growth of the National Fire Data Center at the U.S. Fire Administration has provided more and better data for fire hazard analysis. Using these data as a basis, we perform special studies related to the characterization of specific fire hazards. Current special study topics include the following:

-Identification of factors associated with high fire death rates in rural areas and certain geographical areas.

-Feasibility of linkage of fire incident report files with demographic data bases, to permit future analysis of fire incident data as a function of population characteristics.

-Improvement of fire incident data through quality control in editing and data processing.

Associated Contract

SRI International, Fred L. Offensend - "Continuation of Decision Analysis Studies in Fire Hazard Analysis"

FIRE MODELING
FIRE SAFETY ENGINEERING DIVISION
CENTER FOR FIRE RESEARCH

Technical Staff

James Quintiere, Head
Howard Baum
Daniel Corley
Margaret Harkleroad
Walter Jones
William Rinkinen
Kenneth Steckler

Program Objectives

1. To develop, apply and facilitate the use of computer solutions based on zone modeling techniques to predict fire growth and hot gas flow in rooms.

2. To predict the hydrodynamic flow field and smoke transport arising from fire induced buoyancy driven flows.

3. To develop quantitative methods to assess fire risk utilizing fire growth models, test method data and fundamental analyses, and human tolerance criteria.

Project Area

1. Dynamics of Room Fires

A study on fire induced flows through room openings was completed. It yielded flow coefficient for various fire sizes and opening configurations. These results ranged from 0.5 to 0.8 depending on the method for defining the coefficient, and the coefficient tended to be slightly higher for flows leaving the enclosure.

In another related series of experiments the fire plume angle for centered flow burner fires was measured, and an entrainment rate was estimated. This demonstrated the "wind" effect of the room opening on the floor fire. Other experiments are planned to study the effect of fire location and configuration on entrainment.

An attempt to model wall fire spread in an enclosure has begun. This utilizes zone modeling techniques and incorporates analytical expressions for the rate of flame spread and the rate of burning per unit area. The expressions have been developed from material test data and more fundamental results, and include the effects of oxygen concentration and incident radiative heat flux. An experimental effort to support this modeling activity is planned.

A brief series of experiments to measure the "filling" characteristics of building corridors subject to a room fire were conducted. The room fire and corridor size were varied and the smoke layer interface position was determined by measuring either the temperature, smoke optical density, or direct visual sighting.

2. Buoyant Convection and Smoke Dynamics

Computational methods are being developed and implemented to predict the thermal-flow field arising from an idealized fire source in a two-dimensional enclosure. Various special case problems have been examined.

The theory of smoke particle coagulation and growth has been incorporated with the governing equations for buoyancy driven flows to predict the smoke transport characteristics. This has been done for a simple buoyant plume and particle tracking techniques are being developed to imbed the particle growth model into the two-dimensional transient computations for enclosures.

Associated Grants and Contracts

Pennsylvania State University, G. M. Faeth - "An Investigation of Fire Impingement on a Horizontal Ceiling".

California Institute of Technology, E. E. Zukoski - "Experimental Study of Environmental and Heat Transfer in a Room Fire".

TRW, Fendell and Carrier - "Modeling of Wind-Aided Fire Spread.

Case Western Reserve, J. Tien, - "Flame Spread and Spread Limits".

FIRE PROTECTION SYSTEMS RESEARCH
FIRE SAFETY ENGINEERING DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

Edward K. Budnick, Research Head
Richard G. Bright, Senior Research Engineer
Richard W. Bukowski, Research Engineer
David D. Evans, Mechanical Engineer
Warren D. Hayes, Fire Prevention Engineer
John H. Klote, Mechanical Engineer
John G. O'Neill, Fire Prevention Engineer

Research Group Objectives

An integrated approach to fire protection design includes considerations for 1) alerting the occupants prior to the attainment of adverse environmental conditions, and 2) actively prohibiting or reducing the growth and spread of the fire and combustion products. The principal objective of this research group is to provide the engineering basis necessary to rationally incorporate hardware technology which addresses these considerations into a broader, more integrated fire protection design.

At this time there are three general areas of concentration in this group: fire detection, fire suppression, and smoke control. The primary activities in these areas include the development of engineering design, installation, performance, and reliability requirements which will lead to appropriate test methods upon which to judge system capabilities, and overall design technology.

Two key factors in the development of technology for these fire protection systems are 1) the ability to extend research results to innovative uses, and 2) the need to create cost reductions through refinements in system designs. In order to provide the necessary attention to these factors, parallel research efforts will be pursued to provide both a fundamental understanding of the physical phenomena to which hardware systems respond, and the design and performance of the systems themselves.

Project Areas

1. Automatic Fire Detection: Considerable research is ongoing in this area to identify key parameters and conditions which must be considered when measuring the performance of detection devices. Extensive full-scale and laboratory testing is being utilized as the basis for the identification process and will be extended to support program efforts to develop standard tests for measuring detector performance. Current activities also include studies on

the arousal potential of state-of-the-art detector alarms, and the reliability of detector components and systems. Much of the technology developed in this program is inputted directly to U.S. and international standards groups for automatic detection. A long term objective in this area is the development of a prediction methodology for siting and sensitivity of detection systems. Success in this endeavor will be highly dependent on efforts outside this research group, including modeling of smoke formation and aging, and fire growth modeling. Work will continue within the group on studying the effects of aerosol types, concentration, and particle size distribution on smoke detector response.

2. Full-Scale Smoke Detector Performance Test: A full-scale test facility has been completed which will be used initially to replicate and compare the current "standard" tests used by UL, and in the proposed International Standards Organization (ISO) for performance of smoke detectors. This effort will provide initial technical information necessary to evaluate detector performance for a wide range of smoke aerosols produced in fires.

3. Fire Detection in Health Care Facilities: This project is designed to provide data and ultimately guidance on means of optimizing detection system performance in health care facilities. Full-scale tests have been conducted in a simulated health care environment to provide data on performance of detectors under actual fire conditions. A technical report was published based on the results of Phase I testing. Phase II is now complete and data analysis is ongoing. Field data has been collected and analyzed to assess the performance of detection systems currently being used in typical health care facilities. A report based on these studies is nearly complete and will provide interim guidance on detector location and response, and long term user information regarding performance, false alarm propensity, and benefits derived from different types of maintenance programs in health care facilities.

4. Automatic Fire Suppression: A great demand exists for technology advancement for automatic fire suppression systems. Efforts in this area have been directed toward full-scale performance testing under varying conditions and exposure fires. Initial work included an experimental study to develop design criteria for the use of automatic sprinklers for the protection of corridors from fires beginning in adjacent rooms with open doorways for multi-family and care-type facilities. Work has also been done in development of water distribution mapping techniques, identification of factors affecting the geometric distribution of water from sprinklers, examination of statistical parameters of water droplet populations from sprinklers as a function of pressure and deflector design, and the use of sprinklers in health care facilities.

In addition to this long range work, continuous efforts are made to assist in the development of U.S. and international standards for automatic sprinkler systems and components. This work has included analysis of water distribution patterns, K-factor (coefficient related to orifice pressure and flow rate) measurement techniques, and mechanical safety factors applied to sprinkler devices.

5. Fire Tests of Patient Rooms with Automatic Sprinklers: The objective of this study is to provide engineering design information on health care facilities incorporating automatic sprinklers. The effectiveness of sprinklers is being measured in terms of overall fire control, time available for evacuation, and the maintenance of tenable conditions for patients who cannot be evacuated. Current nationally used fire safety design criteria for health care facilities are being specifically examined from the viewpoints of life safety of the occupants and cost efficiency of system designs.

   Phase I tests were conducted during 1977 and 1978, and provided important information on the movement and concentration of selected combustion gases throughout the test space. Phase II of this project, completed during 1980, examined variations in water flow rates and nozzle pressures of sprinklers, thermal response of sprinkler links, and different exposure fire growth rates. Improved techniques were utilized to measure smoke movement and concentration in a corridor adjacent to the room of fire origin under these many variations.

   This work will be continued into 1981.

6. Sprinkler Protection of Open Stairways: The objective of this study was to develop engineering design information for alternative methods of protecting open stairways using sprinkler and spray nozzle systems. This work was designed to refine and update test results dating back to the 1940's which serve as the basis for methods currently used in the National Fire Protection Association (NFPA) sprinkler and life safety codes. Experimental full-scale testing was conducted in a specifically constructed four story facility. A propane burner served as the energy source and was operated at two heat release rates, 5.5 and 13.6 M Btu/hr (≃ 1500 and 4000 KW). Performance curves were developed, based on temperature effects, for these systems to indicate their capacity to inhibit passage of combustion gases into the stairway resulting from the convective heat flow from the burner. A report has been prepared on this work.

7. Sprinkler Response to a Compartment Fire: A modest effort was initiated this year to examine the response characteristics of sprinkler heads at different locations in a compartment to various simulated fire growth rates. Of particular interest was the collection of empirical data on time variations for sprinklers having identical thermal link characteristics, depending on whether they

were positioned in a pendent location in the center of the room, or in a sidewall location along either a solid wall or above an open doorway. Limited measurements of temperature effects on simulated links of varying mass were also included. This work is intended to provide initial information which will lead to engineering guidelines for the use of sidewall sprinkler installations, where delays in activation due to sprinkler location may significantly affect fire control at low water supply rates. The analysis of this work is ongoing, and is expected to extend into 1981.

8. Fire Suppression Systems for Offshore Platform Blowout Fires: During 1980, an analysis of blowout fire histories was conducted to identify the key elements of the problem. As a result of this study, a project plan has been developed.

   The long range objective is to develop fire suppression systems technology for blowout fires on offshore oil and gas platforms. The objectives of the FY 81 phase of the project include development of interim design criteria for fire protection of structural members in wellhead areas. Also included is the development of an experimentally based estimation of various fire suppression techniques for large flowing hydrocarbon fires, with special attention given to the flow rates of suppression agents and the appropriate delivery mechanisms.

9. Smoke Control Systems: The smoke control project has been in operation for a number of years. During that time the work has developed along two parallel and now converging directions. Initially work was done with simple computer modeling of smoke movement in buildings. This effort builds upon the work of the National Research Council of Canada and others. At the same time field tests were conducted in actual office, apartment and hospital buildings using sulfur-hexafluoride tracer gas to study the movement of simulated smoke under a variety of mechanical systems and climatic conditions. Included in the field work were several studies of buildings equipped with smoke control systems. In each case the building was evaluated both with and without the smoke control system in operation. This allowed for comparison of the relative effectiveness of the systems compared to a building without any smoke control.

   Work has also been done to compare the results of sulfur-hexafluoride smoke movement studies to actual movement of smoke in dwellings. This work demonstrated a qualitative correlation between the simulated smoke and real smoke. Future work will involve the development of smoke control methodologies for residential application.

   The primary output mechanisms for the results of this research are through additions or changes to various voluntary standards including NFPA and the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standards.

10. Field Investigations of Smoke Control Designs: Field tests have been conducted using the sulfur-hexafluoride (SF_6) tracer gas technique to determine smoke flow patterns in various types of occupancies, including office, apartment and health care facilities. One investigation was conducted in the NIH Clinical Center in Bethesda, MD, in which both winter and summer conditions were tested. The objectives of these tests were to gain understanding of smoke flow in buildings under normal operations, and under operation of the smoke control systems. A report was completed on this work during 1980.

11. Stairwell Pressurization Systems: The use of stairwell pressurization systems has grown in the U.S. over recent years. Field tests, including sulfur-hexafluoride (SF_6) tracer gas tests, pressure-velocity tests, and smoke candle tests have been conducted in buildings in Nashville, Tennessee which incorporate multiple injection systems.

    As an adjunct to this project a computer based model was developed to simulate smoke migration in stairwells having pressurization systems. This model provides a useful tool for the design of stairwell pressurization systems in multistory buildings. A progress report of this effort was prepared during 1980.

    During 1981, a joint effort will be conducted with CSTB to verify the stairwell pressurization model with empirical data. In addition, the model will be extended to include analysis of elevators and vestibules.

12. Computer Modeling of Smoke: Two computer programs designed to model smoke movement in buildings have been developed under contract to Integrated Systems, Inc. (ISI). One of the programs, designed to evaluate steady-state conditions, is currently undergoing verification testing by comparing results with other computer models and with manual calculations. Upon successful completion of this in 1981, verification of the transient model will be initiated. These programs will serve as a basis upon which to develop a methodology for analysis of building designs in order to optimize the design of the smoke control systems.

13. Smoke Movement in Merchant Ships: This project will extend the use of the SF_6 technique to study the smoke flow patterns aboard a merchant marine ship in order to provide recommended guidelines for smoke control in such vessels.

    Field tests have been conducted using pressure mapping and SF_6 tracer gas to simulate the movement of "cold smoke". Evaluation of this data is ongoing to determine the suitability of applying smoke control techniques for buildings to merchant vessels, and necessary modifications. A progress report will be prepared during 1981.

14. Smoke Penetration through Acoustical Tile Ceilings: A project was initiated in 1980 to examine the smoke penetration of acoustical, fire rated ceilings under actual fire conditions as would typically occur in a hospital patient room. The project will determine whether smoke will penetrate the ceiling or flow into other hospital areas. A test facility consisting of four hospital rooms and a section of corridor was built within another building. The test facility has a ventilation system which will simulate the air movement from a hospital HVAC system.

Associated Grants/Contracts

"An Investigation of the Water Quality and Condition of Pipe in Existing Automatic Sprinkler Systems", H. E. Hickey and J. E. Alleman, University of Maryland.

"Waking Effectiveness of Household Smoke and Fire Detectors", E. H. Nober, University of Massachusetts.

"Mechanical Designer's Smoke Control Manual", J. Fothergill, Integrated Systems, Inc., New Brunswick, Maryland.

FIRE TOXICOLOGY RESEARCH
FIRE SAFETY ENGINEERING DIVISION
CENTER FOR FIRE RESEARCH

Professional Staff

Merritt M. Birky, Head
Maya Paabo, Research Chemist
Barbara C. Levin, Research Biologist
James E. Brown, Research Chemist
Alan Stolte, Technician
Dolores Malek, Guest Worker/JHU
Greg Smith, SPI Research Associate

Program Objective

The objective of research in fire toxicology is to reduce human fire losses from inhalation of toxic combustion products by providing test methods and recommended practices for predicting and reducing the hazard.

Project Areas

1. The development of a toxicity test method.
2. The correlation of small scale toxicity test system with large scale fire experiments.
3. The identification of specific toxic products in thermal degradation products.
4. The development of a gas generator to calibrate portable "sniffers" to be used for arson investigation (Arson).

1. Development of Toxicity Test Method

A test method has been designed to identify materials that produce "unusually" toxic and/or "super toxic" combustion products. An ad-hoc committee from industry, academia, and government was established to critique and participate in an interlaboratory evaluation (ILE) of the proposed toxicity test method.

The experimental phase of the ILE has now been completed. Seven laboratories participated and 12 materials were examined. All the laboratories tested Douglas fir (the reference material) and 4 other materials. The toxicity of the combustion products of each material was determined at three decomposition temperatures, one flaming (25°C above auto-ignition) and two non-flaming temperatures (25°C below auto-ignition and at the non-flaming decomposition temperature of Douglas fir). At each temperature, both animal incapacitation and lethality were utilized as endpoints.

The results of the ILE indicated that no statistically significant variation existed between the participating laboratories. In addition, the data showed that the classification of materials was similar regardless of whether the incapacitation or lethality endpoints were examined. The ad-hoc toxicity group agreed that a lethality endpoints based upon the 30-minute exposure and 14-day post-exposure period provides sufficient data with which to distinguish those materials which produce combustion products that are much more toxic than Douglas fir. The laboratories compared the toxicity of materials based on a statistically determined LC_{50} result. The LC_{50} is the concentration which causes lethality in 50% of the animals.

Considerable amount of planning is going into relating the toxicity data obtained from the test method to a hazard assessment. That is, the potential hazard associated with the use of a given material is not limited or determined by the toxicity of the combustion products from this material. The hazard must take into account not only toxicity but such parameters as ignitability, flame spread, heat release, smoke, etc. Incorporation of these parameters into a hazard index is the desired goal.

2. Correlation of Small Scale Toxicity Test System with Large Scale Fire Experiments

Smoldering combustion of two materials, flexible polyurethane foam and cotton, has been carried out in large scale (closed room) experiments for comparison with the protocol procedure (small scale). Chemical analysis of the products generated and animal exposures in both systems are used as basis for determining whether toxic products generated in the protocol system are consistent with self-smoldering combustion in large scale. Smoldering combustion of cotton and polyurethane was chosen since smoldering ignition of these 2 materials is the principal fire scenario that leads to loss of life.

In the case of flexible polyurethane foam, the yield of carbon monoxide (CO) and carbon dioxide (CO_2) is very nearly the same in the large scale and protocol experimental procedures. Total hydrocarbon production is somewhat lower in the large scale self-smoldering case, while hydrogen cyanide (HCN) is higher. However in both cases, the HCN concentrations are not high enough to be the primary toxicological factor. "Fingerprint" profiles of the products from the 2 types of combustion are qualitatively very similar.

Animal experiments confirm the relative significance of the CO and HCN results. However, the LC_{50} results show the protocol to be toxicologically more severe than the self-smoldering large scale experiments. The toxicological syndrome also appears to be different in the 2 cases. The cause of the difference is being pursued actively.

In the cotton comparison, the yields of degradation products between the 2 scales are very similar for CO and CO_2. Preliminary toxicological data suggest that the 2 experiments are also very similar.

3. Identification of Specific Toxic Products

The toxicity of thermal degradation products from materials containing chlorine in their structure, such as poly(vinylchloride) (PVC), is frequently attributed to compounds such as phosgene. For example, individuals in the fire services report unique toxicological products that have been attributed to fires involving vinyls. As a result of these factors, a study was undertaken to determine if phosgene is produced during the thermal degradation of PVC.

Four types of experiments were performed to approximate scenarios in which PVC is involved. They are:

1. thermal degradation of PVC in a furnace,
2. electrical over-loading of wire insulated with PVC,
3. electrical arcing between wires coated with PVC, and
4. electric-arc initiated flaming combustion in a cup furnace.

Minor concentrations (less than 5 ppm) of phosgene were found in the first two scenarios. In the third scenario, concentrations in the order of 50 ppm have been measured. A report on the identification and measurement of phosgene generated from PVC has been published (Journal of Analytical Toxicology, p. 166-173, July/August 1980).

4. Development of Gas Generator (Arson)

Combustible gas detectors, frequently referred to as "sniffers", are often used in on-the-scene fire investigations as the first step to ascertain the presence of accelerants in cases where arson is suspected. At the present time, a standard technique does not exist for the calibration of such detectors. As a result, a gas generator is being developed to be used for the calibration of combustible gas detectors. The accelerant gas generator will be used to establish a performance standard for the evaluation of the sensitivity and selectivity of detectors.

The vapors of four organic compounds have been used as calibration gases. They are: hexane, isooctane, toluene and o-xylene. These four compounds were initially chosen as a result of their prevalance as components in gasoline and other accelerants. Vapor pressure was also an important consideration since the more volatile compounds are not likely to be present after a fire has occurred. Using these four compounds, although the generation system can be used for other compounds as desired, a vapor standards system has been developed and calibrated. A report describing this research is in review. Performance evaluation of commercial sniffers is in progress using the vapor standards.

Associated Grants

University of Maryland, Maryland Institute for Emergency Medical Services, Roy Myers, "Fire Casualty Study".

University of Pittsburgh, Y. Alarie, "Toxicity of Plastic Combustion Products".

Johns Hopkins University, Z. Annau, "Evaluation of Toxicity of Combustion Products".

AD HOC WORKING GROUP ON MATHEMATICAL FIRE MODELING
CENTER FOR FIRE RESEARCH

Professional Personnel

Robert S. Levine, Chairman of Steering Committee
John A. Rockett, Chairman of Computer Committee
Irwin A. Benjamin, Chairman of Users Needs Subcommittee
James G. Quintiere, Chairman of Models Subcommittee

Note: The Modeling Committee is chaired by Professor Howard Emmons of Harvard University, and the Subprogram Committee by John DeRis of Factory Mutual.

A number of CFR personnel are members of the technical committees.

Program Objectives

The objectives of this committee are to facilitate the development and use of mathematical models of fire and to coordinate and facilitate research needed to improve the models. The steering committee includes members from other Government agencies who have influence on their agencies' R and D in this field. The coordination, of course, is voluntary.

Project Areas

Each applicable area is included in another program abstract. The major portion of the CFR effort is in the Fire Physics Research Program.

Associated Grants

1. Harvard University/Factory Mutual Research Corporation, Howard Emmons and John DeRis - "Home Fire Project"

2. Several others as listed elsewhere.

ARSON PROGRAM
FIRE RESEARCH RESOURCES DIVISION
CENTER FOR FIRE RESEARCH

Professional Personnel

Nora Jason, Technical Information Specialist
James Brown, Research Chemist
Robert Levine, Division Chief
Richard Bright, Senior Research Engineer
Bernard Levin, Research Psychologist

Program Objectives

The objectives of the Arson Program are to carry out certain specific tasks in the U.S. anti-arson program. The overall program is coordinated by the U.S. Fire Administration in FEMA, and the Law Enforcement Assistance Administration in the Department of Justice.

Project Areas

The CFR tasks include:

1. Preparation of a handbook for fire investigators (Jason and Bright)

2. A device to calibrate "Sniffers" (used by fire investigators to detect accelerants) (Brown)

3. A consensus standard for the laboratory analysis for accelerants (Brown, FY 1980)

4. Psychology of Arson (Levin)

CONTRACTS AND GRANTS

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Auburn University

Grant No.: NB80NADA1012

Grant Title: Investigations of the Safety Problems Associated with Fireplace Inserts

Principal Investigators: Professor Glennon Maples
Professor Timothy Maxwell
Professor David Dyer
Department of Mechanical Engineering
Auburn University
Auburn University, Alabama 36849

Other Professional Personnel: Thomas E. Burch

NBS Scientific Officer: Richard Peacock

Technical Abstract:

The increased popularity of fireplace inserts has brought to light a need for further investigation of the capabilities as well as the problems and limitations of the different fireplace and fireplace insert combinations. The objective of the Auburn University effort is to classify fireplace inserts according to generic types and to give some insight into their relative safety and efficiency when used in different types of fireplaces. This effort involves a laboratory testing program to evaluate the efficiency, heat output, creosoting potential, and necessary clearances for representative units from each classification. Selected units will also be field tested in homes in the Auburn area to supplement the laboratory results. It is hoped that the information obtained in this study will aid home owners in choosing equipment best suited to their needs and manufacturers in their efforts to supply safer and more efficient equipment.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Brown University

Grant No.: NBS Grant G7-9009

Grant Title: Flame Propagation and Extinction for Solid Fuels

Principal Investigator: Professor M. Sibulkin
Division of Engineering
Brown University
Providence, RI 02912

Other Professional Personnel: A. Kulkarni, Graduate Research Assistant
S. Malary, Graduate Research Assistant

NBS Scientific Officer: J. Rockett

Technical Abstract:

The objectives of this program are to advance our understanding of flame propagation and extinction for fuels involved in urban fires. An understanding of the theoretical basis of flame propagation which leads to quantitative predictions of flame spread rates is of importance in several areas of the fire problem. A knowledge of rate of flame spread on isolated components is necessary input information for the calculation of more complex room fire scenarios, and may be the determining factor in the time for fire build up to hazardous conditions. A more fundamental understanding of extinction mechanisms should enable improved methods of fire suppression to be developed more rapidly than by wholly empirical testing. In spite of the deficiencies of small scale tests, they continue to be essential for the materials development community. Our work aims to relate the results of such tests to the test geometry and the material properties. In the past we have examined the effects of gas phase extinguishing agents on propagation and extinction by a combination of experiment and mathematical analysis. Recent work is concentrating on the extinction of burning vertical surfaces. Different hypotheses as to the controlling physical mechanisms are tested by comparing the predicted conditions for extinction with the measured ones. Future work will attempt to extend these efforts to other materials and to solid phase extinguishing agents.

Work has continued on the problem of a natural convection, diffusion flame burning on a vertical fuel surface. The fuel sample is thermally thick and sufficiently small that the flow is laminar. The governing boundary layer equations are transformed to a set of ordinary differential equations using a local similarity approximation, and numerical solutions are obtained by a finite difference procedure. During the previous reporting period, results were

obtained in the thin flame limit (i.e., for infinite chemical reaction rate) with emphasis on the effects of thermal radiation from the hot fuel surface. During the present period, results have been obtained for cases having finite chemical reaction rates, and gas phase radiation has been included in the mathematical model.

Since gas phase radiation is a local heat loss mechanism, it was found (as expected) that it resulted in a reduction in the temperature level in the flame which led to a reduced convective heat flux to the wall. However, it was then found that this convective heat loss was approximately balanced by the radiative heat flux absorbed by the wall. The net result is that the burning rate was almost independent of gas phase radiation. This result differs from that found for pool burning and for larger, turbulent fires on vertical surfaces.

Since the true kinetics of hydrocarbon flame chemistry is still unknown, the process was modelled by a one-step, second-order reaction having a specific reaction rate constant of the form $k=A_g\exp(-E_g/RT)$. Calculations were made for PMMA burning in mixtures of oxygen, nitrogen and CF_3Br. The reaction rate constants A_g and E_g were treated as parameters using results from the literature as base-point values.

The results which have been obtained using this model may be summarized as follows:

(1) At conditions for which a flame exists, the burning rate is nearly independent of the chemical reaction rate. As a consequence, the mathematically simpler flame sheet theory adequately predicts burning rates. This is illustrated in Fig. 1 which shows nondimensional burning rate m_w^* as a function of ambient oxygen mass fraction $Y_{O,\infty}$. (The calculation includes PMMA surface radiation.)

(2) The extinction limit depends upon two parameters for a prescribed fuel-gas system, viz., the chemical reaction rate and the rate of heat loss from the fuel surface by thermal radiation. Surface radiation can lead to extinction even in the limit of infinite reaction rate.

(3) Experiments made using N_2 and CF_3Br as gas phase extinguishing agents had shown that, at the same oxygen concentration, the effect on burning rate was nearly the same; the effect on extinction, however, was significantly different. This qualitative behavior is reproduced by the calculated results when the "chemical effect" of CF_3Br is modelled by reducing the chemical reaction rate. These results are shown in Fig. 2.

Reports and Papers:

"Effect of chemical reaction rate on burning and extinction of wall fires," by A.K. Kulkarni and M. Sibulkin, Eastern Section Meeting of The Combustion Institute, Nov. 1979.

"Effects of radiation on the burning of vertical fuel surfaces," by M. Sibulkin, A.K. Kulkarni and K. Annamalai, Eighteenth Symp. (Int.) on Combustion, 1980 (in press).

"Burning on a vertical fuel surface with finite chemical reaction rate," by M. Sibulkin, A.K. Kulkarni and K. Annamalai (submitted for publication).

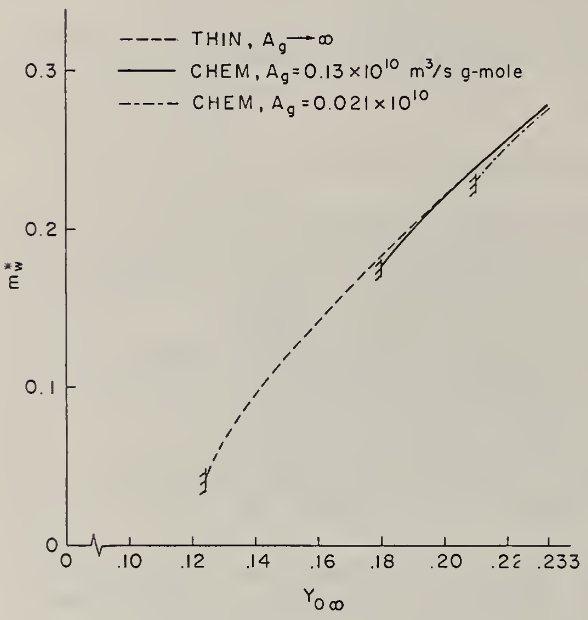

Fig. 1. Burning rate and extinction limit as a function of ambient oxygen concentration for three chemical reaction rates. E_g=180 kJ/g-mole.

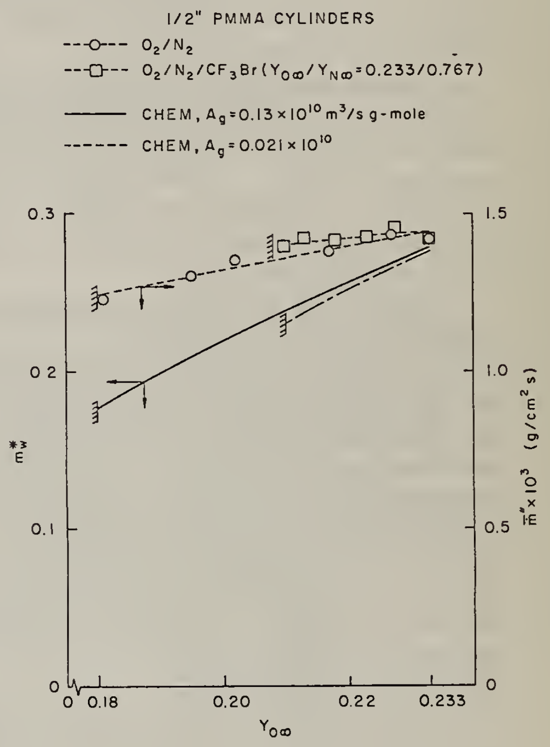

Fig. 2. Comparison of calculated burning rate behavior with measurements on vertical, PMMA cylinders. E_g=180 kJ/g-mole in calculated cases.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: California Institute of Technology

Grant No: NBS Grant G8-9014

Grant Title: Experimental Study of the Environment and Heat Transfer in a Room Fire

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Technical Abstract

We are investigating a number of fluid dynamic and chemical processes which occur in the early stages of a fire located in one room of a multi-room structure. Under these conditions it is often possible to divide the gas in any room into an upper layer which contains hot combustion products diluted with air, called here the ceiling layer, and a lower layer where the gas is cooler even though it may also be contaminated by combustion products. In order to be able to describe the growth of a fire in such a room, we must be able to predict the history of the height of the interface between these layers and the temperature of gas in the layers. To do this, we must be able to describe the turbulent heat and mass transport processes which take place between the layers, and between the layers and the surrounding structure.

At present we are investigating experimentally several mass and energy transport processes. We have spent most of the past year studying the entrainment rate of fire plumes both far from the fire and in the neighborhood of the fire. In addition, we are studying the mass and energy transfer processes which occur between the two layers as a result of flows into and out of a room through various openings. We have also completed our work on convective

heat transfer produced by the impingement of a fire plume on a ceiling when a ceiling layer is present. Finally these processes are being modeled and the models are being used in the development of a simple computer code which will allow the prediction of the interface heights and layer densities in a multi-room structure due to a fire of specified but unsteady heat release rate located in one room.

The results of this work will also be used in more complete models of fire spread. The development of a reasonably complete computer model for the prediction of the rate of spread of combustion products and fire through a complex structure is a primary aim of this research work. This code will allow quantitative assessments of risk to be made and will become a major factor in fire safety design work.

The following paragraphs describe in more detail the work now in progress at Caltech concerning fire-plume entrainment.

Experimental Approach

The problem we have been studying is illustrated by the sketch of Figure 1. A fire with average height Z_f is present in a room

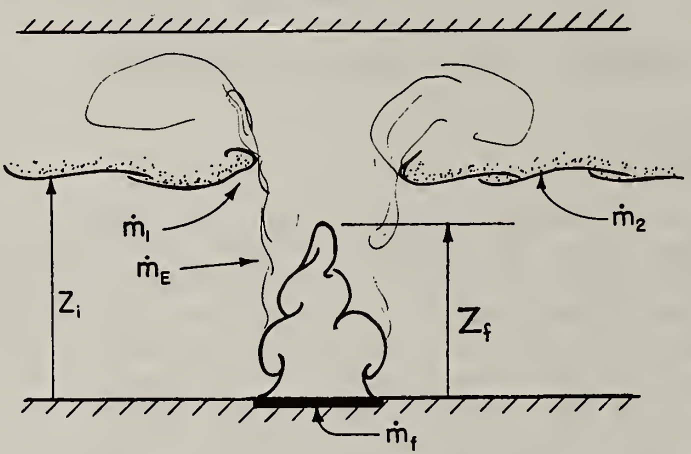

Figure 1

and has produced a ceiling layer with an interface height Z_i. In the early stages of the fire, the hot products of combustion are usually segregated in a well stirred ceiling layer whose properties are roughly homogeneous. The flame and the buoyant plume it produces entrain cool air from the room, $\dot{m}_E$, and heat it in the fire by combustion processes and in the plume by mixing with the hot plume gas. This heated gas is buoyant and flows into the ceiling layer at a rate $(\dot{m}_E + \dot{m}_f)$. Other gas may flow into the ceiling layer as a result of the disturbance produced by the plume as it plunges into the ceiling layer $(\dot{m}_1)$ or as a result of other mixing processes which may occur at the interface separating the hot ceiling layer from the cool air layer $(\dot{m}_2)$. Thus, the total mass flux to the ceiling layer, $\dot{m}_C$, will be the sum of these contributions,

$$\dot{m}_C = (\dot{m}_E + \dot{m}_f + \dot{m}_1) + \dot{m}_2 \quad .$$

The terms $(\dot{m}_C + \dot{m}_f + \dot{m}_1)$ are directly associated with the fire plume and are called the plume mass flux $\dot{m}_p$. We need to be able to describe this flux as a part of any model which is used to predict the behavior of the early stages of a fire. Because the interface between the hot and cold gas is stabilized by the gravitational field we expect that the mass entrainment rate at the interface far from the fire, $\dot{m}_2$, will often be negligible in the absence of some other active mixing process such as air flow through a door or window.

The primary purpose of our experiment is to measure the plume related mass flux, $\dot{m}_p$. This is accomplished by use of a hood shown schematically in Figure 2. The interface level of the

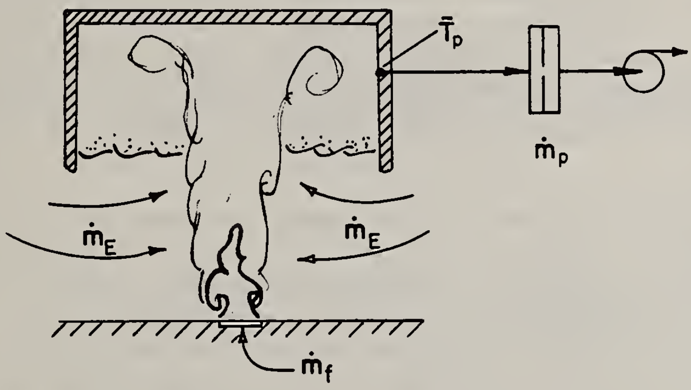

Figure 2

ceiling layer in the hood is maintained at a constant height above the fire by withdrawing a suitable flow of hot ceiling layer gas from the hood. The hood is made large enough to insure that the gas in the hood is kept relatively quiescent so that it will not entrain air at the interface ($\dot{m}_2$ of Figure 1). When this entrainment can be neglected, a simple conservation of mass argument shows that the mass withdrawal rate required to maintain a fixed interface height is the plume mass flux $\dot{m}_p$.

The top of the flame shown in Figure 1 lies below the interface (i. e., $Z_f < Z_i$); in many interesting situations it may lie well above the interface and then the flame must depend on the vitiated ceiling layer gas for its oxygen supply. We expect that the geometry of the flame is an important parameter in the problem and that we must be able to predict at least the flame height as part of the solution of the entrainment problem.

Experimental Results

The results of experiments show that a simple Boussinesq model can be used to give a useful prediction of plume mass flow, $\dot{m}_p$. The form of the results is:

$$\dot{m}_p = \alpha \rho_\infty \sqrt{gZ}\, Z^2 (Q^*)^{1/3} \quad \text{where} \quad Q^* = \dot{Q}/\rho_\infty Cp_\infty T_\infty \sqrt{gZ}\, Z^2$$

and α is a parameter. Here, ρ_∞, T_∞ and Cp_∞ are the density, temperature, and specific heat of the ambient fluid, Z is the elevation above the base of the fire, g is the gravitational constant, and $\dot{Q}$ is the heat release rate of the fire. For the "far field" (where $Z_i \geq 2 Z_f$) the constant α has values which range from 0.25 for the 0.5 m burner to 0.19 for the 0.1 m burner. The value 0.21 appears to be a useful average value. As the interface height approaches the flame height, the value of the parameter α decreases and, for $0.8 \leq Z_i/Z_f \leq 1.5$, it is in the range 0.16 to 0.18.

We have determined that for $0.8 \leq Z_i/Z_f \leq 10$, α is almost independent of the heating value of the fuel for the range 15 to 50 kJ/kg, and that aerodynamic disturbances can produce 50 to 100% increases in α. In addition, proximity to a wall can have a large effect when the plume is attached to the wall. An interesting deduction from the data is that the fuel-air ratio at the top of the flame is close to .06 of the stoichiometric value for a wide range of conditions.

The results described above are presented in detail in ref. 2.

We have also begun to study entrainment in the range $0 \leq Z_i/Z_f \leq 0.8$ and preliminary results suggest that α is of the order of 0.15 for $0.4 \leq Z_i/Z_f \leq 0.8$ and increases by factors of 2 to 4 as Z_i/Z_f approach zero. Visible soot is present in the combustion products when the fuel-air ratio of the ceiling layer gas rises above 80% of the stoichiometric value and flames appear at the interface at about 100%. For lower values of the fuel-air ratio, combustion appears to be complete even when $Z_i/Z_f \leq 0.25$. These preliminary results were obtained in a small hood and probably depend on the size of the hood and gas temperature in the hood which is affected by heat losses.

References and Reports

Zukoski, E.E. and Kubota, T. "Two-Layer Modeling of Smoke Movement in Building Fires", Fire and Materials, Vol. 4, No. 1, 1980, pp. 17-27.

Zukoski, E.E., Kubota, T. and Cetegen, B. "Entrainment in Fire Plumes", California Institute of Technology, April 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Case Western Reserve University

Grant No.: DA-1017

Grant Title: Flame Spread and Spread Limits

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NBS Scientific Officer: Dr. James G. Quintiere

Technical Abstract

Most fires start from a small ignition source. The initial flame will spread and grow in size if the environment is favorable. The limiting conditions for a flame to spread and the manner in which a flame propagates are directly related to fire safety.

A theoretical model for flame spread limits in opposed flow has recently been published [Frey and T'ien, Combustion and Flame, 36: 245-262 (1979)]. In that work, a one-step finite rate gas-phase chemical reaction and fuel-pyrolysis kinetics are included in the formulation. Flame extinction limits, due to increased opposed velocity, reduced pressure and reduced ambient oxygen, are all obtained in the results calculated from this theory. Systematic examination of the detailed computed profiles also reveal the extinction mechanism. In all cases, as extinction is approached, the extent of chemical reaction decreases within one gas-phase thermal length (i.e., preheating distance) and the gas flame is shifted downstream (non-dimensionally) relative to the pyrolysis zone. As a result, less heat from the flame goes to preheat the fuel, less fuel vapor is produced in the preheat zone and a lower flame spread rate occurs until finally the flame is extinguished.

So far, experimental results from several independent investigations tend to support the basic formulation of the above-mentioned theoretical work. The near-term objective of this research is to extend this model for more practical applications. Two new elements will be added to the theoretical model. The first is an external radiant flux term. This will be used to simulate the well-known radiant panel test for floor coverings and other materials. The second is the effect of additives in solid fuels on the extinction limits. Both should have practical implications on material flammability.

The longer range objective is to formulate and to solve the extinction problem in downwind flame spread.

Since the project is in its very initial phase, no progress can be reported at this time.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Clemson University

Grant No.: NBS Grant NB79NADA0011

Grant Title: Antimony Oxide-Organohalogen-Polymer Substrate Interactions in the Solid Phase

Principal Investigator: Dr. M. J. Drews
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NBS Scientific Officer: Dr. R. Gann

Technical Abstract:

The objective of this proposed research was the characterization of the pyrolytically initiated reactions among antimony oxides, organohalogens and polymer substrates in the solid phase. The role of the polymer substrate in the generation of volatile antimony halides and oxyhalides was to be elucidated. These results would then be used to delineate the relative importance of the solid phase (as compared to gas phase) reactions in the flame retardant efficiency of antimony oxide/organohalogen additives and finishes. The effect of antimony oxide/organohalogens on oxidative surface reactions occurring in the polymer substrate melt were also to be explored. The organohalogens studied were organobromine derivatives since, in general, they are more efficient flame retardants than chlorinated organics of comparable structure. In addition, several reactions postulated as important in the retardant mechanism for chlorinated organics are more exothermic for brominated organics and, therefore, more thermodynamically favorable for the brominated analogs.

The research plan followed was initially divided into two phases. The first phase was to consist of the study of the interaction between antimony oxides and the model organohalogen compounds. In the second phase, the effects of the three polymer substrates on the antimony oxide/organohalogen reactions characterized during the first phase were to be determined. However, as the research progressed, it became apparent that it would be necessary to more completely characterize the decomposition behavior of the additives themselves, the polymer substrates, and the polymer:organobromine binary mixtures. All of these rameters were not considered in the initial research plan to be as significant as the early data suggested that they might be. In addition, the dramatic effects observed on going from a purely pyrolytic

to an air oxidative environment were such that these experiments were considered to have been beyond the scope of the original research plan. As a result, the work reported on here is concerned only with the characterization of the decompositions of the individual components and their binary mixtures.

The thermal reactive characteristics of the polymer substrates and organobromine additives were the primary considerations used in choosing materials for this study. For the polymer substrates, the principal considerations were thermal stability, mode of depolymerization, and presence of labile hydrogen atoms. The criteria used in selecting the organobromine additives were thermal stability, potential for in situ fixation during pyrolysis, and intramolecular hydrogen bromide release.

Based on these criteria, the polymer substrates chosen to be employed in this study were polymethylmethacrylate (PMMA), polypropylene (PP), and polyethylene terephthalate (PET). The decomposition of PMMA is characterized by relatively low thermal stability and a chain unzipping mechanism producing primarily monomer. Polypropylene exhibits intermediate thermal stability and random chain scission, producing a sequence of volatile components differing primarily in molecular weight and site of homolytic bond cleavage. Polyethylene terephthalate exhibits relatively high thermal stability and a random chain scission decomposition involving primarily heterolytic bond cleavage.

Of the organobromine additives studied, decabromodiphenylene oxide (DBDPO) exhibits the highest thermal stability, has no potential for forming intramolecular hydrogen bromide, and appears to volatilize without decomposition. Hexabromocyclododecane (HBCD) has relatively low thermal stability, a low temperature release of hydrogen bromide, and a complex subsequent degradation mechanism. Several different classes of brominated flame retardants were screened using thermal analysis before tetrabromobisphenol-A was chosen as the third organobromine additive to be used in this study. In addition to its intermediate thermal stability, tetrabromobisphenol-A has the potential for undergoing an in situ fixation via a trans-esterification reaction during the pyrolysis of PET.

The thermolysis and/or volatilization of the organobromine additives DBDPO, HBCD, and TBBPA, as well as the polymer substrates PMMA, PP, and PET, were studied by thermal gravimetric analysis, pyrolysis gas chromatography and pyrolysis in the direct insertion probe of the mass spectrometer. In addition, binary mixtures of organobromine additives and either the polymer substrates or antimony oxides were studied. In the thermal analysis experiments the heating rate was varied from 2^{o}C per minute to over 100^{o}C per minute. In addition, pyrolysis under nitrogen was carried out under isothermal conditions from 270^{o}C to 480^{o}C. The bromine to antimony mole ratio was varied from 1.5:1 to 3:1. The products of the TGA thermolysis experiments were characterized by trapping the volatile bromide species produced, analyzing for the ionizable antimony species volatilized, determining the distribution of antimony among the TGA sample pan, the TGA furnace tube, and the bromide ion trap. In addition, volatiles were trapped and their infrared spectra and their gas chromatographic separation patterns recorded and compared.

Based on the results of these experiments, it is possible to draw some conclusions concerning the nature of the reactions necessary to form volatile antimony species under pyrolytic conditions in the presence of an organobromine additive. The heating rate was found to have no discernable effect on either the individual component, major decomposition product distributions, or the extent of component interaction in the binary mixtures.

Hexabromocyclododecane was observed to dehydrohalogenate on heating above 250°C to produce HBr which interacted directly with antimony trioxide to generate volatile antimony halide and oxyhalide species. In the presence of antimony trioxide, a catalytic effect on the rate of dehydrohalogenation was observed. With all three polymer substrates the amount of free HBr released was found to decrease rather than increase.

Tetrabromobisphenol-A was determined to undergo in situ fixation when pyrolyzed in the presence of PET but not either PP or PMMA. In the presence of PET this in situ fixation results in an apparent increase in the hydrogen bromide release. Antimony trioxide appears to catalyze the dimerization of the TBBPA, producing a less volatile species which consequently undergoes more extensive degradation resulting in an increase in hydrogen bromide release and residue formation.

No significant interaction was found to have occurred between decabromodiphenyl oxide and any of the polymer substrates or Sb_2O_3.

Based on the results of this study to date, it appears that for the organobromine additives studied here, if no intramolecular HBr is produced, then no volatilization of antimony occurs when the antimony is present as Sb_2O_3 in the initial mixture. Perhaps more significantly, with the exception of the binary mixture of TBBPA and PET, at no time was the polymer substrates observed to interact with the organobromine additives in such a way as to increase the amount of hydrogen halide generated during pyrolysis over that which occurred for the organobromine additive alone under the same experimental conditions. Even in those cases where the temperature of the maximum rate of weight loss of the additive and the polymer coincided, there were no dramatic increases noted in the generation of hydrogen halide during pyrolysis. The results to date appear to emphasize the potential importance of the ternary reaction, which apparently must occur between the antimony oxide/polymer substrate and organobromine additive to generate the required volatile antimony halide and oxyhalides, during the decomposition of the flame retarded polymer substrates. This must especially be important for additives such as DBDPO which do not, either by themselves or in simple binary mixtures, undergo condensed phase reactions consistent with current theories regarding organohalogen/antimony oxide flame inhibition.

Consequently, it is anticipated that once the solid phase ternary reactions between polymer substrate-organohalogen-antimony oxide are characterized with respect to organohalogen and polymer functionality, these results will lead to a better understanding of the system parameters necessary for more efficient and safer flame retardation of thermoplastic materials. In addition, the results of this work could provide the basis for new studies into the role of antimony oxide itself in flame retardant formulations.

Reports and Papers:

Jarvis, C. W., Drews, M. J., and Leibner, J. E., "Organobromine/Antimony Oxide/Polymer Substrate Interactions in the Solid Phase. Part I." Binary Interactions, Organic Coatings and Plastics Preprints, 43, 000 (1980).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Factory Mutual Research Corporation

Grant No.: NB79NADA0014

Grant Title: Determination of Fuel Parameters for Fire Modeling

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Mr. R. F. Pion, Assoc. Research Scientist

NBS Scientific Officer: Dr. David D. Evans

Technical Abstract

Generalized relationships are being developed for fuel parameters as functions of fuel structures and experimental variables for fire modeling, hazard evaluation, and analysis of fire test data. The parameters are being examined under the following variable experimental conditions: fuel size (about 0.1 m and 0.3 m in diameter in a horizontal pool configuration, and up to about 1 m in height in the vertical wall configuration); air velocity; oxygen concentration; external heat flux, $\dot{q}''_e$; and water application rate. The fuels being examined are: 1) granular polymers - polyoxymethylene, polyethylene, polypropylene, polystyrene, polymethyl methacrylate, polyvinyl chloride, chlorinated polyethylene, and nylon; 2) solid polymers - red oak and Douglas fir, with and without fire retardants; 3) foamed polymers with and without fire retardants - flexible and rigid polyurethanes, polyisocyanurates, polystyrenes, phenolics, and polyethylenes. Special emphasis is placed on char-forming fuels.

The following parameters are being quantified as functions of experimental variables:

1) Ignition energy, E_{ig}, and fraction β, of external heat flux supplied and/or removed by sources other than external heat source in the ignition process. The ignition process is characterized in terms of $E_{ig}/1+\beta$. In addition, the critical mass loss rate and heat release rate for ignition and flame extinction, $\dot{m}''_c$ and $\dot{Q}''_c$ respectively, are also being quantified. For several fuels, the relationships between $E_{ig}/1+\beta$, $\dot{m}''_c$, and $\dot{q}''_e$ have been examined[1]. $E_{ig}/1+\beta$ appears to be a useful quantity for the examination of flame spread data such as from the ASTM E-162 radiant panel test and the ASTM E-84 tunnel test as well as ignition data reported in the literature. β appears to depend on test conditions, whereas E_{ig} appears to be independent of test conditions. $\dot{m}''_c$ lies between about 3 to 5 g/m^2s for piloted ignition and appears to be independent of the physical and chemical properties of the fuels and the experimental conditions.

2) Heat required to generate a unit mass of fuel vapors, L, flame radiative and convective heat flux to the fuel surface, $\dot{q}''_{fr}$ and $\dot{q}''_{fc}$ respectively, and surface heat losses, $\dot{q}''_{rr}$. For several fuels, the relationships between $\dot{q}''_{fc}$, $\dot{q}''_{fr}$ and oxygen concentration have been examined[2,3]. Under combustion dominated by radiation, it appears, for many types of fuels, that the mass loss rate, $\dot{m}''_b$, can be expressed as $\dot{m}''_b \approx K\ (\dot{q}''_e + \dot{q}''_{fr})/L$, where K is a constant. This expression has been found to be useful for the examination of large-scale fire test data, for example, in the U.S. Bureau of Mines large gallery fire tests performed at Factory Mutual.

3) Net heat of complete combustion, H_T, combustion efficiency, χ_A (including its radiative and convective components, χ_R and χ_C, respectively). H_T/L is one of the fundamental properties of the fuel, independent of experimental conditions. The heat release rate is given by $\dot{q}''_n\ \chi\ H_T/L$, where $\dot{q}''_n$ is the net heat flux absorbed by the fuel; $\dot{q}''_n$ and χ depend on the experimental conditions. For many types of fuels, the relationships between the heat release rate and $\dot{q}''_n\ H_T/L$ are being developed. It appears that fuels follow the relationships according to

their chemical structure, i.e., non-aromatic, aromatic, and highly chlorinated. The relationships are useful for fire modeling, fire hazard evaluations, estimation of magnitude of heat in fire scenarios, determination of human escape potential and operation of fire sensing devices[4]. It has also been possible to examine the data from other heat release rate apparatus such as the Ohio State heat release rate apparatus and large-scale fire tests.

4) Elemental composition of the fuel and yield of products, Y_j (j = CO_2, CO, total hydrocarbons, soot, low-vapor pressure liquids, NO_X, HCl and HCN only). Y_j is equal to $\alpha_j k_j$, where k_j is the stoichiometric yield of the product and α_j is the fraction of the stoichiometric yield. k_j/L is a fundamental property of the fuel, independent of experimental conditions, whereas α_j is dependent on experimental conditions. The product generation rate is given by $\dot{q}''_n\ \alpha_j k_j/L$, where $\dot{q}''_n$ is the net heat flux absorbed by the fuel. For many types of fuels, the relationships between the individual product generation rate and $\dot{q}''_n\ k_j/L$ are being developed. It appears that fuels follow the relationships according to their chemical structure, i.e., non-aromatic, aromatic, and highly chlorinated. The relationships are useful for fire modeling, fire hazard evaluations, estimation of concentration of products in fire scenarios, determination of human escape potential and the operation of fire sensing devices. It has also been possible to examine data from large-scale fire tests.

5) Optical density, $D = \ell n\ (I_o/I)/\ell$, where ℓ is the optical path length and I and I_o are optical transmission in the presence and absence of the products. D depends on the mass loss rate, $\dot{m}$, total volumetric flow rate of product-air mixture, $\dot{V}_T$, fraction of the products in the mixture responsible for light obscuration, η, and wavelength of light, i.e., $D = k\eta\dot{q}_n/L\ \dot{V}_T$. The relationship between D and $\dot{q}_n/L\ \dot{V}_T$ is being examined for a variety of fuels and it appears that the fuels follow this relationship according to their chemical structure, i.e., non-aromatic, aromatic, and highly chlorinated.

For fire testing of materials on a small-scale, the parameters described are expressed in terms of indices such that only a few simple tests are required, on the basis of which relative fire hazard of materials can be evaluated[5].

An attempt is currently being made for the establishment of parameters for flame extinction by water sprays and by reduced oxygen concentration.

Reports and Papers

1. Tewarson, A., "Ignition of Polymeric Materials" - in preparation for J. Combustion and Flame.

2. Tewarson, A., Lee, J.L., and Pion, R.F., "The Influence of Oxygen Concentration on Fuel Parameters for Fire Modeling," 18th Symposium (International) on Combustion, The Combustion Institute, August 1980 (to be published).

3. Tewarson, A., Lee, J.L., and Pion, R.F., "Flame Radiation and Convection from Nitrogen and Chlorine Containing Polymers" in preparation for J. Combustion and Flame.

4. Tewarson, A., "Heat Release Rate in Fires", J. Fire & Materials (to be published).

5. Tewarson, A., "The Factory Mutual Combustibility Apparatus for Reliable Fire Testing of Materials on a Small Scale", Modern Plastics (to be published).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Harvard University, Factory Mutual Research Corporation

Grant No.: NBS Grant 7-9011

Grant Title: The Home Fire Project

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NBS Scientific Officer: Dr. John Rockett

Technical Abstract

The purpose of this project is to develop a flexible procedure with which to predict the progress of a fire ignited in an enclosure, however complex. The calculations are carried out with a deterministic mathematical "model" of the physics, and are of arbitrary accuracy. This explicitly includes the calculation of ignition of secondary fires, development of flashover, and the transport of toxic (and other) substances throughout the house, building, or other enclosure. This model constitutes a powerful tool for several purposes, and primarily for establishing the fire safety of given house designs. This (obviously) results from knowing whether a particular design and configuration will lead to flashover or not; if it does, it will tell us how much time it will take between ignition and flashover, how much time between activation of a smoke alarm and flashover. It will tell us how dangerous a smoke layer is from the point of view of radiation, toxicity, and impairment of visibility. And so on.

To this end, research proceeds in two main areas: a. The devel-

opment of a large-scale computer program which solves the equations describing the principal relevant phenomena, and which thereby gives the evolution of a fire from its inception to burnout or extinguishment. b. Development of the understanding of the dynamics (physics, chemistry) involved in fire and its associated phenomena: the structure of turbulent flames, spread of fire over various surfaces, mixing of hot and cold gases at openings, etc. These basic research tasks are carried out in part at the Factory Mutual Research Laboratories and in part at Harvard University. The knowledge gained is then utilized in the mathematical model.

Task 1: Burning of Pool Fires in Vitiated Air

Task Leader: Dr. Franco Tamanini, FMRC

Technical Abstract

The main objective of this task is to determine the effect of decreased oxygen concentration on the gas-phase burning distribution and heat transfer characteristics of flames above pool fires. In order to better simulate realistic conditions, the decrease in oxygen concentration is obtained by mixing ambient air with the products of combustion from a propane flame. At the time of this writing we have completed construction, debugged and calibrated the experimental facility. It consists of a 1.2 m diameter, water-cooled enclosure which is designed to allow testing with pool sizes up to 0.4 m in diameter. The inlet air supply can provide $0.32 m^3/s$ of air (670 cfm) at oxygen concentrations in the range from 21% (ambient) to 17% by volume. This design point was selected to assure that it would be possible to supply 30 times the stoichiometric (ambient) air requirement of a 40 kw flame. Because of the size and relative complexity of the facility, we have devoted considerable effort to insure that experiments can be run safely by a single operator. For this reason we have implemented a series of automatic controls for flow and flame monitoring, as well as safety interlocks. All these features are now fully operational and have been found to perform as planned.

This combustion facility will certainly find a range of applications which go beyond the scope of our present study. At the moment we are concentrating on making measurements of the distribution of O_2, CO, CO_2, H_2O and total hydrocarbons (unburnt fuel being a very important species to monitor) as a function of height in propane jet flames. These measurements are made by drawing the flame gases through a heat exchanger which quenches the reaction, and by analyzing the mixture collected downstream of this catcher-quencher device. Our current efforts are addressing the question of the dependence of the measured flows of major species on the amount of suction applied through the heat exchanger. For the acquisition of concentration data we are using a new piece of equipment, consisting of fast-response ($\sim$ 1 second) continuous analyzers and a sampling system which can multiplex 8 gas lines. We are developing a digital interface which will allow us to operate the gas analysis and gas sampling equipment using a low-cost computer (Commodore 2001-32N).

The measurements of total flow of unburnt fuel and products as a function of height in the flame provide needed experimental data to our theoretical work. The aim of the theory is to develop an integral approach for the prediction of turbulent fire plumes. We have made progress in this area by adapting the k-ε-g model of turbulence to the integral approach: our results for jet flames show good accuracy in the predictions with a saving of almost two orders of magnitude of computing time over the 2-D approach.[(1)]

We are currently monitoring the radiation emitted by horizontal slices of the flame using a slit radiometer. We anticipate that we will soon start additional measurements, particularly of the radiative properties (Schmidt temperature and absorption coefficient) of the flame gases. Earlier results obtained in a smaller enclosure (0.76 m diameter) with PMMA 0.3 m diameter pool fires have been analyzed and will be presented at the 18th Combustion Symposium.[(2)] These tests, which were carried out in nitrogen-diluted ambient air, have provided guidance for the planning of measurements of radiative properties of flames in the present program. We belive that these results as well as those from the gas analysis data are necessary inputs which are required for validation of models of enclosure fires.

Reports and Papers

1. Tamanini, F., "An Integral Model for Turbulent Fire Plumes", Paper accepted for presentation at the 18th International Symposium on Combustion, University of Waterloo, Canada, 17-22 August 1980.

2. Santo, G., and Tamanini, F., "Influence of Oxygen Depletion on the Radiative Properties of PMMA Flames," Ibid.

Task #2a: The Prediction of a Fire

Task Leaders: Dr. Henri E. Mitler, Professor Howard W. Emmons, H.U.

Other Professional Personnel: B. London

Technical Abstract

Our mathematical model computes the development of a fire ignited on a horizontal surface, in a vented enclosure. The calculation can be carried forward as far as desired, through burnout and cooldown. Fairly thorough discussion of the problem, plus a bibliography, are given in references 1, 2 and 3.

Progress of the program in the last year has occurred in three areas:

1. Numerics: A very substantial improvement in speed of convergence has been obtained by changing from the Jacobi to the Gauss-Seidel version of our successive-substitution method. A further improvement

has resulted from making this method more "robust" by using a damping constant after a small number of iterations. The "predictor" calculation has been optimized. Finally, variables are now prevented from wandering or oscillating beyond physically reasonable bounds; this also contributes materially to the stability of the calculation.

2. Physics: A subroutine has been written which gives a fast-spreading ignited fire. Another, which overcomes a previous difficulty with spread-rate for large fluxes. The calculated smoke concentration has been used to find the absorptivity of the layer. Radiation to vertical surfaces has been incorporated. Improvements have been made in the pool fire subroutine, so that it runs more smoothly. An improved expression for radiative absorption by the layer has been derived, but not yet incorporated; perhaps by the end of the summer this will be in. The same remarks apply to the calculation of the H_2O, particle, and unburnt fuel concentrations in the layer; once these have been found, Modak's absorptivity subroutine can be used. Flame-flame interaction is being studied now, and (hopefully) will be incorporated by August. The new VENT routine has been programmed and checked out for one room; it is to be incorporated into the overall program by August. Considerable progress has been made with the multi-room version, but substantial problems remain in inserting it into the Computer Fire Code as it is structured at present.

3. Program Structure: A new INPUT routine has been written which is much more convenient to use, and which permits correction of any input errors (data or syntax). An improved wall-indexing arrangement developed last summer has finally been successfully incorporated. The option to use "Newton Fast" has been dropped, with a consequent simplification in the program. The large number of COMMONS is being halved, and the program "cleaned up," as well as documented.

Finally, we might mention that an improved and generalized treatment of experimental data has been devised, which permits us to extract a mean layer depth and temperature from an array of thermocouples in a room.

References

1. Emmons, H.W., Mitler, H.E., and Trefethen, L.N. Jr., "Computer Fire Code III," Home Fire Project Technical Report No. 25, Harvard University, January 1978.

2. Mitler, H.E., "The Physical Basis for the Harvard Computer Fire Code," Home Fire Project Technical Report No. 34, Harvard University, October 1978.

3. Mitler, H.E., "Computer Fire Code IV," Program Tape, Harvard University, 1979.

Reports and Papers

1. Emmons, H.W., "Scientific Progress on Fire," Am. Rev. Fluid Mech. 12:223-36, 1980.

2. Emmons, H.W., "The Growth of Fire Science," Plenary Lecture, Symp. on Advances in Fire Physics, Washington, D.C., April 14- 18, 1980.

3. Mitler, H.E., "Computer Fire Code IV," Program Tape, Harvard University, 1979.

Task #2b: A Study of Computer Code Structures and Organization

Task Leader: John Ramsdell, Harvard University

Technical Abstract

We want to restructure the fire program with three goals in mind:

1. To improve transportability,
2. reduce the difficulty of modifying the program, and
3. reduce the numerical work required to find a solution at each time step.

Transportability: This can be improved in two ways. First, the fire code should be written assuming most of the users will run the program in batch mode. Second, the fire code should be written in one uniform, consistent language. FORTRAN 77 should be considered.

Program Modification: At present, it is difficult to incorporate a new physical subroutine into the fire code. The basic reason for this is that logical divisions between sections of code have been blurred by programmers interested in writing the code fast rather than logically, with a consequent difficulty in introducing new variables. A problem with the code is the large number of common blocks that also blur logical boundaries of the program. There perhaps should be no common blocks in the physical subroutines. We should redo the indexing scheme of the program in such a way that any contributor of a physical subroutine to the fire program need not know the details of how indexing is done in the code.

The efficiency of the numerics can be improved by eliminating variables,as discussed in other reports,and by carrying out numerical integrations in the numerical routines. One can take advantage of knowing which variables are integrated because they have different convergence properties and never need be put through a Newton-like root-finding routine.

Progress: I have written a small and incomplete fire program implementing most of the ideas above. The code is meant to test a vent routine for a many-room single-story building, but it also is a model for what I believe is a better and well-structured fire code. The code was written in PASCAL rather in FORTRAN 77, because (a) a compiler for the latter is not yet available to us, and (b) I wanted to use a struc-

tured language to study the structure problem. A clear top-down description of the fire code has been written, and it will not be long before these ideas are implemented.

Task #3: Radiation from Pool Fires

Task Leader: Dr. Ashok T. Modak, FMRC

Other Professional Personnel: L. Orloff

Technical Abstract

Fire prevention engineers often need to estimate (1) fire growth and peak burning rates, (2) time to ignition of remote fuel elements, and (3) the influence of sprinklers and reduced enclosure oxygen on these quantities. In each case the underlying problem is the evaluation of burning rates for fuels in their sundry arrangements. Flame radiation is a fundamental aspect of this problem, because in realistic fire situations, radiation is the principal (80-95%) mode of heat transport to the fuel. The present program investigates modeling thermal radiation from pool fires.

The objective of developing engineering calculations[1,2] that are both relatively simple and generally applicable to a broad range of practical fires is currently being pursued in this program. Detailed studies[3,4] have shown that pool fires are inhomogeneous and nonisothermal. For simplicity, however, it is desirable to be able to treat these fires as if they were homogeneous and isothermal. A simplified model is developed to describe these fires by an equivalent homogeneous, isothermal, spectrally grey volume of flame gases defined by a composite flame shape. Input parameters are 1) the axisymmetric flame shape for particular fuel scale, and configuration derived from photographs; 2) an averaged absorption-emission coefficient, $\bar{k}_f$, from flame transmittance measurements; and 3) an averaged flame temperature, $\bar{T}_f$, from measurements with a radiometer viewing the flames through a horizontal slit. The averaging of radiative properties accounts for most flame inhomogeneities.

Simple analytic expressions are provided for calculations of radiative feedback to the fuel surface and radiant transfer to targets away from the fire. Results of those analytic calculations are in good agreement with exact numerical computations and with experiments.

The simplified model is verified with measurements on 381 mm and 730 mm diameter PMMA pool fires. A two-fold variation in average pyrolysis rates is induced at the 381 mm scale by systematic variation of the distance between the fuel surface and the container lip.

Composite photographic flame shapes are obtained for seven 381 mm diameter pool fires with lip sizes between 0 and 76 mm, and for one 730 mm pool with a 13 mm lip. Identical averaged radiation property parameters $\bar{k}_f$ (= 1.55 in.$^{-1}$ for PMMA and $\bar{T}_f$ = 1260 K for PMMA) are used with those respective flame shapes. Calculated radiant feedback and radiant transfer to target locations are in good agreement with measurement for PMMA pool fires.

For PMMA pool fires this equivalent homogeneous model appears to be satisfactory for diameters at least up to 0.73 metres. Highly sooting fires (e.g., polystyrene) are, however, likely to be considerably more inhomogeneous than PMMA. Several current studies are directed towards generalizing and further simplifying existing radiation models to be able to account for more sooty fuels than PMMA and larger diameters than 0.73 inches.

Reports and Papers

1. Orloff, L., 18th Int. Comb. Symp. "Simplified Radiation Modeling of Pool Fires", 1980 (in press).

2. Orloff, L., "Simplified Radiation Modeling of Pool Fires," Factory Mutual Technical Report, RC80-BT-9, 1980.

3. Markstein, G. H., 17th Int. Comb. Symp. "Radiative Properties of Plastics Fires", p. 1053, The Combustion Institute. 1979.

4. Modak, A. T., "The Burning of Large Pool Fires", Proceedings of Advances in Fire Physics Symp, April 14-15, 1980. (in press)

Task #4: Study of Radiation From Flames and Smoke Layers

Task Leader: Dr. George H. Markstein, FMRC

Technical Abstract

In many fires, energy transfer from the flame to the fuel and the surroundings occurs predominantly by thermal radiation. For sufficiently large fires, e.g., pool fires with diameters exceeding about 0.3 m, consideration of nonuniform distribution of radiation sources within the fire was found to be essential for quantitative evaluation of radiative transfer. (See Task "Radiation From Pool Fires".) In the present task, three instruments have been developed for the measurement of nonuniformly distributed radiative properties of fires.

One of these, the scanning radiometer, can provide a complete map of the spatial distribution of the time average of radiance (radiant power emitted per unit solid angle and unit source area) of a fire. Moreover, the instrument yields statistical data that characterize the radiance fluctuations in turbulent fires; such data are important for the development of analytical models of these fires. A series of measurements on 0.73-m diameter and 0.38-m diameter polymethyl methacrylate (PMMA) pool fires have been performed. Results, including averaged radiance distributions, radiant power per unit flame height, radiance intermittency, spatial cross-correlation coefficients, and emission-absorption coefficients computed by Abel inversion of the optical depth

under the assumption of constant radiation temperature, are reported in one of the publications listed below.

The second instrument is a water-cooled and nitrogen-purged fiber-optic absorption probe that can be inserted into a fire to measure the local absorption coefficient. By means of a corner-cube reflector, absorption of square-wave-modulated radiation from an infrared-emitting diode ($\lambda=0.96$ µm) is measured by double-pass over a path length of about 64 mm. Initial tests with a 0.73-m diameter PMMA pool fire yielded results in good agreement with data obtained by other methods (see Task "Radiation From Pool Fires"), as reported in another publication listed below.

The third instrument is a modification of the Schmidt method for measuring radiation temperature and emissivity of fires. The conventional Schmidt method uses a furnace blackbody source of background radiation, and is therefore slow and cumbersome, since the measurements must be repeated at several settings of the source temperature. The present "fast-Schmidt" instrument employs a tungsten-filament source with a sapphire window that permits rapid change of effective source temperature. Digital feedback control is used for matching the effective background temperature automatically to the flame radiation temperature. Results of measurements on gaseous-fuel (C_2H_6, C_3H_8 and C_3H_6) pool fires currently underway indicate good agreement with conventional Schmidt data.

Reports and Papers

1. Markstein, G.H., "Scanning-Radiometer Measurements of the Radiance Distribution in PMMA Pool Fires." Paper to be presented at the 18th Symposium (International) on Combustion, Waterloo, Ontario, August 1980; FMRC Technical Report RC80-BT-4, May 1980.

2. Markstein, G.H., "Measurement of the Soot Absorption Coefficient in Fires by a Fiber-Optic Probe," Paper No. 12, Fall Technical Meeting, Eastern Section, The Combustion Institute, Atlanta, Georgia, November 1979.

Task #5a: Experimental and Theoretical Study of Horizontal Fire Spread on Wood

Task Leader: Arvind Atreya, Harvard University

Technical Abstract

Our understanding of how fire spreads on wood is at best in its early stages. Apart from a scientific interest, there is a more urgent need for such an understanding i.e., to prevent or reduce the severity of home fires. The present study is limited to fire spread on horizontal surfaces in a quiescent atmosphere.

The dynamics of fire spread on wood differs from that of the most commonly studied synthetic materials in two major respects:

1. It forms an insulating layer of char (to date there does not exist experimental data and a theory for any charring material).
2. The directional properties of wood. The rate of flame spread was found to be related to the orientation of the grain, because the pyrolysis gases are issued in preferred directions.

A solution to this problem requires a theoretical model that includes charring and anisotropy, along with supporting experimental data.

The experimental equipment described in Task 5c is used to measure (as a function of time):

1. the pyrolysis weight loss of the sample,
2. the energy evolved by the growing fire, and
3. the flame spread radius.

Radiation and vitiation are treated as parameters. With the present methodology and calibration the energy measurements can be made within $\pm 3\%$ error.

In the first set of experiments on wood a repeatable geometry of spread was not obtained. This non-uniformity has been traced to —

1. Non-uniform external radiation. (New, more powerful radiant heaters have been installed with radiant flux now varying no more than 2.5% about the mean.)
2. Variable orientation of the grain with respect to the surface.

A second set of experiments has been started to study the behavior of various kinds of wood and orientations of the grain.

On the theoretical side, analytical solutions to the moving boundary problems (boundary between char and virgin material) encountered in the solid phase of a charring material have been obtained. The cases for which solutions have been found are:

a) a steadily traveling isothermal hot plate,
b) a growing hot strip, and
c) a growing hot disk,

each in contact with the surface of an infinite slab of material. The chemical heat of pyrolysis is liberated at the char-virgin material interface. Analytical solutions for cases b) and c) were possible only for an expansion rate proportional to $t^{1/2}$.

Considerable amounts of work need to be done before the gas and the solid phase are knit into a complete theory.

Task #5b: Horizontal Fire spread on Plastics

Task Leader: Seng-Chuan Tan, Harvard University

Technical Abstract

Data from preliminary test burns with a retarded flexible polyurethane foam provided a basis for starting work on a theoretical model that superposes equivalent point-radiant heat sources above the fuel surface to simulate heating by a flame. Some progress has been made on the first part of the model, which requires the solution of the time-dependent conduction equation in an axi-symmetric body with special boundary conditions.

A survey series of experimental runs using many of the PRC foam samples demonstrated strengths of our experimental methods as well as a few problems. The matched computer data acquisition system permitted detailed analysis of a burn, even to the extent of yielding an approximate measure of burning efficiency as a function of time. Gas samples analyzed on a chromatograph gave remarkable agreement with burning rate measures, supporting our calibration procedures. Two major difficulties remain, however, without satisfactory solutions; ignition under some conditions, and measurement of total radiated flux when burning takes place deep within a sample.

Electrical ignition of a wax match that leads to spreading fire on foam gives reproducible and very satisfactory knowledge of the time when flaming ignition begins. When high levels of radiation are required for retarded foam ignition, this procedure cannot be used, as the match melts. A wooden match has not proved reliable. In fact, greater energy has been required, so that small plastic cylinders with thin edges are used as ignition sources; but different foams require larger cylinders to initiate sustained burning. In a few cases, we have not obtained sustained spread of fire for lack of sufficient controlled ignition or a high enough radiation level.

Using a wide-angle small radiometer, distant from the flames and level with the fuel surface, has given satisfactory flux measurements in cases where the flames spread mostly across the upper surface of the plastic. For low density foams and some retarded samples, the flames plunge downward and then spread with a cylindrical front within the sample, where much of the radiant flux is unseen by our radiometer. Moving the radiometer high enough to see the flux brings other heat transfer to the detector, as well as complicating the view factor estimation.

Systematic work with plastic samples that behave suitably in our facility will continue. A gas ignition system is being readied to provide a carefully controlled point source for all conditions. Further study continues to determine techniques of radiant flux measurement for all burning configurations.

Task #5c: Fire Spread Research Facilities

Task Leader: Richard I. Land, Harvard University

Technical Abstract

Measurement of the total energy release from certain transient fires has been achieved in our facility. Exhaust gas analysis using a chromatograph and oxygen concentration measurements gave data in remarkable agreement with flow and radiometer measures for both calibration pool fires and growing fires on flexible foam. These tests also provided data for the design of appropriate fast-response gas analysis equipment. We are using a polarographic oxygen detector, dual beam infrared absorption for CO and CO_2, and a dewpoint detection system for water vapor measurement. A flame ionization technique will probably be used for total hydrocarbon detection, although it only gives methane equivalent readings; but no available continous device seems wholly satisfactory. The gas analysis system design has been closely coordinated with associates at Factory Mutual, who have also developed such a system. Flexibility, response times of the order of a few seconds, ease of calibration, and broad future use have been design goals.

Dangerous and inadequate radiant heaters have been replaced. We now have a controlled power source, capable of more than 20 KW; and heaters in place that provide a reasonably flat flux distribution, on the order of $1\,W/cm^2$ over a 60 cm square area for our samples.

An input air flow plenum has been built, and the facility can be operated with a closed ventilating loop. These improvements reduce the biased fire growth from air inflow nonuniformities, offer accurate measurements of exhaust gas mass flow, and permit burning at sustained values of reduced oxygen concentrations. Control and measurement of other gas concentrations should be simplified, and temperature of inflow air is stabilized. Soot and particle measurement and removal systems are still being designed and investigated.

The complexity of our testing has outgrown the nine year old PDP/8e system, and is being replaced by an LSI/11 data acquisition system. Programming had become too difficult within the limitations of slow speed and limited memory in the old twelve-bit format.

A modest investigation of venting room fires was completed, using a small model with fixed size enclosure and doorway.[1] Several fuel area sizes and distances between the ceiling and fuel surface were used. During a burn, a large vent in the center of the ceiling could be opened. In all cases of interest, the presence of a hot layer decreased the pyrolysis rate of the plastic foam when the ceiling vent remained closed. Opening the vent after layer development increased the pyrolysis rate, generally more dramatically as the fuel was closer to the top of the enclosure. In several cases, the interior temperature rose after venting, as the burning rate increased faster than the cooling effect of incoming air.

Reports and Papers: Land. R.I., "Fire Ventilation Reconsidered," International Fire Chief, Vol. 46, No.3, pp. 14-17, March, 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: IIT Research Institute

Contract No.: NB79-SBCA-0068

Contract Title: Preflashover Room Fire Model: Parametric Sensitivity Analysis and Development of a Submodel for Burning Furniture Items.

Principal Investigator: R. Pape
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NBS Scientific Officer: V. Babrauskas

Technical Abstract

This program has three objectives. The first objective is to conduct a parametric sensitivity evaluation of the IITRI (RFIRES) room fire computer model. The second objective is to develop a user's manual for the RFIRES code, including a discussion of the parametric sensitivity study. The third objective is to develop a preliminary burning furniture item model that ultimately could be incorporated into a room fire code, such as RFIRES.

At the present time the user's manual, including a discussion of the program's parameter sensitivities, is being finalized. The majority of the program effort however has been devoted to the development of the burning furniture item model. A summary of the approach and status for this aspect of the program follows.

A review of flame spread literature has been completed to identify analytic expressions which could be used to predict the progression of the pyrolysis zone's boundary. In addition a number of furniture burns and flame tracking experiments were conducted. It was determined that the speed at which the pyrolysis zone's boundary progresses (loosely denoted the "flame speed") can be estimated from simple experiments using the actual material being evaluated (eg., downward spread with different levels of imposed radiant heat flux), or by adapting the models of deRis, Lastrina et. al. and Fernandez-Pello. In all these cases, a basic downward flame speed is derived and modified by preconditioning of the surface just ahead of the progressing pyrolysis front. This preconditioning can be from radiation from hot surfaces and flames

elsewhere in the room, elsewhere on the item, or from the adjacent flame itself.

The other elements needed to construct a burning furniture item model are submodels for predicting fuel generation, the fire plume characteristics, the heat transfers, and the combustion process. For predicting fuel generation, it was decided to simply relate mass generation rate to heat influx by an empirically derived latent heat.

Relatively simple heat transfer models are adequate for the furniture item model. Conduction related to flame spread is inherently included in the determination of the "basic" downward flame speed. Convection, is derived automatically in the plume model. For radiation from the flame gases to solid surfaces, three simple approaches have been examined. The first is based on the average temperature of a finite volume of gas in the flame. This approach may require that the grid be relatively fine in order to resolve the flame configuration details to obtain the correct partitioning of radiative and convective losses. The second approach assumes that within each volume of flame gas a constant fraction of the energy released in combustion is radiated. The third approach assumes that the flame envelope radiates as a surface with a constant empirically derived emissive power. All three approaches are numerically quite simple but must be tested to determine which gives the most realistic results.

Similarly, combustion models have been identified for the preliminary furniture item model: (1) a model based on availability of oxygen to fuel, (2) a model based on resolving the flammable zone, and (3) a model based on an ignition criteria. The first approach (availability of oxygen to fuel) was selected for the preliminary furniture item model.

The area where the most effort has been expended and the most difficulties encountered has been development of a plume dynamics model. For the burning furniture item model, it is necessary that the flame configuration (locations of the hot packets of gas) be known. These hot packets of gas are the starting point for the heat transfer calculations which in turn define the fuel generation rate and pyrolysis zone boundary movement. Therefore, the flame shape (plume dynamics) dominates the furniture fire problem, and the available simple axisymmetric or vertical wall plume models are in themselves not adequate for this application. Consequently, IITRI was forced to seek a new approach capable of predicting the flame configuration for complex furniture item geometries. A new approach was required because the model must be simple with low computer costs in spite of the extremely complex, coupled inherently 3-dimensional problem that must be solved. As a result, a new plume modeling technique ("Macroscale Fluid Dynamics") has been developed and preliminarily tested. It appears to give realistic results and have all the practical features required.

In summary, all the furniture item submodels have been chosen or developed, however they have not been combined into the overall furniture item model at this time. Once a burning furniture item model is developed and incorporated into a room fire model, the required experimentally derived inputs that are identified can be the basis for truly meaningful standard tests whose data can then be related to the full scale "real fire" by means of the furniture item and room fire models.

Reports and Papers

"Preflashover Room Fire Model: Parametric Sensitivity Analysis and Development of a Submodel for Burning Furniture Items" Phase 1 Report IITRI Projects J6485, September 1979.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Integrated Systems, Inc.
(a Maryland corporation)

Contract No.: NB-79-SAC-A0230

Project Title: Development of a Mechanical Designer's Manual for Smoke Control Systems

Principal Investigator: J. W. Fothergill, Jr.
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M. Johnson, Sr. Technical Writer

NBS Scientific Officer: J. Klote

Technical Abstract

The objective of this project is to develop a basic mechanical engineer's manual for designing the mechanical portion of smoke control systems based on the present state of the technology.

The approach that has been and is being applied to achieve the objective is defined as follows:

1. To establish the extent of coverage of the various forms of occupancies, forms of structures, and forms of HVAC (mechanical) equipment.

2. Develop a systems approach and the requirements for a conceptual systems manual treating all aspects of building design and define the interface between such a manual and the mechanical designer's manual.

3. Based upon the results of the above two efforts, define the requirements for the mechanical designer's manual and its conceptual form and content.

4. Collect for the manual available and necessary data and information, and generate necessary data, graphs, nomographs and tables covering stairwells, stairwell vestibules and elevator lobbies.

5. Collect for the manual available and necessary data and information, and generate necessary data, graphs, nomographs and tables covering the balance of the structures for the occupancies to be treated in the manual.

6. Develop the final design of the manual and prepare the manual.

A cataloging of structures by architectural features and mechanical systems as well as the definition of a conceptual systems manual have been completed. Coverage of the manual and the conceptual form and content of the manual has also been completed. Currently, data is being collected and generated for designing pressurized stairwells, vestibules, and elevator shafts. The availability of an effective mechanical designer's manual for designing smoke control systems should materially reduce failures in smoke control systems and thereby improve the potential in saving lives during structural fires.

Reports and Papers

Fothergill, J.W. and Hedsten, G.C., "Testing of the IDS Tower Smoke Control Systems," Vol. 86, Part 1, ASHRAE Transactions 1980.

Fothergill, J.W., "The Atrium as a Fresh Air Channel — A Different Concept in Smoke Control," Vol. 86, Part 1, ASHRAE Transactions 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Applied Physics Laboratory, The Johns Hopkins University

Grant No.: NB79NADA 0016

Grant Title: Combustion Research and Synthesis, Task I-Inhibition, Extinction and Retardance.

Principal Investigator: Doctor R. M. Fristrom
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Other Professional Personnel: C. H. Hoshall, Senior Staff Engineer

NBS Scientific Officer: Doctor R. G. Gann

Technical Abstract:

The objective of the program has been to explore the chemistry of flame inhibition, extinguishment, and fire retardance with the goal of interpreting these phenomena in terms of elementary reaction mechanisms. This has been a continuing program since 1971. Collaborative studies have been undertaken with the University of California, Berkeley; the Institute of Physical Chemistry of the University, Göttingen, West Germany; and the University of Louvain la Neuve, Belgium. The work has produced theories which quantitatively link flame inhibition and extinction with elementary flame reactions.

Three projects were undertaken during the current year. (Ref.1).

RADICAL SPECIES IN THE SURFACE LAYER OF BURNING LIQUIDS - (Ref.2).

A drop burner with a quartz microprobe leading directly into the molecular beam inlet mass spectrometer (Fig.1) was constructed to see if radicals produced in the burning zone of flames could be detected just beneath the fuel surface. Methanol was the fuel. I_2 was added as a radical scavenger to identify radicals. Preliminary runs with the apparatus were unsuccessful because of clogging of the probe and flooding of the beam-forming chamber. A modified inlet is planned to circumvent these problems.

CHARACTERIZATION OF SPECIES APPEARING IN THE INTERSTITIAL SPACES OF BURNING CELLULAR POLYMERS

An apparatus was constructed (Fig.2) which allowed sampling below the surface of a burning polymer block. The effluent was withdrawn from one end of the "sampling" tunnel which was flushed with inert gas (Ar). The sample was separated into fractions of differing

volatility. In future runs, the objective will be to take multiple samples in the course of each test run; tests comparing a foam with and without fire retardant are planned.

EXTINCTION LIMITS OF FLAMES - (Refs. 4,5,6;Fig.3).

The extinction limits of flames (both self-induced and induced by additives such as halogens) are of interest in fire safety. There has been a long debate as to whether the observed limits are true chemical-physical limits or are artifacts associated with quenching. We have used an extension of the zonal flame model to examine this question.

We would like to verify our theoretical predictions experimentally and have planned the study of some low-velocity, near-limit flames. To reduce quenching we built a 30cm.-diameter burner suitable for sampling at atmospheric or reduced pressure. In a preliminary test the behavior of a pilot flame immersed in various methane/air atmospheres was studied (Fig.4). Results suggest that pilot flames in situations with gas leaks may be less dangerous than previously supposed and that an effective combustible gas detector could be made using the measured luminosity or increased temperature of the pilot.

EIGHTEENTH SYMPOSIUM ON COMBUSTION

One of the tasks was to act as program chairman of the Eighteenth Symposium on Combustion. During the past year some three hundred manuscripts were processed and sent to some two hundred reviewers. One hundred eighty five papers were chosen for presentation, and the program was organized for presentation at Waterloo, Canada, August 17-22, 1980. (Ref.7).

REPORTS AND PAPERS

(1) R. M. Fristrom and C.H. Hoshall, "Combustion Research and Synthesis-Inhibition, Extinction and Retardance", Proposal NB 79 NADA 0016 to Center for Fire Research, National Bureau of Standards (1979).

(2) C. H. Hoshall, "Sampling Condensible Liquids with the Molecular Beam Inlet Mass Spectrometer", RCP Internal Memo FR-1 (June, 1980).

(3) C. H. Hoshall, "Sampling of Interstitial Gases Evolved from Burning Cellular Polymers", RCP Internal Memo FR-3 (July, 1980).

(4) R. M. Fristrom and P. Van Tiggelen, "An Interpretation of the Inhibition of C-H-O Flame by C-H-X Compounds", Eighteenth Symposium on Combustion, the Combustion Institute, Pittsburgh, PA., p.773, (1979). (Presented at Leeds in August, 1978).

(5) R. M. Fristrom, "Chemical Factors in the Inhibition and Extinction of C-H-O Flames by Halogenated Compounds Interpreted with a Zonal Flame Model", Submitted for presentation at the Fall 1980 Meeting of the Western States Section of the Combustion Institute.

(6) C. H. Hoshall, "Large-Diameter Burner for the Study of Flames Near the Extinction Limits", RCP Internal Memo FR-2 (June, 1980).

(7) R. M. Fristrom, "Tentative Agenda for the Eighteenth Symposium on Combustion", May, 1980.

Fig. 1- SAMPLING OF BURNING DROPS

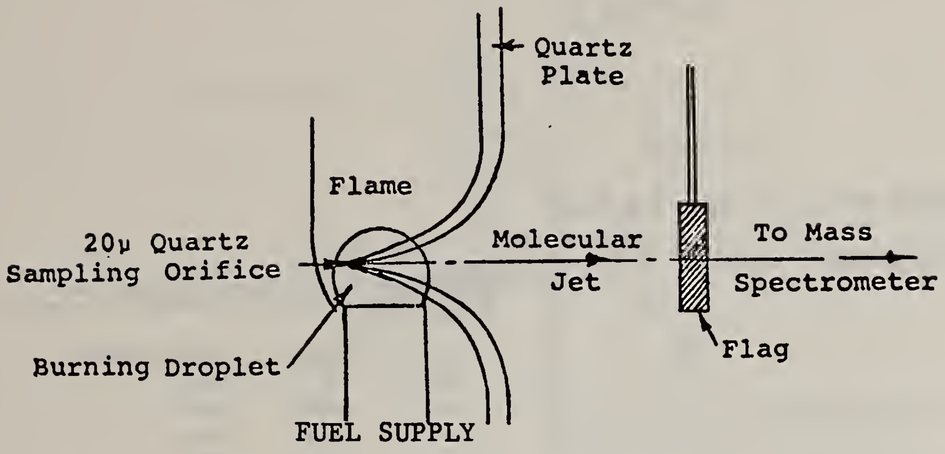


Fig. 1- Schematic of Droplet Burner Sampling Rig for Studying the Composition of Liquid Surfaces During Combustion.

Fig. 2- SAMPLING OF CELLS IN BURNING FOAMED POLYMER

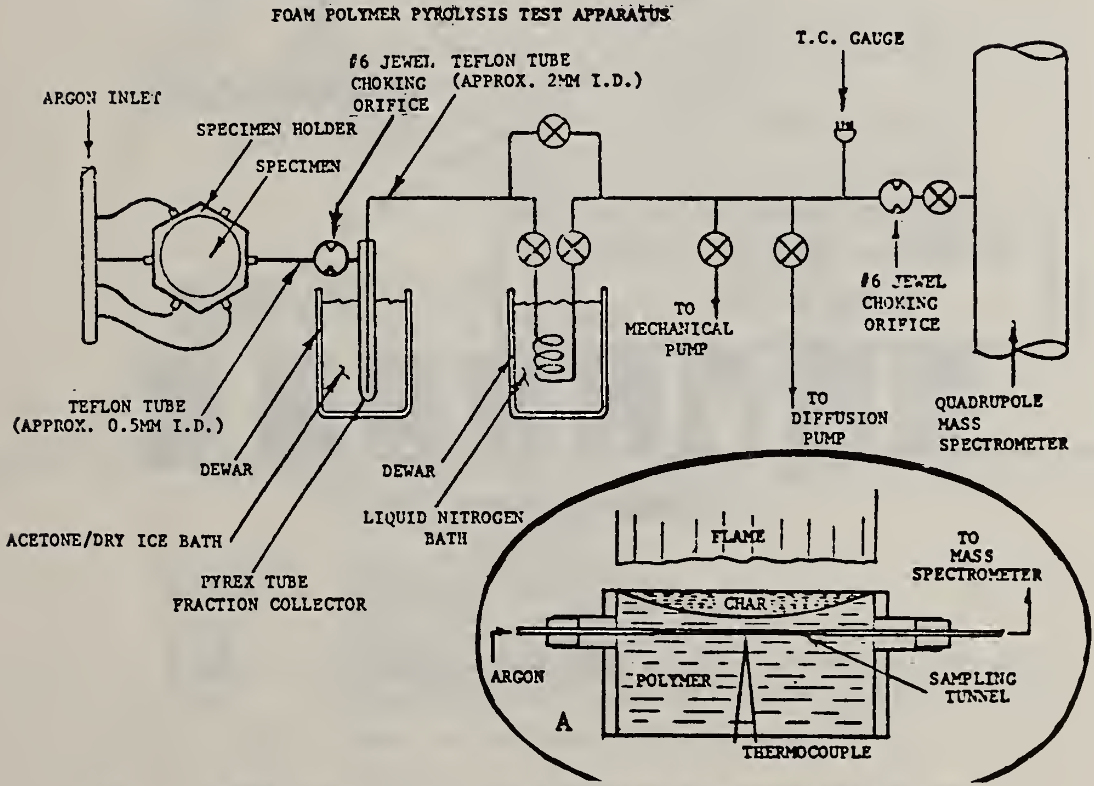


Fig. 2- Apparatus for Studying the Intercellular Gasses Evolved During Combustion of Foamed Polymers.

Insert: Schematic of Sampling Procedure.

Fig. 3-EFFECT OF Br_2 ON H_2 - AIR FLAME

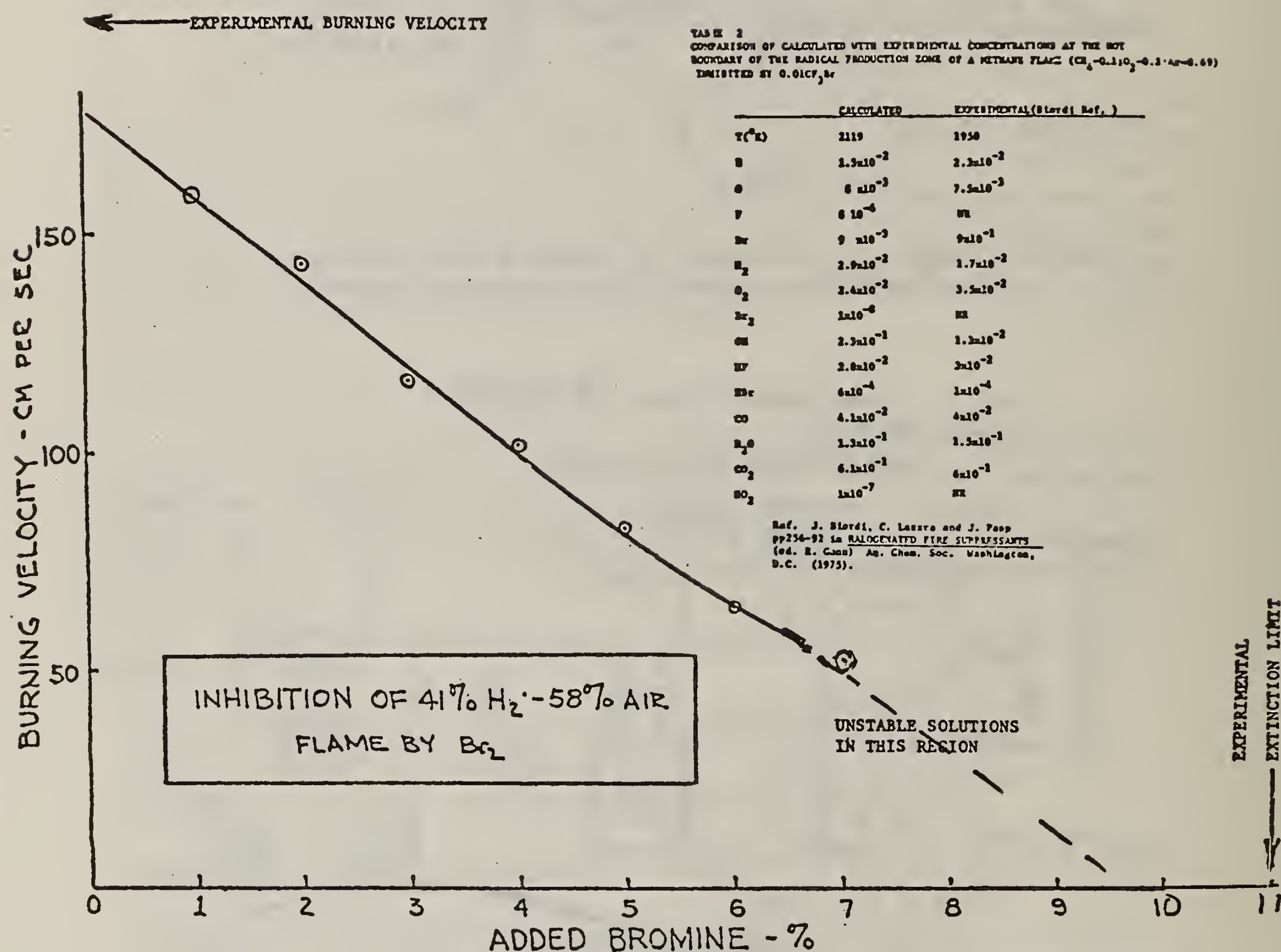


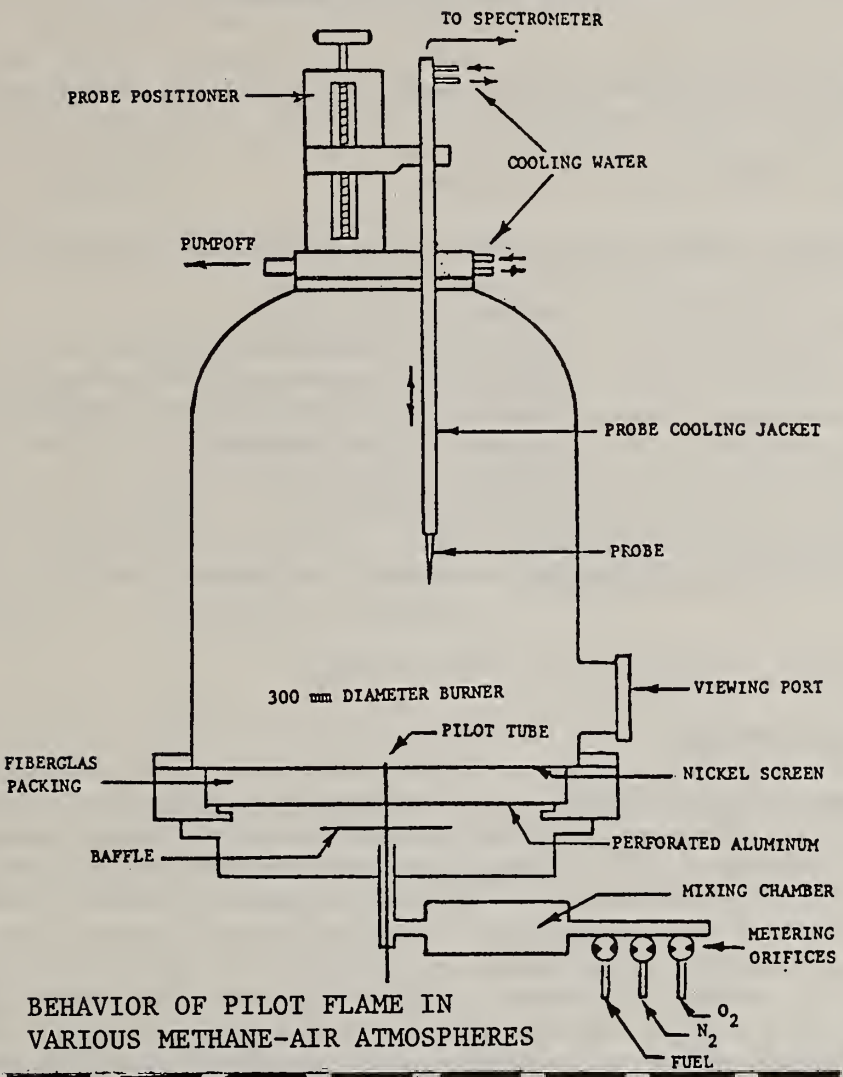
TABLE 2
COMPARISON OF CALCULATED WITH EXPERIMENTAL CONCENTRATIONS AT THE HOT BOUNDARY OF THE RADICAL PRODUCTION ZONE OF A METHANE FLAME (CH_4-0.11; O_2-0.2; Ar-0.69) INHIBITED BY 0.01CF_3Br

	CALCULATED	EXPERIMENTAL (Biordi Ref.)
T(°K)	2119	1950
H	1.3×10^{-2}	2.3×10^{-2}
O	6×10^{-3}	7.5×10^{-3}
F	6×10^{-4}	NR
Br	9×10^{-3}	9×10^{-1}
H_2	2.9×10^{-2}	1.7×10^{-2}
O_2	2.4×10^{-2}	3.5×10^{-2}
Br_2	1×10^{-6}	NR
OH	2.3×10^{-1}	1.3×10^{-2}
HF	2.0×10^{-2}	3×10^{-2}
HBr	6×10^{-4}	1×10^{-4}
CO	4.1×10^{-2}	4×10^{-2}
H_2O	1.3×10^{-1}	1.5×10^{-1}
CO_2	6.1×10^{-1}	6×10^{-1}
HO_2	1×10^{-7}	NR

Ref. J. Biordi, C. Lazzra and J. Papp pp256-92 in HALOGENATED FIRE SUPPRESSANTS (ed. R. Gann) Am. Chem. Soc. Washington, D.C. (1975).

Fig. 3- Burning Velocity as a Function of Added Bromine for a 41% H_2 - Air Flame.

Fig. 4 LARGE BURNER FOR LIMIT FLAMES



BEHAVIOR OF PILOT FLAME IN VARIOUS METHANE-AIR ATMOSPHERES

0	0.02	0.03	0.04	0.05	0.06	0.08	0.10

METHANE CONCENTRATION (M.F.)

V= 1 CM/SEC

0-0.02	PILOT BRIGHTENS
0.02-0.04	SECONDARY CONE FORMS
0.05	LEAN LIMIT WAVERING FLAME
0.06	ATTACHED ISLANDS
0.08	WANDERING ISLANDS
0.1	FLAME STRIKES BACK

Fig. 4- Large Burner for the Study of Near-Limit Flames.

Bottom: Behavior of a Small Pilot Flame in Various Methane-Air Atmospheres. Flow Velocity of Mixture 1 cm/sec. Pilot Diameter 1.5 mm.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: The Johns Hopkins University, School of Hygiene and Public Health

Grant No.: NBS Grant NB 79-NADA0010

Grant Title: Evaluation of Toxicity of Combustion Products

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Technical Abstract

Behavioral disruption as a consequence of exposure to the thermal decomposition products of polymeric materials presents a serious hazard to fire victims. Prior to exposure to lethal concentrations of toxic gases, central nervous system functioning may be impaired resulting in inappropriate behavioral responses which prevent escape from a fire situation. To assess the behavioral disruption which results from exposure to a polymeric material, flexible polyurethane foam, (PUF) two measures were used: a continuous avoidance procedure and a variable ratio schedule of water reinforcement using licking as the response. These measures showed differential disruption as a function of exposure to polyurethane foam. Licking was disrupted at very low concentrations; avoidance responding remained intact until much higher concentrations of polyurethane foam were decomposed.

Male Long-Evans rats served as subjects in all experiments. The rats were individually housed in a temperature and humidity controlled room with a 12-hour light-dark cycle.

Exposures were conducted in a 200 liter plexiglas exposure chamber which housed four individual experimental chambers. A modified ceramic coil furnace was underneath an opening in the base of the exposure chamber. Carbon monoxide and oxygen concentrations were monitored at five minute intervals throughout the exposure period with gas return lines insuring constant conditions inside the chamber.

Rats were exposed to 2.0, 4.0, 6.0 or 8.0 grams of flexible polyurethane foam (PUF) (GM-21). Each rat was used for only one exposure. The furnace controller was set to rise to 650°C. This provided a temperature ramp which, although not linear, was constant across exposures. The time course for combustion was consistent across concentrations of PUF and across exposures. When the furnace was turned off at 30 minutes, the chamber was cleared. Rats remained in the chamber for an additional 30 minutes.

<u>Experiment I</u>: Effects of exposure to polyurethane foam combustion products on avoidance responding

On the continuous avoidance schedule brief electric shocks (0.5 sec., 2 ma) were delivered through a grid floor every 5 seconds unless the rat pressed the lever. Each lever press response postponed the next shock by 30 seconds. The total session length was 75 minutes with the first 15 minutes considered a warmup period. The data from this period was not used in analysis. A PDP 8/e computer controlled the schedule contingencies and data recording. Total responses and shocks in five minute intervals were recorded. Experimental sessions were conducted five days/week.

<u>Results</u>:

Response rate during the 30 minute exposure period decreased at all the concentrations of PUF tested. Shock rate showed a consistent increase over control rate. In the 30 minute period following the exposure, response rate showed a dose related decrease. Shock rate was also increased during the post-exposure period, with the predominant effect at 8 g apparent in the post-exposure period.

Examination of the distribution of responses and shocks during the 60 minute experimental session showed a consistent pattern under control conditions. Rats averaged about 5 shocks and 30 responses per 5 minutes during the session. The effect of 2 g and 4 g PUF on avoidance responding was a decrease in responses and an increase in shocks during the middle of the session. Exposure to 6 g and 8 g PUF produced a more pronounced disruption in the distribution of responses and shocks, especially in the post-exposure period.

<u>Experiment II</u>: Effects of exposure to polyurethane foam combustion products on licking behavior

Rats were trained to lick a drinking spout on a variable ratio 50 (VR 50) schedule for water reinforcement. On this schedule, the number of licks required for one reinforcement varies from reinforcement to reinforcement in an irregular fashion. The average number of licks required on the VR 50 is 50.

Following stabilization of the licking rate, rats were exposed to polyurethane foam under conditions identical to those described in Experiment I. Exposures took place in the same exposure chamber as was used for avoidance exposures.

Results:

Licking behavior was sensitive to disruption by PUF during both the exposure period and the post-exposure period. At 1.0 and 2.0 g PUF, responding during the exposure period showed a decrease to approximately 50% of control responding. During the post-exposure period there was some increase in responding but the responding remained decreased below control levels (approximately 70% of control rates). Exposure to 8 g PUF produced a decrease in responding during the exposure period to 32% of control values. This decrease persisted during the post-exposure period.

Control performance on the licking schedule showed a slight positive acceleration at the beginning of the 60 minute experimental session. This was followed by a constant rate of responding for the remainder of the session. At 0.1 g PUF there was a depression in responding around 25 minutes into the session. By 40 minutes into the session responding had returned to control values. Both 1 g and 2 g PUF showed similar patterns, with the depression in responding occurring slightly earlier, around 15 minutes. Responding was consistently abolished from 25-35 minutes into the session. Return to baseline was not complete until the last 15 minutes of the session. Exposure to 8 g PUF resulted in an earlier and larger decrease in responding. For at least 15 minutes there was no responding by any of the rats tested.

Experiment III: Interactions of ethanol and carbon monoxide on avoidance responding

Examination of human fire victims reveals that in a large percentage of these victims high blood alcohol content can be measured. This elevated blood alcohol content in combination with the carboxyhemoglobin content of the blood may result in the inability of the person to engage in well coordinated escape behavior at carbon monoxide concentrations where people with no prior alcohol intake may have no difficulty. To determine whether treatment with ethanol, carbon monoxide (CO) and ethanol and CO in combination differentially alters behavior, rats performing on the avoidance schedule described previously were tested following 1.0, 2.0 and 4.0 gm/kg ethanol (p.o., immediately pre-session), 150, 500, 1500 ppm CO (30 minutes exposure) and a combination of the three CO levels and 4 gm/kg ethanol.

Results:

Exposure to 150 and 500 ppm CO for 30 minutes did not affect avoidance responding either during the exposure or during the 30 minute post-exposure period. Exposure to 1500 ppm CO produced a decrease in responses and an increase in shocks during both the exposure and the post-exposure periods.

Ethanol (1.0, 2.0 and 4.0 gm/kg) produced a dose dependent decrease in responding and increase in shocks during the first 30 minutes of the session. By the second 30 minutes of the session, responding had returned to control levels for all doses tested; shocks remained above control levels only at 4 gm/kg.

During the 30 min. exposure period, the interaction of 4 gm/kg ETOH with 150 and 500 ppm CO had less effect on avoidance responding than 4 gm/kg ETOH alone. Ethanol combined with 1500 ppm CO resulted in a decrease in responses and an increase in shocks comparable to that seen with 1500 ppm CO alone. The largest effect of the CO-alcohol interaction occurred in the 30 min post-exposure. All interactions produced an increase in shocks which was greater than that seen with CO or ethanol (4 mg/kg) alone. Response rate decreases at 500 and 1500 ppm (plus ETOH) were also below those seen with individual treatments.

The use of behavioral methodology in assessing the toxicity of thermal decomposition products represents a new and critical change in the evaluation of toxicity. Prior emphasis has been on the determination of the lethal concentration (LC_{50}) of toxic gases. Examination of fire fatalities suggests early disruptions in central nervous system functioning and the consequent behavioral impairment (i.e. inability to escape from the fire situation) account for fatalities. For this reason, assessment of impaired behavioral performance may provide more critical information on the potential hazards of materials at levels below those of the LD50.

Exposure to the combustion products of flexible polyurethane foam produces differential disruption as a function of the behavioral measure assessed. Avoidance responding is more resistant to disruption than is responding for water reinforcement on a variable ratio schedule. This suggests the need for assessing more than one behavioral response when evaluating the potential behavioral toxicity of combustion products.

The interaction between carbon monoxide and ethanol is complex and dependent on dose and time parameters. The increased behavioral disruption which occurs during the 30 minutes following CO exposure suggests a synergistic effect of CO and ethanol. Thus, the presence of ethanol represents an increased hazard in fire situations when CO is present.

Reports and Papers:

McGuire, P.S. and Annau, Z.: Behavioral effects of polyurethane foam combustion products. Society of Toxicology, March, 1980.

McGuire, P.S. and Annau, Z.: Effects of combustion products from flexible polyurethane foam on two measures of behavior in rats (in preparation).

McGuire, P.S. and Annau, Z.: Interaction of ethanol and carbon monoxide on avoidance performance in rats (in preparation).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Lawrence Berkeley Laboratory, University of California, Berkeley

Grant No: P. O. 812464

Grant Title: Fire Growth Experiments - Toward a Standard Room Fire Test

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Other Professional Personnel: Wai-Ching Teresa Ling, Ph.D. candidate

Fred L. Fisher, Development Engineer

NBS Scientific Officer: William Parker

Technical Abstract:

The object of this fire research project is to develop experimental methods which can be utilized for a standard room fire test. There is a growing trend to use full-scale room fire experiments for evaluation of the fire growth characteristics of materials and building systems. Yet, in spite of this, there is still no standard version of a room fire test. The exact details of a standard room fire test are presently being debated by working groups within the American Society of Testing and Materials (ASTM). Their place of departure is the ASTM E603-77 Guide for Room Fire Experiments[1] which discusses the choices available for such parameters as compartment design, ignition source, instrumentation, test procedure, analysis of data and reporting of results.

The purpose of a large-scale standard test would be to evaluate the fire performance of materials under actual in-use situations. Tests at the Forest Products Laboratory[2] to relate the 8-foot tunnel furnace to realistic fire situations, and more recently, Lee and Parker's research[3] on the contribution of furnishing and lining materials to fire growth, have found that compartment or room-like experiments were necessary to predict realistically the behavior of a specimen when subjected to a pre-flashover fire environment.

The two principal small-scale, or laboratory scale fire test methods for fire growth in the United States, ASTM E84 and E162, have simplistic data reduction schemes masking much of the true test specimen performance. In addition, many plastic specimens give little indication of how they will behave under end-use conditions. Presently, a series of small-scale tests are being developed, but there is a need for full-scale test data to support the validity of these tests.

It is the researchers' view that a standard room fire test could be used as both a development tool and as a performance evaluation method until the series of smaller, less expensive tests have been verified. Even then, new materials and systems would continue to require full

scale testing to prove applicabliity of the small-scale tests.

The experiments conducted in connection with this research have been directed toward answering the following questions:

1. Can a room fire test be expected to be a repeatable, scientific experiment and supply information on which to base a prediction of the contribution of materials to fire growth?
2. What details have to be fixed to insure a meaningful standard test and what values should be chosen for such important parameters as the ignition source?
3. What is the contribution of a thin cellulosic material to fire growth under the standard test conditions?

Eleven room fire experiments were conducted in a 2.44m x 3.66m x 2.44m (8' x 12' x 8') test compartment shown in Fig. 1. The experiments had a variety of materials on all walls and ceilings:

Test No.		
C-162	Glass Fiber Insulation	Glass Fiber Insulation
C-162,171,172	Gypsum Wallboard	Gypsum Wallboard
C-164	Plywood	Gypsum Wallboard
C-169	Plywood	Glass Fiber Insulation
C-165 - 168	Glass Fiber Insulation	Plywood
C-170	Plywood	Plywood

The experimental conditions were chosen to be consistent with an earlier version of the standard room test method under consideration by ASTM in which a gas flow of 0.117 m^3/min (419 ft^3/min) of CH_4 was specified. This is 50% of that in the current draft standard. Measurements were made of 1)the oxygen depletion in the exhaust gases leaving the room, 2) the air temperature at a number of locations, 3) the air flow and temperature at the doorway, and 4) heat fluxes at several locations.

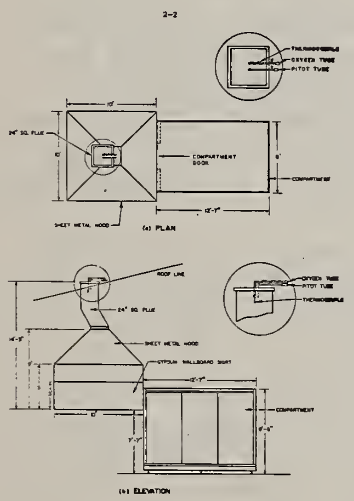

Fig. 1 The experimental compartment and vent system as shown in plan (a) and elevation (b).

ACCOMPLISHMENTS DURING 1979

The eleven separate experiments are summarized in Table 1. They fall into the following categories:

1. Experiments C-162, 163, 171, and 172 are essentially calibration experiments in which the ignition source released the only significant energy within the compartment.

2. Experiments C-164 and 169 are duplicate experiments; both had plywood on the walls. These two experiments are particularly interesting since they took approximately the same time to flashover (within 15 seconds) and thereby illustrate the repeatability of such experiments.

3. Experiments C-165, 166, 167, and 168 prove that the plywood ceiling was not ignited unless the flame from the ignition source played directly on its surface. In experiment C-168, the ignition source was raised to enable the flames to reach the ceiling and the compartment reached flashover in 6 minutes, 13 seconds. Typical measurements of air temperature 1" below the ceiling and heat flux as a function of time are shown for C-168 in figs, 2 and 3 respectively.

4. Experiment C-170 with plywood on both walls and ceilings proved to be the fastest and most intense fire.

The results of these experiments have led the researchers to believe that it is indeed possible to evolve a standard room fire test which is a repeatable, scientific experiment able to supply the information allowing a prediction of the contribution of materials to fire growth.

The observations reported by these eleven experiments should be considered in establishing the many details which have to be fixed in order to prevent undesirable scatter in the results of a standard test. Other items, such as criteria for and

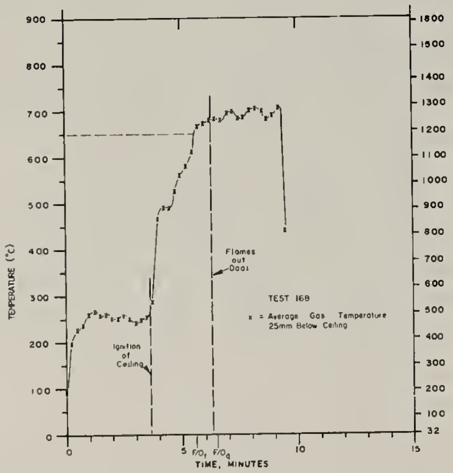

Fig. 2 Average temperature 1" below ceiling for experiment C-168 which had exposed glass fiber insulation on the walls (except in the ignition corner which was covered with gypsum wallboard) and 6.4mm (1/4") unfinished A-D plywood on ceiling.

Table 1. Summary of fire test

TEST NUMBER	MATERIAL		DURATION OF STATES			TIME TO FLAMES OUT THE DOOR	EXTINGUISH TIME	NOTES
	WALL	CEILING	J	6	L			
			min:sec	min:sec	min:sec	[illegible]	min:sec	
C-162	Glass Fiber Insulation	Glass Fiber Insulation	-	-	-	-	15:00	A
C-163	Gypsum Wallboard	Gypsum Wallboard	0:33	-	-	-	15:00	A
C-164	Plywood	Gypsum Wallboard	0:45	0:51	3:09	2:45	4:42	B MC = 6.16%
C-165	Glass Fiber Insulation	Plywood	-	-	-	-	10:00	B, D MC = 8.54%
C-166	Glass Fiber Insulation*	Plywood	-	-	-	-	1:00	B, D MC = 7.32%
C-167	Glass Fiber Insulation*	Plywood	-	-	-	-	10:00	A, D
C-168	Glass Fiber Insulation*	Plywood	-	3:42**	2:11	6:13	8:20	C MC = 7.23%
C-169	Plywood	Glass Fiber Insulation	0:30	0:50	3:40	4:00	5:13	A MC = 8.11%
C-170	Plywood	Plywood	0:16	0:16	1:56	2:51	8:10	A MC = 10.71%
C-171-2	Gypsum Wallboard	Gypsum Wallboard	-	-	-	-	15:00	A, E

NOTES

A - Surface of burner is 12" above the floor, against the wall

B - Surface of burner is 12" above the floor, 1" away from wall

C - Surface of burner is 14" above floor, against the wall

D - No ignition of the plywood occurred

MC - Moisture content of plywood at time of test

E - Calibration tests done with Gypsum Wallboard on the corner walls and ceiling. The remaining inside surface area of the compartment consisted of exposed glass fiber insulation

* - Gypsum Wallboard in corner on both walls behind ignition source

** - Ignition of ceiling

size of the ignition source, are more than mere details; they are major components of a standard test method. These experiments also contributed to a better understanding of this major test method parameter.

The ignition source used in this research proved to be a reliable, repeatable device, yet there are some problems in utilizing it in a standard room fire test. It is the researchers' opinion that the flames should reach the ceiling from its standard location without the walls contributing to the flame spread. This is necessary if ceilings and walls are to be evaluated separately.

As mentioned above, the gas flow in these experiments was less than the draft standard currently under consideration by ASTM. Preliminary experiments show that if the gas flow is increased to the burner to achieve 176 KW/sec (10^4 Btu/min), the value under current consideration, the flames reach the ceiling. This is true for either methane or propane. The current ASTM draft standard specifies propane because it has higher radiation which more closely approximates some actual ignition sources. Measurements of the oxygen depletion of the fire in the compartment lead to the determination of the heat release rate shown in Fig.4, which makes it apparent that the proposed increase in heat release rate of the ignition source would not have been excessive. Figure 4 shows that the specimen contribution increased from approximately 211 KW/sec to approximately 845 KW/sec in the one minute following 6:13 when the flames emerged from the door. Because of the time delay in the measurement system, this increase probably occurred prior to the flames emerging from the door, and it illustrates that the increased heat release rate from the proposed ignition source is well below the heat release rate required for flashover.

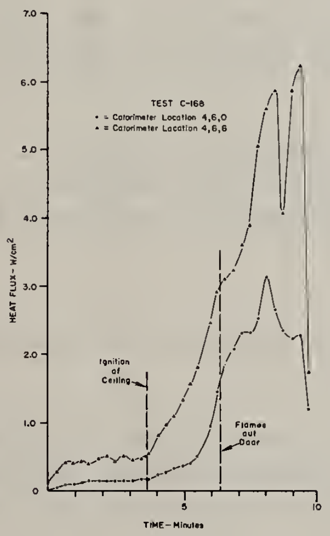

Fig. 3. Total heat flux to the center of the floor(location 4,6,0) and to the center of the ceiling (location 4,6,8) for experiment C-168.

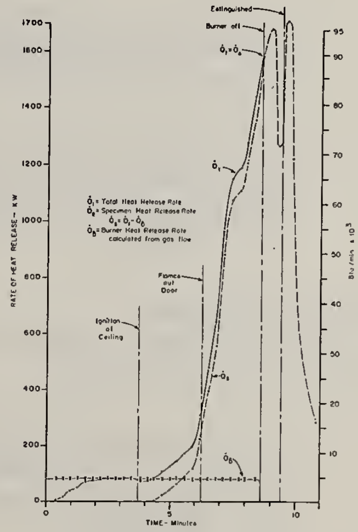

Fig. 4. The heat release rate for experiment C-168 is shown here as a function of time.

Table 2. Comparison to total time of States J, K, and L (i.e., "Time-to-Flashover") with the measurement of temperature, heat flux or the observation of flames out the doorway.

TEST NUMBER	TIME TO FLASHOVER (MIN) AS DETERMINED BY TIME TO REACH		
	650°C Ave. Gas Temp. 25 mm Below Ceiling	Flames Out of Compartment Door	2w/cm^2 at Floor Level (Center of Compartment)
C-162	-	-	-
C-163	-	-	-
C-164	3.2	3.5	NO DATA
C-165	-	-	-
C-166	-	-	-
C-167	-	-	-
C-168	5.6	6.2	6.5
C-169	3.3	4.0	4.0
C-170	2.1	2.9	3.1
C-171-2	-	-	-

The results of these eleven tests provide data on the contribution of a thin cellulosic material to fire growth under standard test conditions. This information will enable all parties involved in the consensus standard process to put the proposed test methods into perspective. Furthermore, it is also the researchers' view that the proposed standard room fire test will be utilized on materials contributing considerably less to fire growth than the thin cellulosic material used here, and that these 11 experiments will become a benchmark for comparison with other materials. For this purpose, a pass/fail criteria might be imposed based on the average ceiling temperature, time-to-flashover, heat flux at the floor, heat release rate or other data from the tests. But considerable research, particularly with regards to a precise definition of flashover, needs to be undertaken before establishing such criteria.

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1. Annual Book of ASTM Standards. American Society for Testing and Materials, 1916 Race St., Philidelphia, PA.

2. Anonymous, "Surface flammability as determined by the FPL 8-foot tunnel method," U.S.D.A. Forest Products Laboratory Report 2257 (1962).

3. R.B. Williamson, "Fire performance under full-scale test conditions - A state transition model," 16th Symposium (International) on Combustion, The Combustion Institute, 1357-1372 (1976).

REPORTS AND PAPERS

This includes papers written under earlier projects but published during the current year.

1. "Fire Growth Experiments - Toward A Standard Room Fire Test," (with F. L. Fisher) presented at the Western States Section, the Combustion Institute, Berkeley, CA, October (1979), Paper No. WSS-79-48.

2. "Post-Flashover Compartment Fires - Application of a Theoretical Model," (with V. Babrauskas), Fire and Materials, 3,1, pp. 1-7 (1979).

3. "Coupling Deterministic & Stochastic Modelling to Unwanted Fire," Presented at 'Advances in Fire Physics' Symposium to Honor Philip H. Thomas, National Bureau of Standards, April 14-15, 1980, Proceedings to be published in Fire Safety Journal, 1980.

4. "Using Fire Tests for Quantitative Risk Analysis," (with W.C.T. Ling), Presented at the ASTM Symposium on Fire Risk Assessment, Hilton Head, S.C., June, 1980, Proceedings to be published as ASTM Special Technical Publication.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Lawrence Berkeley Laboratory, University of California, Berkeley

Grant No.: 809252

Grant Title: Fire Modeling

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Karen Den Braven
Arthur Ortega

NBS Scientific Officer: Dr. W. Gary Mallard

Technical Abstract:

The overall goal of this project is to develop physical and mathematical models of the detailed combustion phenomena which control a fire's growth within a compartment of origin and its subsequent propagation through a structure. These experimental and theoretical studies may provide bases for development of test methods and for evaluation of the real fire hazard of materials. This work is divided into two broad categories: (1) soot volume fractions in diffusion flames, and (2) extensions and applications of excess pyrolyzate to systems with radiation.

1. Flame Soot: Measurements are reported of the evolution of soot particle size distributions within a pool fire for several flame scales and fuels. The multi-wavelength laser transmission technique used has been previously described. The particle size distributions all peak near particle diameters of 0.08 μm with concentrations ranging from 10^8 to 5×10^9 cm^{-3}. Polystyrene (PS) and polymethylmethacrylate (PMMA) represent two distinct cases for which the flame is or is not optically thick, respectively. For the optically thick PS the volume fraction appears independent of fuel scale, decreases slightly with height within the flame and is ~ 3×10^{-6}. For PMMA the volume fraction increases with fuel scale from 2×10^{-7} to 10^{-6} and decreases slightly with height, presumably due to oxidation. The practical consequence is that

for fuels which produce optically thick flames, laboratory results may be used to calculate directly radiation of full-scale actual fires.

2. Excess Pyrolyzate: Flame heights have been obtained for many PRC sample bank materials in several useful geometries [1,6,7]. Emphasis is now being placed on making a firm connection between laboratory test results and full-scale fire behavior. Dr. Philip Thomas spent three months at Berkeley this year and presented several lectures on compartment fires. Work is in progress relating excess pyrolyzate to his thermal instability analysis of flashover. In addition, boundary layers with radiation are currently being examined experimentally and theoretically since these phenomena tie together the two separate modeling problems discussed here.

Reports and Papers:

1. C.M. Kinoshita and P.J. Pagni, "Laminar Wake Flame Heights," Journal of Heat Transfer 102, 104-109, 1980.

2. S. Bard, K.H. Clow and P.J. Pagni, "Combustion of Cellular Urethane," Combustion Science and Technology, 19, 141-150, 1979.

3. P.J. Pagni and S. Bard, "Particulate Volume Fractions in Diffusion Flames," Proceedings of the Seventeenth Symposium (Int'l) on Combustion, 1017-1028 (1979).

4. M.S. Sahota and P.J. Pagni, "Heat and Mass Transfer in Porous Media Subject to Fires," International Journal of Heat and Mass Transfer, 22, 1069-1081 (1979).

5. P.J. Pagni, A.R. Ortega, R. Toossi and J. Holthuis, "Flat Flame Burner Analyses," in press.

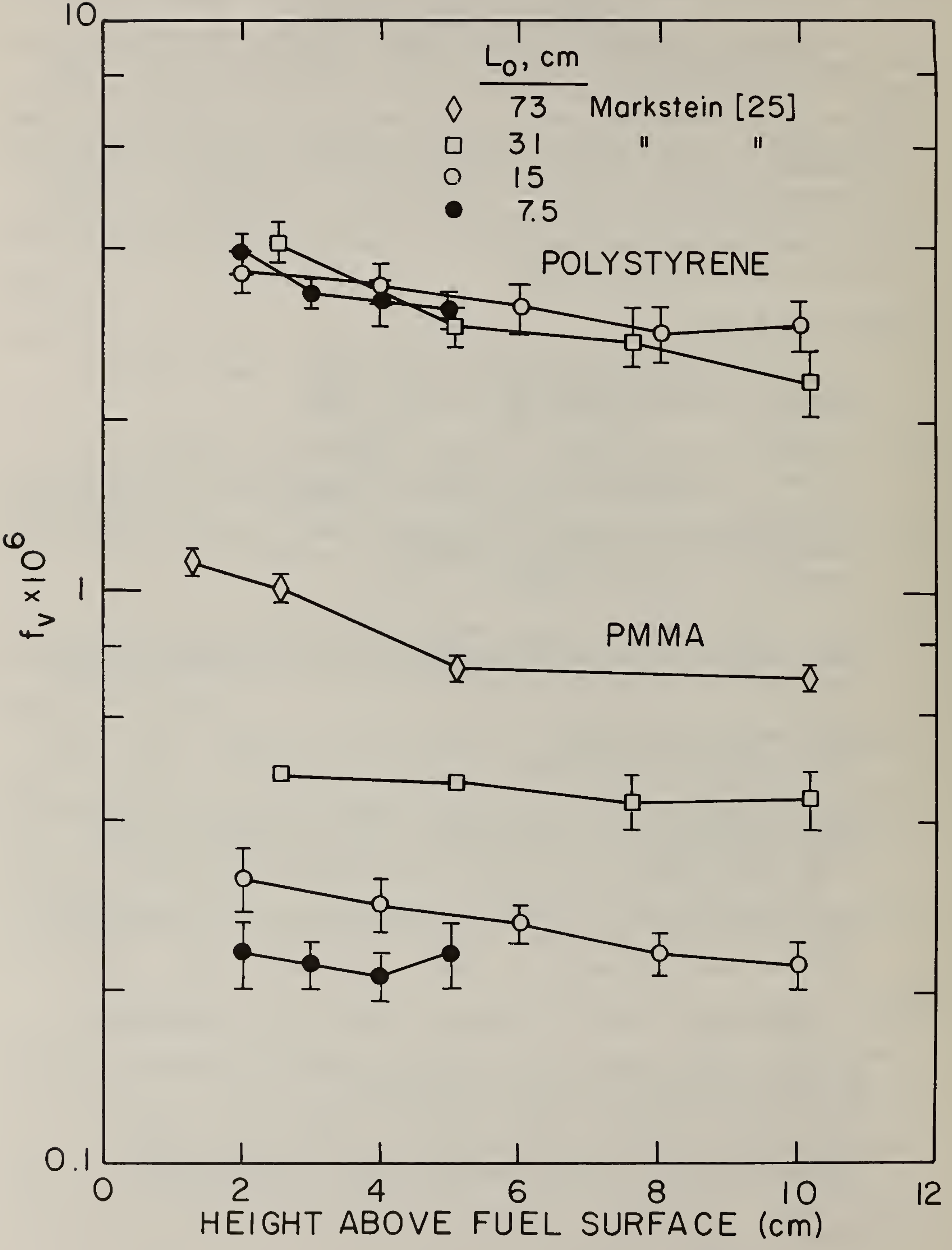
6. C.M. Kinoshita, P.J. Pagni and R.A. Beier, "Opposed Flow Diffusion Flame Extensions" to be published in the Proceedings of the Eighteenth (International) Symposium on Combustion, August, 1980.

7. C.M. Kinoshita and P.J. Pagni," Stagnation-Point Combustion with Radiation" to be published in the Proceedings of the Eighteenth (International) Symposium on Combustion, August, 1980.

8. S. Bard and P.J. Pagni, "Diffusion Flame Soot," in preparation.

9. S. Bard and P.J. Pagni, "Induced Fluorescence and Scattering in Pool Fire Diffusion Flames," in preparation.

10. S. Bard and P.J. Pagni, "Spatial Variation of Soot Volume Fractions in Pool Fire Diffusion Flames," in preparation.



L_o, cm
73 Markstein [25]
31 " "
15
7.5
POLYSTYRENE
PMMA
$f_v \times 10^6$
10
1
0.1
0
2
4
6
8
10
12
HEIGHT ABOVE FUEL SURFACE (cm)

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Lawrence Berkeley Laboratory, University of California, Berkeley

Grant No.: NB80NAGE1653

Grant Title: Thermal Radiation of Luminous Flames and Smoke

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NBS Scientific Officer: Dr. Takashi Kashiwagi

Technical Abstract:

The overall goal of this project is to establish a simple physical framework for complex fire and smoke radiation calculations. The basic research approach is based on developing approximate formulations by systematically experimenting and analyzing the fundamental aspects of the problem. The present research is focused on three topics: (1) experimental investigation on soot radiation in flames, (2) analysis of radiative heat transfer in scattering media, and (3) computation of fire radiation and plume convection in an enclosure.

Experiments on Soot Radiation: Measurements of optical and infrared radiation attenuation in small-scale flames of solid plastics are being carried out to provide more information on soot radiation and other related characteristics. Of particular interest are the effects of various soot parameters such as optical constants, particle sizes, and particle number density on flame radiation. The experimental system allows comprehensive and accurate measurements of emission, transmission and scattering characteristics of various kinds of flames under controlled environmental conditions.

Analysis of Radiative Transfer with Scattering: Soot and smoke particles absorb and scatter visible and infrared radiation. Radiative heat transfer in flames and smokes can be modeled on the basis of dispersed particles acting as independent absorbers and scatterers in the gaseous medium. Simple, convenient representation of the absorption-scattering field is being investigated. In particular, the mean beam length formulation for anisotropic-scattering and the resistance network

representation of an absorbing-scattering system has been developed on the basis of the two-flux and the linear anisotropic scattering model.

Computation of Enclosure Convection and Radiation: Different computation schemes for enclosure convection (elliptic-type) have been examined carefully with their respective strengths and limitations. Progress has been made in achieving simple approximate solution for radiation heat transfer in one-dimensional, non-planar geometries and multi-dimensional geometries. Interaction between enclosure convection and radiation is being pursued currently.

Reports and Papers

1. L. C. Chow, Y. K. Cheung, and C. L. Tien, "A Higher-Order Difference Scheme for Convective-Diffusive Equations," AIAA Proc. 4th Comp. Fluid Dyn. Conf., Paper No. 79-1466 (1979).

2. T. W. Tong and C. L. Tien, "Resistance-Network Representation of Radiative Heat Transfer with Particulate Scattering," Paper No. 79-42, Western States Section/The Combustion Institute, Fall Meeting (1979); to appear in J. Quant. Spect. Radiat. Transfer.

3. W. W. Yuen and C. L. Tien, "A Successive Approximation Approach to Problems in Radiative Transfer with a Differential Formulation," J. Heat Transfer, 102, (1980).

4. S. C. Lee and C. L. Tien, "Optical Constants of Soot in Hydrocarbon Flames," Proc. 18th Int. Symp. Comb. (1980).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: North Carolina State University

Grant No.: DA-0012

Title: Occupant Egress from Simulated Fires

Principal Investigator: Richard G. Pearson, Professor
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NBS Scientific Officer: Bernard Levin

Technical Abstract

A program of research is proposed in which response times and behaviors of residential occupants to simulated fire emergency situations will be evaluated under laboratory and field conditions. A variety of egress scenarios will be used to provide data relative to such factors (constraints) as human physical and sensory ability characteristics, alertness, environmental designs, level of visibility, personal needs adjunct to egress, and responsibility for others and for property. Studies will involve emergency egress from a "living facility" laboratory containing two bedrooms and a hallway, and from a sleep state as confirmed by EEG recordings. Based upon collected data, a computerized simulation model will be developed for predicting the total time for egress under various conditions of fire behavior, building design, and occupant characteristics.

The descriptive behavioral data are expected to have educational value relative to occupant guidance for fire emergency egress. Response time data for egress, including specific component times, would be related to probabilities of successful egress. The sleep study will provide data on "sudden-awakening" behaviors. Finally, the simulation model would have value in predicting total egress times under a variety of environmental and human constraints as related to fire survival.

Accomplishments to date include the following:

1. A smoke and odor simulator was developed. A schematic, parts list, and operational description have been furnished to the NBS Scientific Officer. Basically the device involves mechanical components, including valves which are under the control of programmable electronic circuitry. The simulator operation permits presentation of either low or high "smoke" (from liquid nitrogen) flow, of a tar odor, or of a

pleasant odor (bubble gum).

2. A "Detection and Decision Time Study" was completed as part of a doctoral student's dissertation (see "Reports and Papers" for citation to this as well as to related papers by the same author). The study was conducted to test hypothesized relationships between attitudes toward fire, personality dimensions, and perceived danger of fires, and (a) time to detection of fire cues, (b) time to decision on a sequence of actions to take in response to fires, and (c) actual sequences of actions taken in response to fire conditions. Twenty-seven male and twenty-seven female subjects filled out a questionnaire measuring personality traits and general attitudes toward and also beliefs about fires, and were randomly assigned to one of three experimental groups. A subject in Group 1 saw a burnt wall with blackened and exposed wires and was given to believe that a fire accident had once occured in the immediate environment; each subject in Group 2 saw the same wall but also saw a smoke detector which he/she was told was installed for complete protection; each subject in Group 3 saw no such burnt wall. While performing a tracking task requiring sustained attention, each subject was then required to detect four fire related stimuli and two non fire related stimuli presented. The subject was then subjected to simulated fire conditions and required to make a series of decisions regarding appropriate behavior in fires.

Attitude items from the questionnaire were subjected to factor analysis; seven identified factors were named. The questionnaire also included items concerning personality traits of sensation-seeking, manifest anxiety, and locus of control, taken respectively from the Zuckerman, Taylor and Rotter scales. A factor analysis here identified four factors.

Results indicated significant effects of attitudes on decision times and on sequences of actions taken in response to simulated fire conditions, but not on stimulus detection times. Several personality variables were found to be related to detection times and decision times. Perceived danger was found to be related to the detection of odor stimuli and several effects of experiential variables on detection and decision times were noted. Regression equations were written which appeared to be able to predict detection times, decision times, or actions chosen in response to fires on the basis of attitude and personality factors. The first, second, and third "most common actions" taken by subjects were "alert others," "call fire department," and "leave building" respectively. These results are identical to those reported by Bryan (1976) for behavior in real fires. Thus our findings support the use of a laboratory simulation approach to the investigation of human behavior in fire situations.

Overall, the results support the contentions of past researchers that behavior in fire situations is related to individual attitudes and personality variables, providing empirical information on the magnitude and direction of these heretofore hypothetical relationships. Results also suggest a need to inform the public about the dangers of total reliance on smoke and fire detectors for fire warnings, to the extent of ignoring physical cues to fire which may be detected earlier by the individual himself.

3. Data collection on egress behavior involving non-disabled college-student subjects, adults confined to wheelchairs, and blind adults has recently been completed. Six scenarios were involved; these vary in starting point (bedroom--on bed, or seated/reclining on couch in living room), complexity of behavioral responses required (e.g., search for child under bed or in closet), and egress mode (hall door, main entry, window). All subject movements are viewed by television cameras located in the rooms and hallway and connected to a television monitor located in the control room. Specific events noted in the scenarios are timed thru the use (a) of microswitches connected to all doors, the dresser drawer, and telephone, or (b) of pressure-sensitive mats located outside of door and window exits. All such events are recorded (for time-analyses) on a 20-channel event recorder. Additionally, an electronic timer is used to measure the total time of egress for each scenario. This is activated by the onset of the fire alarm, and terminates with the final response, i.e., exit thru door or window. A printer then prints out the total egress time in .01 seconds.

Data analysis completed to date reveals that, as compared to non-disabled (N-D) subjects (N=18), blind subjects (N=11) have longer mean egress times, much larger standard deviations, and higher minimum and maximum subject egress times for all scenarios. For example, for the "easiest" scenario mean egress times were 14.3 and 49.8 seconds respectively; for the "hardest" scenario, the respective differences were disproportionately greater -- 56.4 versus 120.3. Minimum subject egress times for these same scenarios (easy-hard) respectively were 10.0 (N-D) versus 23.5 (blind) and 38.7 versus 59.7, while maximum times respectively were 21.0 versus 104.8 and 99.5 versus 227.8 seconds. In brief, considerable individual differences are observed in the data, and, in the case of blind subjects, there is clear indication of longer latencies of behavioral responses associated with egress.

Reports and Papers

Schwalm, N. D. An Exploratory Study of Human Behavior in Simulated Fire Situations as a Function of Perceived Danger, Personality and Attitudes. Doctoral dissertation, North Carolina State University, 1979.

Schwalm, N. D. Human Behavior and Escape Times from Fires. Fire Journal, accepted for publication.

Schwalm, N. D. Attitudes and Human Behavior in Fires: An Exploratory Study of Relevant Concepts. Journal of Fire and Flammability, 1980, in press.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Northwestern University

Grant No.: NB80NADA 1021

Grant Title: Fire Propagation in Concurrent Flows

Principal Investigator: Professor A. C. Fernández-Pello
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Other Professional Personnel: C.-P. Mao, Ph. D. Candidate

NBS Scientific Officer: W. J. Parker

Technical Abstract

A research program has been undertaken to study the mechanisms controlling the spread of fire in gas flows moving in the direction of fire propagation. In fire-spread processes where the induced (naturally or forced) oxidizing gas flow moves in the direction of propagation, the environment favors the propagation of the fire. As a result the fire spread process is more rapid and hazardous than in other modes of propagation and, consequently, of great interest in the fire safety field. Fire propagation in concurrent gas flows (wind-aided propagation) typically occurs during the spread of fire up vertical walls, along wall-ceiling corners, ceiling or corridors with air currents generated in the direction of propagation by ventilations in the building. During the research program, experimental and analytical studies will be performed of some of the above fire spread configurations. Efforts will concentrate on the ceiling fire configuration both in natural and forced convection.

1. Ceiling fire spread in natural convection:

A theoretical analysis of this mode of fire propagation is currently under way. At the present time the analytical solution of the gas phase equations is being pursued. Two approaches, one making use of a self-similarity analysis and the other applying a Polhausen technique, are being followed. Both solutions will be compared to verify the nature of their respective solutions and to improve, if necessary, their underlying approximations. The gas phase solution will be used as boundary condition in the solid phase analysis from which the rate of fire spread will be determined.

Experimentally, the rates of fire spread and mass burning under an axisymmetric ceiling configuration will be measured. At present, initial tests are being conducted to determine the optimum scale of the experiments, ignition method and techniques to measure the rates of fire spread. The possibility of performing the measurements under two-dimensional flow configuration is also being considered. The experimental results will be used to verify the theoretical predictions. If the results of the comparison are negative, a numerical solution of the couple gas and solid phase equations will be followed.

2. Ceiling fire spread in forced convection:

A second effort of the research program will concentrate on this configuration of fire spread. It has been selected because it provides the simplest way for studying the influence on the fire propagation process of such parameters as initial temperature of the solid combustible and of the gas flow, oxygen concentration of the oxidizer and environmental pressure under well-controlled conditions. An experimental installation consisting of a small scale wind tunnel, a pressurized gas settling tank and solid and gas heaters will be constructed. Measurements of the rate of flame spread as a function of the velocity of the gas flow, oxygen concentration, temperature and pressure will follow. The experimental results will be used in an attempt to develop non-dimensional parameters which could describe the fire spread process, and to compare predictions of present theoretical models.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: The Pennsylvania State University

Grant No.: NBS Grant 7-9020

Grant Title: An Investigation of Fire Impingement on a Horizontal Ceiling

Principal Investigator: Professor G. M. Faeth
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Other Professional Personnel: H-Z. You, Ph.D. Candidate

NBS Scientific Officer: H. Baum

Technical Abstract

The structure and heat transfer characteristics of turbulent fires and fire plumes impinging on a horizontal ceiling is being investigated in order to provide a better understanding of unwanted fires within structures. The results of the study have application to modeling fires within buildings, to determining heat transfer to structural members during fires, and to estimating the environment of fire detectors and fire suppression devices mounted near a ceiling. Particular emphasis is placed on summarizing experimental results using either correlations or simplified theory in a manner which facilitates their use within comprehensive fire models for rooms and structures.

Measurements have been made of convective and radiative heat fluxes to the ceiling, radiative heat fluxes to the ambiance, and flame shape. These experiments have employed laboratory-scale apparatus involving ceiling diameters of 610-1000 mm, ceiling heights of 58-940 mm, fire source diameters of 10-107 mm, flame heat release rates of 54-14250 W, with fires simulated by liquid fuels burning from wicks as well as natural gas diffusion flames.

Two flame configurations have been selected for detailed structure measurements in order to provide a better understanding of flame radiation properties, air entrainment rates, energy release rates, rates of fuel consumption and ceiling heat transfer rates. The configuration in this case involves a 1000 mm diameter water cooled ceiling located 400 mm above a 55 mm diameter burner tube, which flows natural gas. The heat release rates for the two flames are 1.67 and 8.41 kW, yielding flames which just impinge on the ceiling or spread roughly 200 mm along the ceiling, respectively. The measurements include profiles of

mean velocities and turbulent fluctuations using a laser Doppler anemometer, mean temperature using fine-wire thermocouples and mean concentrations of gaseous species (CH_4, C_2H_6, H_2, CO_2, CO, H_2O, O_2 and N_2) using isokinetic sampling and gas chromatography. Flame shape is measured by probing and by photography. Measurements are also made of static pressure variations and radiative and convective heat fluxes along the ceiling as well as radiative heat fluxes to the ambiance.

Measurements of flame heights, flame lengths along the ceiling and convective heat fluxes to the ceiling have been correlated using simple dimensionless parameters. The structure of the flow is being examined theoretically employing a turbulence model for the plume. Finally, simple integral models are being applied to both the plume and the ceiling flow.

The turbulence model for the plume is a k-ε-g model which involves numerical solution of Reynolds averaged governing equations for mean quantities. Turbulence characteristics are determined by solving model transport equations for turbulent kinetic energy and dissipation, and for concentration fluctuations. It is assumed that the exchange coefficients of all species and heat are the same, that chemical equilibrium is maintained at each point in the flow, and that kinetic energy and viscous dissipation of the mean flow are negligible. Radiation is treated as a perturbation where it concerns flow properties. Under these assumptions mixture fraction is a conserved property of the flow, and the equation of state (providing instantaneous temperature, composition, etc.) is only a function of mixture fraction. In this circumstance, average properties (temperatures, compositions, etc.) at any point in the flow can be determined from the value of mean mixture fraction and concentration fluctuations, in conjunction with an assumed form for the probability density function for the mixture fraction (taken to be a clipped Gaussian function).

This model has been calibrated using constant and variable density noncombusting flows and combusting jets--where buoyancy effects are small. The model constants were not changed for the present calculations for the two buoyant flames. Calculations were initiated using measurements at the lowest axial station as the initial condition.

The turbulence model provided fair predictions of mean and turbulence quantities in the two test flames (mean velocity, mixture fraction, temperature, species concentrations and Reynolds stress); however, agreement between predictions and measurements was poorer than for earlier combusting flows where buoyancy effects were small. The major discrepancy involved flow widths, which were generally underestimated by the model. Potential sources of error involve buoyancy and low Reynolds number effects that were not considered in the model, as well as flow disturbances from the ambiance. It is concluded that the model provides useful predictions, however, further development is needed to improve quantitative accuracy. In this regard new data is needed on noncombusting weakly and strongly buoyant plumes in order to allow systematic development of the model. Results for larger scale turbulent fires are also needed, in order to assess Reynolds number effects. Work is planned in this laboratory to provide these results.

Current activities involve the development of integral models for the plume and ceiling flow regions. Great emphasis is being placed on simplicity, so that the models can be adapted for use within more comprehensive models of fires within structures. This involves the use of top hat profiles, entrainment expressions allowing for flow acceleration and Richardson number effects, and a simplified turbulent reaction rate expression based on eddy dissipation. The models also consider gaseous radiation. The turning region of the flow is being treated similar to earlier work by Alpert, at Factory Mutual Research.

The results of this research provide heat transfer parameters that can be used in building design to reduce potential fire losses. The structure measurements provide benchmark data for well-defined conditions which can be used to test fire models at all levels of sophistication. Initial turbulence modeling efforts appear promising, continued model development has the potential for reducing the need for expensive large-scale tests for fire hazard evaluation. The integral model provides a rational means of correlating information on fire structure, which can be applied in more comprehensive models of fires within structures.

Reports and Papers

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You, H-Z. and Faeth, G. M., "Ceiling Heat Transfer During Fire Plume and Fire Impingement," Fire and Materials, Vol. 3, 140-147, 1979.

Ahmad, T. and Faeth, G. M., "Turbulent Wall Fires," Seventeenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, 1149-1160, 1979.

You, H-Z. and Faeth, G. M., "Measurements and Predictions in Buoyant Turbulent Fires," in preparation.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Physio-Behavioral Consultants
996 So. 1500 E.
Salt Lake City, Utah 84105

Grant No.: Work conducted under purchase order agreement

Grant Title: Toxic Gas Tenability Limits in Fire Environments

Principal Investigator: S. C. Packham, Ph.D.

NBS Scientific Officer: M. M. Birky, Ph.D.

Technical Abstract

This project addressed the issue of estimating survivable exposures of humans to toxic gases frequently encountered in smoke from fires in residential and other occupied structures. A rational basis for estimating these "tenability limits" was formulated from a review of laboratory animal data and available information from human exposures both controlled and accidental.

Survivability was adopted as a working synonym for tenability and biological endpoints ranging from respiration and escape/avoidance responses to death were reviewed as relevant models of survivability which could be objectively qualified and scientifically studied. The ability of a chosen endpoint to model the eventual human response of interest was emphasized as the first of two critical elements in estimating tenability limits.

All biological responses reported thus far in inhalation experiments of combustion products have been found to be sensitive to both toxicant concentration and duration of toxicant exposure. This characteristic is the second necessary element in a tenability limit determination. For any given biological endpoint an increase in toxicant concentration will elicit an effect in a shorter exposure period once the toxicant's effective threshold concentration is exceeded. An endpoint will also have a characteristic time asymptote, i.e. as toxicant concentrations become excessively large. The minimum time-to-effect will approach a fixed interval. The graphical representation of this time x concentration relationship usually yields curves hyperbolic in form.

The exact placement of TC curves relative to the time and concentration axis is a function of the biological endpoint and the percent of the exposed population one wishes to prevent from reaching that endpoint. For example, endpoints based on a median population response, if strictly applied and perfectly predictive,would represent and generate tenability limits effective for fifty percent of the

population. Thus either zero threshold effect levels must be determined or some "safety factor" applied to median-response data. In either case the report explains the time x concentration x percent/effect response surface from which TC curves and tenable exposure conditions can be estimated.

Two compounds, CO and HCN, were reviewed and tenability limits based on motor coordinated behavioral responses were offered as illustrative examples which applied the approach developed in the report.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Princeton University

Grant No.: NBS Grant 7-9004

Grant Title: An Experimental Investigation of Flame Spread Over Condensible Combustibles: Gas Phase Interactions

Principal Investigators: Profs. I. Glassman and F.L. Dryer
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NBS Scientific Officer: B. McCaffrey

Technical Abstract

Work reported previously has shown that the dependence of flame spread rate on the opposed flow velocity is a strong function of the ambient oxygen concentration. For oxygen mass fractions above approximately 0.34, the flame spread rate was observed to increase with opposed flow velocity while for lower concentrations it decreased. Following a consideration including chemical kinetics, the results were correlated by two non-dimensional parameters,one describing the gas phase kinetic effects (a Damkohler number, $\bar{D}$) and the other describing the process of heat transfer from the flame to fuel (a non-dimensional flame spread rate, $\bar{V}$).

$$\bar{D} = C \frac{\mu_g p^n A_g Y_o (\ell n\ (1+B)/B^{0.15})}{Le\ \rho_g^2} \exp\ (-E_g/RT_f) \qquad (1)$$

$$\bar{V} = \frac{\rho_s C_s \lambda_s V\ (T_v - T_a)^2}{\rho_g C_p \lambda_g U_m (T_f - T_v)} \qquad (2)$$

The symbols are the standard ones used and it is to be noted that U_m is the opposed flow velocity, V- the flame spread rate, and the subscripts on T stand for vaporization, ambient and flame. The non-dimensional rate was taken from the analysis of de Ris[1] for thick fuels.

This approach was similar to that used by Altenrich et al[2] for thin fuels. Previous work on thin fuels in an opposed flow has been exclusively in air[3-5]. Consequently we extended our work on the effect of oxygen concentration in opposed flows to thin fuels, paper, with the realization that the mechanism of heat transfer for thin fuels is dif-

ferent from that for thick fuels. The analysis of de Ris[1] provides the following non-dimensional velocity flame spread velocity for thin fuels

$$\bar{V} = \frac{\rho_s C_s L V \, (T_v - T_a)}{2^{1/2} \, \lambda_g (T_f - T_v)} \qquad (3)$$

where L is the fuel thickness.

Expression (3) predicts that V is independent of U_m but increases with Y_o, which was exactly the trend of the experimental results found. Further a plot of $\bar{D}$ vs $\bar{V}$ correlated all the extensive experimental results for thin fuels extremely well. Both correlations (thick and thin fuels) were reported in a recently presented paper.[6]

Additional experimental work on thick fuels was undertaken to evaluate the thermophysical properties of the gas phase which are important parameters in the Damkohler number. The major modification made was to replace the nitrogen diluent with argon. Although the results obtained displayed all the trends present in the work reported above, the correlations were not as good. The scatter obtained raised some questions concerning the fluid dynamical aspects of the problem. It seems possible that a transition to turbulent flow occurs within the range of velocities studied. Another possibility is the influence of the flame on the flow field upstream, which would thereby change the opposed flow velocity experienced by the pre-mixed flame front.

Because of these questions, it was then decided to investigate in detail the flow field ahead of the spreading flame, particularly just in front of the premixed flame. It is hoped that some light might be shed on what is the proper characteristic velocity for the correlations, rather than simply the mid-flow velocity used. Also, a preliminary experiment using paper in an underdeveloped flow configuration seemed to indicate the importance of the velocity gradient at the fuel surface when the flame is near extinction. To achieve these aims, a wind tunnel was constructed with a flexible ceiling. The cross sectional area of the tunnel could thus be varied to produce a constant velocity gradient along the surface of the fuel.

Some results have already been obtained showing the influence of the flame on the upstream flow field. The flow is decelerated as it approaches the flame until a point just ahead of the flame where the velocity increases. This last increase is presumably due to the thermal expansion of the gases leading to a drop in density and hence a rise in velocity. Work is presently continuing using different flow rates to see how the velocity gradient and the detailed flow field vary. It is hoped that a clearer understanding of the flow field and its interaction with the flame will help toward a more concise application of the correlation to the flame spread problem.

The success of our LDV system not only for making velocity measurements, but also measurements close to the flame, encouraged us to extend our work to the axisymmetric horizontal flame spread and mass burning problem. Essentially this problem is one of a buoyant plume and a major objective is to measure the entrainment by the plume and the major parameters which affect the entrainment. LDV measurements have been made on 2, 3 and 4 inch pool flames. Although progress has been made, current efforts are directed to adapting the LDV system to this experimental configuration, analyzing the turbulent transition conditions, and modifying the associated microprocessor equipment.

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4. Hirano, T. and Sato, K.: Fifteenth Symposium (Int'l) on Combustion, The Combustion Institute, 233 (1975).
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6. Fernandez-Pello, A.C., Ray, S.R. and Glassman, I.: Flame Spread in an Opposed Forced Flow: The Effect of Ambient Oxygen Concentration, accepted for publication in Eighteenth Symposium (Int'l) on Combustion.

Reports and Papers

Fernandez-Pello, A.C., "Flame Spread in a Forward Forced Flow", Comb. and Flame, 36, 63 (1979).

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Ray, S.R., Fernandez-Pello, A.C., and Glassman, I., "An Analysis of the Heat Transfer Mechanisms in Horizontal Flame Spread", ASME Publication 79-HT-25 (1979).

Santoro, R.J., Fernandez-Pello, A.C., Dryer, F.L., and Glassman, I., "Laser Doppler Velocimetry as Applied to the Study of Flame Spread Over Condensed Phase Materials", in "Laser Velocimetry and Particle Sizing", H.D. Thompson and W.H. Stevenson, Eds., Hemisphere Publishing Company, Washington, D.C. p. 166 (1979).

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CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Fire Research Department, Construction Technology Laboratories, Portland Cement Association

Grant No.: NBS Grant NB80NADA1009

Grant Title: Extension of Short-Term Creep Tests at Elevated Temperatures

Principal Investigator: Michael Gillen
Fire Research Department
Construction Technology Laboratories
Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077

Other Professional Personnel: None

NBS Scientific Officer: L. Issen

Technical Abstract

This program is an extension of a previous investigation, also funded by NBS, of the short-term creep behavior of concrete at elevated temperatures. The current program examines the influence of variables not studied in detail in the initial program, but that were observed to have a measureable effect on concrete strain behavior. In particular, the role of moisture in influencing creep behavior will be studied at a number of loads and temperatures. In addition, one test series will examine the effect of these variables on concrete compressive strength.

At the conclusion of the experimental portion of the program, an effort will be made to use the data to develop an analytical expression that will adequately model concrete creep behavior as a function of the variables studied. A suitable model for the short-term creep of concrete at elevated temperatures is essential for the accurate evaluation of the design of a concrete structure to withstand fire.

The experimental program includes 276 creep and compressive strength tests on concrete cylinders made from three types of mineral aggregates. Significant variables are:

a. Aggregate type - calcareous, siliceous, and lightweight aggregates,
b. Temperature - ambient to 649C (1200F),
c. Static load - 0.3 to $0.6f'_c$,
d. Concrete curing - 10, 50, and 100% RH, and
e. Test duration - 6 to 24h.

The analytical portion of the program will begin with, but not be limited to, a comparison of test data to models proposed by other investigators in the field of creep of concrete at room and elevated temperatures. In addition, some alternative expressions will be examined in the course of determining the mathematical model that best matches experimental results.

Funding for the program was approved at the end of March, 1980. Work completed from that time has included the fabrication of over 100 test cylinders, and the development of computer programs for processing the large volume of test data generated by the experimental program. Creep tests on mature concrete specimens will begin during July, 1980, and continue for the following 12-15 months. Work on the analysis of data and model-building will be carried out in parallel with the experimental portion of the program.

Reports and Papers

None

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Fire Research Department, Construction Technology Laboratories, Portland Cement Association

Grant No.: NBS Grant G8-9027

Grant Title: Fire Tests of Reinforced Concrete Beams

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Fire Research Department
Construction Technology Laboratories
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Other Professional Personnel: Dr. W. G. Corley and M. S. Abrams

NBS Scientific Officer: L. Issen

Technical Abstract

The objective of this program is to obtain experimental data for validating the computer program developed by the National Bureau of Standards. The computer model provides for the analysis of shear failure mechanisms in continuous beams exposed to fire. Because the computer program considers the effect of various temperature-related parameters on thermal and structural responses of beams, the analytical procedure becomes extremely complicated. It is, therefore, important to validate this computer software by the use of experimental data.

The program involves six fire tests of reinforced normal-weight concrete beams. All beams are 27 ft. (8.2m) long. Five beams have cross sections of 21 in. x 9 in. (530mm x 230mm), and one has a cross section of 24 in. x 10 in. (610mm x 250mm).

Standard test methods described in ASTM Designation E119 are being used. Four beams were exposed to fires that were regulated to follow ASTM Standard Time-Temperature Curve. Two beams will be tested with a high-intensity, short-duration fire. Throughout the tests, specimens were loaded to the level that the applied moments were equivalent to nearly 60% of the moment capacities of the beams.

The measured data during fire tests include steel and concrete temperatures, deflections, and change of angle at several points along the top surface of the member.

Major apparatus for the tests include a full-scale beam furnace equipped with a hydraulic system that has a half-million pound capacity, temperature recording equipment, and a data acquisition system controlled by an HP9830 computer.

An effective method for measuring angle changes of the beam during the fire test was developed. A sizeable program was prepared for use with a HP9845 computer to analyze the flexural behavior of beams due to load and fire.

To date, four beams have been tested. Shear cracks generally occurred about 30 min. after start of heating, and flexural cracking began nearly 2 hr later. However, the flexural cracks progressed much faster than the shear cracks, and imminent flexural collapse ended all four tests. Duration of tests was about 4 hr.

Comprehensive test data will be submitted to NBS as soon as the test program is completed. The information will make validation of the computer program possible. This computer program will be useful in resolving difficult problems associated with analyzing structural behavior under fire. Ultimately, this validated computer program should be a powerful tool for designing more fire-resistive concrete structures.

Reports and Papers

Lin, T.D. and Abrams, Melvin S., "Fire Tests of Reinforced Concrete Beams," A report to National Bureau of Standards, Washington, D.C., (August, 1979).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: SRI International

Contract No.: EO-A01-78-00-3569

Contract Title: Continuation of Decision Analysis Studies in Fire Hazard Analysis

Principal Investigator: Fred L. Offensend, Ph.D.
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Co-Principal Investigator: Burke E. Robinson, Ph.D.
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Technical Abstract

The objective of the project is to develop and apply decision analysis methods to problems of fire safety planning. The project is being conducted by personnel from CFR's Program for Information and Hazard Analysis and SRI's Decision Analysis Group. Three principal fire problems have been addressed during the course of the project: upholstered furniture fire safety, electric transformer fluids fire safety, and residential fire safety.

Most of the work during fiscal year 1980 has been directed toward the residential fire safety problem. The purpose of the effort has been to develop a decision analysis model for use in evaluating alternative strategies for use in reducing residential fire losses. The model is also to be used to provide insight for identifying research priorities for ameliorating the residential fire problem.

The decision analysis model has several important features. One feature is that separate sub-models are included to reflect the public acceptance and implementation of the alternatives. These sub-models are important because the ultimate effectiveness of an intervention strategy depends not only on the underlying technical effectiveness of the alternative, but also on the extent to which the alternative is implemented by the target population. Sub-models are also included to allow for technological breakthroughs that may occur through research efforts.

Central to the decision analysis model is a fire spread and growth sub-model. This model accounts for type of fire scenario (e.g. interior living space, heating room, etc.), detector performance, size of fire at

time of initiation of effective suppression, extent of flame damage, and personal and property losses. A simple human behavior model is included to account for the fact that some victims are subjected to the fire before the intervention strategy can take effect. As with the other submodels, the fire spread and growth model is developed in the form of a probability tree to account for uncertainty on the various input factors. The model has been purposely kept simple to allow for an initial screening of the most interesting alternatives. Detail will be added to the model as the most important model parameters become evident.

The model is used by first specifying an intervention strategy to be evaluated. The public acceptance and implementation model then calculates the fraction of target residences that implement and install the intervention measure correctly. The fire spread and growth model calculates the change in personal and property losses that occur, given the implementation level of the alternative. A value model converts the reduction in fire losses to economic terms, thereby allowing for a determination of the cost plus loss of the alternative in question. The analytical process is repeated for other intervention strategies. From an economic standpoint, the most attractive alternative is the one with the least total cost plus loss.

The model is being used to carry out a preliminary evaluation of residential sprinklers and smoke detectors. Where possible we have used 1978 NFIRS data to establish model parameters for current conditions. Expert judgment is used to assess input factors for which statistical data do not exist. Sensitivity studies are performed to determine how the comparison of alternatives changes with changes in the expert assessments. We hope to have initial results ready for review by early autumn, 1980.

Reports and Papers

Levinthal, D., "Application of Decision Analysis to a Regulatory Problem: Fire Safety Standards for Liquid Insulated Transformers" Center for Fire Research, National Bureau of Standards, 1979.

Quinn, D.J., "Combining Expert Judgment and Historical Data: Some Illustrative Examples" SRI International, 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: SRI International

Grant No: EO-A01-78-3559

Grant Title: The Effect of Fire Retardants on the Heat-Release Rate of Building Materials

Principal Investigator: Stanley B. Martin
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NBS Scientific Officer: W. J. Parker

Technical Abstract

Since fire losses are a direct result of the heat released by burning materials during a fire, it would be extremely useful to know how to modify materials to limit their ability to release heat during exposure to fire. It may be unrealistic to expect to appreciably reduce the time-integrated quantity of heat released (per unit area of material exposed to fire) when a material suffers prolonged fire exposure, that is, long enough to oxidize even the most resistant chars. However, it is well within the current knowledge of fire retardant technology to markedly slow the rate of release by enhancing char formation. Carbon-rich chars represent fuel that is not available to the gas-phase combustion processes, thereby reducing the caloric value of the volatiles. It is reasonable to speculate that the reduction in fuel value of the volatiles, a qualitative gain, is the main effect of char-yield enhancement. Yet there are recognized quantitative effects as well--some being antagonistic--that may be either more or less important. For example, char-enhancing additives in cellulose increase the rate of decomposition and volatilization, presumably by reducing either the pyrolysis activation energy or the heat of gasification (or both), to at least partially negate the reduction in calorific value of the combustion of the volatiles. This assumes, of course, that the cellulose, with or without additive, experiences the same temperature-time history. But chars may also act as insulative barriers between the heat source and the undecomposed cellulose to slow heat conduction and, thereby, the rate of volatile supply.

The objective of this research is to experimentally evaluate the

relative importance of these effects of char production in cellulose, which are not known at the present time.

The essential measurement is temperature-time records at various depths below the heated surface during exposure of suitably prepared specimens to selected radiant-heat fluxes in the air stream of a rate-of-heat-release (RHR) calorimeter. Supplementary measurements should include: (1) the corresponding heat-release record, (2) weight loss, (3) char yield and composition, (4) heat of combustion of unburned residues.

Our method to date makes use of the SRI/RHR Calorimeter, a scaled-up version of the original NBS/RHR Calorimeter. With minor modification so that thermocouple leads can be brought out from the specimen to suitable cold junctions and recording equipment, the measurement of temperature-time records can readily be accomplished concurrently with the measurement of the rate of heat release. It would be our preference to also measure the other properties and responses, particularly the weight loss rates, concurrently, or at least in a measurement derived from the resultant state of the exposure of the same specimen. Unfortunately, the SRI calorimeter is not presently capable of continuous weight-loss monitoring nor does its design allow for ready recovery of specimen residuals following an exposure terminated at specified duration. Therefore, these supplementary data may have to be acquired independently, and our approach to date reflects this limitation.

Valid interpretation of measured temperature profiles requires well-defined boundary conditions of specimen exposure, and great simplification is afforded by close experimental approximation to one-dimensional conduction in solids of unlimited depth. The implied requirement of uniform heating over the entire surface, normal to the direction of heat conduction, is met by the design of the radiant heating system of the calorimeter; specimen surface areas up to 18 in. by 24 in. (46 cm. by 61 cm = 2800 cm^2) can be uniformly exposed to radiant heat fluxes in the range from 1 to 7 w/cm^2. Temperature-time histories at various depths in poorly conducting solids such as cellulose (the magnitude of thermal conductivity, k, in most cellulosic solids is on the order of 10^{-3} $watt/cm^2 - {}^oK/cm$) are measured with fair spatial resolution and minor perturbation, due to the measurement itself, with fine-wire thermocouples. However, the required thick specimens are not readily obtained.

Specimen stock composed of high quality alpha-cellulose pulp is commercially available in thicknesses of less than ½ millimeter. These may be laminated to any desired thickness, at the same time providing a convenient method for thermocouple implantation at the lamination interfaces, but such techniques are not used commercially and must be specially developed to suit particular application. At best these techniques are tedious, and so our goal has been to keep the thickness to a bare minimum that is consistent with the requirement for one-dimensional conduction of heat into a uniform solid of unlimited depth. Additionally, it is very desirable to be able to prolong the exposures until an approximation to steady state is achieved. This translates to a requirement for minimum ½-cm slabs.

We have developed a very successful method for making up thick cellulosic specimens with thermocouples implanted at various depths to measure the time-temperature history at each depth from which time-dependent temperature profiles can be derived. These specimens largely overcome the delamination problems that plague applications of large surface area dry laminates of cellulose. Slabs of ½-cm thickness have been exposed in the RHR calorimeter, providing data on heat release and detailed temperature records in both "neat" and $Na_2B_4O_7$-treated (2% w/w add on) cellulose. Clearly marked deficits in heat release rates were exhibited by the treated specimens. This success favors further experimental efforts along the originally proposed lines of investigation.

Temperature measurements to date are limited, and any conclusions must be regarded as somewhat tentative. The data suggest that char enhancement reduces heat release mainly by reducing the caloric value of the volatile products, rather than by slowing the rate of volatile production as a result of any insulating effect of the char. On the contrary, the evidence suggest that rates of pyrolysis are greater in the treated cellulose.

It seems noteworthy that early-time temperature profiles are very regular in shape, conforming to a classical conduction-in-inert-solid form, and distinctly nonclassical features appear only later. This argues that: (1) locations of the implanted thermocouples are precisely known and (2) appreciable sources (and/or sinks) of heat accompany the pyrolytic chemical reactions. A feature that suggests an exotherm can be seen progressing into the material as a thermal wave; this is more pronounced in the $Na_2B_4O_7$-treated cellulose.

Reports and Papers

Martin, S. B. and Inman, L. B., "The Effect of Fire Retardants on the Heat Release Rate of Building Materials," Summary Report, SRI Project PYU-7929, 1980 (in publication).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: SRI International

Grant No.: NBS Grant DA1003

Grant Title: Polymer Degradation During Combustion

Principal Investigator: Dr. S. K. Brauman
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Other Professional Personnel: I. J. Chen, M.S.

NBS Scientific Officer: R. G. Gann

Technical Abstract

The degradation of burning polystyrene is being investigated to provide understanding of the detailed degradation processes occurring in the condensed phase of a burning polymer that result in fuel production and to allow prediction of the effect of certain thermal or chemical variables on the rate or mechanism of fuel production. We are using a novel driven-rod apparatus with superimposed radiant heating to study steady-state linear regression of vertically mounted polymer rods degrading under nonflaming conditions that simulate those of combustion. Absence of the flame simplifies experiments and analysis. The investigation entails: (1) steady-state linear regression rate studies to relate the radiant pyrolysis situation to the combustion situation, and to provide samples and information (temperature profiles, oxygen involvement) needed for analysis; (2) characterization of radiant pyrolysis residues and off-gases to provide mechanistic information of the condensed-phase degradation processes; (3) kinetic analysis of the degradation rates.

The combustion studies in phase 1 have been completed. Typically, for a 0.5-in.-diameter polystyrene rod burning from the top in air, steady-state combustion is achieved after 15 minutes. A steady-state combustion rate of 0.091 cm/min is maintained throughout the remainder of the burn (30-40 min). The temperature profile is determined with a thermocouple embedded in the sample. The surface temperature, or temperature when the thermocouple appears at the surface, is 376 ± 8°C. The temperature profile extends some 2 cm into the polymer. The top 7 ± 1 mm of the rod sample is fluid: the topmost 1 mm is actively bubbling.

Radiant pyrolysis studies using the identical rod configuration are now in progress. We are attempting to achieve the combustion linear

regression rate for nonflaming degradation of the polymer rod in air and nitrogen by using superimposed radiant heating on the top of the polymer rod. To achieve a pyrolysis temperature profile and melt depth resembling those during combustion, we had protected the length of the rod from the incident light with a water-cooled stainless steel shield. From preliminary experiments, the incident light flux on the rod surface required to achieve the desired pyrolysis rate is approximately 3.5 to 4.0 cal $cm^{-2}sec^{-1}$ in air. We expect the required flux level to be independent of atmosphere, indicating that polymer surface oxidation is unimportant during pyrolysis and, presumably, during combustion in this top-burning configuration. Characterization of radiant pyrolysis residues and off-gases will begin in the near future.

The information obtained from this research will contribute to reducing the nation's fire loss by providing understanding of the chemistry of the combustion process of fuel production. With this knowledge, understanding of the effectiveness of and even prediction of improved fire retardants used to control fires by altering fuel production become possible.

Reports and Papers:

Brauman, S. K. and Chen, I. J., "Polymer Degradation During Combustion," SRI International Quarterly Report No. 1, April 4, 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: Underwriters Laboratories Inc.

Grant No.: NB80NADA1016

Grant Title: Investigation of Fire Hazards of Fireplace Inserts in Factory-Built and Masonry Fireplaces

Principal Investigator: Charles H. Gibbons
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Other Professional Personnel: Wayne Terpstra

NBS Scientific Officer: R. Peacock

Technical Abstract:

The purpose of this program is to evaluate installation, constructional and performance features of fireplace inserts in factory-built and masonry fireplaces. Current designs are now being reviewed and an experimental program, to be conducted over the next 12 months, will provide information on the compatibility of inserts and fireplaces with respect to installation and operation.

The experiments will be designed to develop information on the following constructional and operational features:

a. Temperatures on adjacent combustible materials.

b. Temperatures on the fireplace.

c. Temperatures on the fireplace insert and fire chamber walls.

d. Compatibility of the insert with the fireplace.

e. Methods of sealing the fireplace opening.

f. The effects of installation of the insert on airflow and air-cooling of the fireplace.

g. The effects of chimney size and construction on the performance of the insert.

h. Securement or removal of existing fireplace dampers when installing the insert.

i. Material, construction, and structural integrity of the fireplace insert.

j. Evaluation of electrical components and controls associated with the fireplace inserts.

k. Flue-gas temperature and composition.

l. Carbon monoxide leakage.

The experiments will be carried out, using 15 combinations of fireplaces and fireplace inserts. The factory-built fireplaces will be installed in accordance with the manufacturer's installation instructions and the Standard for Safety for Factory-Built Fireplaces, UL 127. Two masonry fireplaces of normal construction and in conformance with building code requirements will be used in the program. The fireplace inserts will be installed in the fireplaces in accordance with the manufacturer's instructions.

The experiments will be conducted, using a fuel source consistent with the methods presently being used for solid-fuel-burning appliances under nationally recognized standards.

The results will be arranged and presented such that model code agencies, trade groups, independent laboratories, etc., can utilize them to modify or develop standards or codes.

ANNUAL CONFERENCE ON FIRE RESEARCH
CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS
GAITHERSBURG, MARYLAND

October 22-24, 1980

Institution: University of California, San Diego

Grant No: NBS Grant G8-9005

Grant Title: Studies of Flame Extinction in Relationship to Fire Suppression

Principal Investigator: Professor Forman A. Williams
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NBS Scientific Officer: T. Kashiwagi

Technical Abstract:

The objective of this work is to develop an improved understanding of mechanisms of fire suppression by studying flame extinction in the presence of suppressive agents. Main suppressants considered are nitrogen and halons. Principal configurations studied are the downward propagation of premixed flames through quiescent mixtures contained in tubes and the counterflow diffusion flame produced by directing an oxidizing gas stream, containing suppressant, downward onto the burning surface of liquid or solid fuel. Data include concentrations (obtained by sampling and gas chromatographic analysis), temperature profiles (measured with thermocouples), flame shapes, flame speeds and extinction conditions. Results are interpreted on the basis of theory which specifies a critical Damköhler number of extinction. Plan is to apply the theory to extract overall chemical kinetic information under conditions near extinction, to attempt to relate such information to chemical kinetic mechanisms underlying suppression, to ascertain differences in the thermal, flow and kinetic aspects of extinction by the different agents, and to develop theoretical descriptions of influences of radiant losses on extinction in the counterflow diffusion flame.

Most of the progress made during the past year concerns studies of premixed flames in mixtures of hydrogen, oxygen and nitrogen. This

work demonstrated the importance of thermo-diffusive instabilities, with negligible effects of buoyancy, in producing cellular flames over a wide range of mixture ratio for near-limit, downward propagation in tubes. Curves of flammability limits, which are of significance in connection with fire suppression by inerting of enclosures, were shown to be affected by these cellular-flame phenomena. In particular, they are responsible for the fuel-rich shift of the peak in the curve of nitrogen content required to prevent flame propagation as a function of equivalence ratio. Also, they cause extinction by conductive heat loss to be uninfluenced by the walls of the tube, since the loss occurs from cells to nonreacting intercellular gases.

Among the theoretical developments was an analysis of the influence of flame curvature (the important cellular-flame characteristic produced by the thermo-diffusive instability) and heat loss on flame propagation and extinction. In this theory, a Newtonian, homogeneous approximation for the heat loss was employed, both for analytical convenience and also because procedures for accurate calculation of two-dimensional, conductive losses are unavailable for these flames. Through approximate identification of the heat-loss term with estimates of transverse rates of heat conduction, approximate agreement of theoretical predictions with experimental curves of flammability limits was obtained. Measurements with fine thermocouples of rates of decrease of temperature behind flames provided heat-loss values consistent with observed extinction conditions, according to the theory. Therefore a theoretical justification for the observations was obtained.

Additional measurements of diffusion-flame extinction in the counterflow experiment were made for polymers that had not been tested previously. Specifically, polyoxymethylene, polystyrene and polyethylene were studied. Previously developed procedures for extracting overall activation energies and pre-exponential factors for the combustion process from the extinction measurements were applied to these fuels to obtain their rate parameters. Radiant heat loss from the surface of the fuels was taken into account in the data reduction and was found to be of some importance for polystyrene. Measurements of regression rates and of surface temperatures (by means of imbedded thermocouples) were made to improve the accuracy of the calculation of the effect of radiant loss.

Apparatus was modified to enable HBr to be used as a suppressant in the diffusion-flame extinction studies. The intent is to compare extinction data of HBr with that obtained previously with CF_3Br for heptane pools, to ascertain if there is a correspondence of extinction effectiveness with bromine content in these experiments. This work is directed toward developing a simplified description of the effect of chemical suppressants on extinguishing gas-phase flames above condensed fuels. It had previously been established that the methods employed for data reduction with inert suppressants did not provide reasonable kinetic parameters if used for bromine-containing suppressants. The rate formula has now been modified by insertion of an efficiency factor for chemical suppression, dependent on suppressant concentration and temperature. Efforts are in progress to ascertain the functional dependence of this factor through use of extinction data. Theoretical considerations of detailed mechanisms of chemical suppression by bromine compounds also are in progress, with the objective of justifying a simplified model that can be used in extinction theory.

Also in progress is a theoretical analysis of influences of radiant heat loss from the gas on diffusion-flame extinction conditions. A perturbation approach is being pursued, with the radiant loss treated as a perturbation to the activation-energy asymptotics. The resulting correction will be negligible for the laboratory experiments performed in this study but may be of significance in connection with extinction of larger fires.

The objective in extracting overall rate parameters is to enable improved estimates of extinction conditions to be obtained in practical situations. In a first approximation, extinction may be said to occur at a critical flame temperature. However, this critical temperature varies somewhat as conditions are varied. The information developed in this program should help to provide a basis for calculating this variation, thereby improving accuracies of extinction calculations.

Information obtained from these results ultimately may afford improvements in techniques for fire suppression, derived from increased understanding of mechanisms of flame extinction, taking into account interactions between chemical kinetics, fluid flow and heat transfer. These studies present the possibility of extracting basic information on both the fluid mechanics and the chemical kinetics of combustion near extinction, which may be useful in analyzing extinctions under widely different conditions of burning and of suppressive action. Consequent improvements in fire suppression may reduce fire loss.

Reports and Papers

Corlett, R. C. and Williams, F. A., "Modeling Direct Suppression of Open Fires," Fire Research, 1, 323-337 (1979).

Mitani, T., "Propagation Velocities of Two-Reactant Flames," Combustion Science and Technology, to appear (1980).

Joulin, G. and Mitani, T., "Linear Stability Analysis of Two-Reactant Flames," Combustion and Flame, to appear (1980).

Mitani, T. and Williams, F. A., "Studies of Cellular Flames in Hydrogen-Oxygen-Nitrogen Mixtures," Combustion and Flame, to appear (1980).

Mitani, T., "Asymptotic Theory for Extinction of Curved Flames with Heat Loss," Combustion Science and Technology, to appear (1980).

Williams, F. A., "A Review of Flame Extinction," Fire Safety Journal, submitted (1980).

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: University of Florida

Grant/Contract No.: NB79NADA0021

Grant Title: Network Models of Building Evacuation

Principal Investigator: Professor Richard L. Francis
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L. Lemonidis, M.Sc. Candidate
J. Madariaga, B.Sc. Candidate

NBS Scientific Officer: Dr. Leonard Cooper

Technical Abstract

The research deals with the further development of the EVACNET approach as presented in the report NBSIR 79-1593, "EVACNET: Prototype Network Optimization Models for Building Evacuation." Basically, the research involves developing modeling guidelines to help make EVACNET accessible to users, developing theory to help identify critical EVACNET computer model output, and developing simpler auxiliary models of building evacuation.

EVACNET work began with a pilot project conducted to analyze the evacuation of buildings by means of computerized network flow optimization models. A major effort during this study involved constructing such an evacuation model of Building 101, an eleven-floor building located at the Gaithersburg, Maryland campus of the National Bureau of Standards. A "skeletal" network model of the building has been constructed which represents the following entities (as well as paths of movement between them): workplaces, halls, doors between workplaces and halls, stairwells, doors between halls and stairwells, doors between stairwells and the lobby, and lobby doors. The model determines by itself an evacuation routing of the people in the building so as to minimize the time to evacuate the building. Further, the model is dynamic, in the sense that it represents the pattern of the building evacuation over time. Just as one might imagine photographing an actual building evacuation using automatic time-lapse cameras which take pictures of relevant evacuation activities over regular time intervals, so the model depicts the evacuation of the building as it changes over time: time is divided into discrete time periods, and the model indicates the changes

in the evacuation status during each time period, as well as the evacuation status at the end of each time period.

The modeling principles developed in the pilot project are quite general, and permit modeling the evacuation of most buildings having well-defined passage ways used for evacution purposes.

Models which depict the evacuation of a building as it changes over time may have a quite substantial computer output, and the magnitude of this output can present assimilation problems to users. Thus theory is being developed to help identify critical output. It is believed that linear programming "dual variable" information will allow the identification of those portions of buildings being modeled which constitute bottlenecks, in the sense that comparable increases of their flow capacities would, among all building portions being modeled, lead to the greatest decreases in building evacuation time.

For some purposes a time-dependent network model, such as discussed above, is unnecessary, and a much smaller network model of the building, referred to for convenience as an "intermediate model", may be adequate. In such a model the building evacuation time is the maximum of the times for flows to traverse certain arcs (e.g., the longest of the times for flows to clear exits), with such time being a monotonic function of the arc flow. Efficient algorithms have been developed which solve the intermediate model in the sense that they determine evacuation flow patterns leading to evacuation of the building of interest in minimum time. The evacution of a number of actual buildings, university dormitories and a classroom building, has been represented by means of the intermediate model.

In order to help make the evacuation models developed accessible to users unfamiliar with network optimization ideas, a "prototype primer" on the use of such models for building evacution analysis is being prepared, and will provide a number of modeling guidelines.

In the long run, it is felt that network models of building evacuation will facilitate the study of the interrelationships of building evacuation with building design, building redesign, and building evacuation standards, and will lead to improvements in design for evacuation.

Reports and Papers

Chalmet, L. G., Francis, R. L., and Saunders, P. B., "Network Models for Building Evacuation," Research Report No. 80-8, Department of Industrial and Systems Engineering, The University of Florida, April, 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: University of Maryland, College Park

Grant No: NBS Grant 7-9014

Grant Title: The Determination of Behavior Response Patterns in Fire Situations, Project People II.

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Other Professional Personnel: Mr. James A. Milke, Research Assistant

NBS Scientific Officer: Dr. Bernard Levin

Technical Abstract

The study involves the identification and analysis of the behavior patterns of building occupants in fire situations. Intensive in-depth open-ended interviews are conducted with participants, supplemented with a structured questionnaire. The interviews have been conducted by the research study personnel at the scene of the fire incident between one to four weeks following the fire incident.

The study population is currently limited to health care and educational occupancies, with other significant occupancy fires within the following criteria for the selection of fire incidents: 1. Any known nursing home or hospital fire in the State of Maryland that involved staff procedural action, the evacuation of one or more rooms, the operation of a fire extinguisher, or the occurrence of any personnel injuries. 2. Any known school fire that involved the evacuation of the students, and procedural extinguishment action by the public fire department. 3. Any known fire in a business, residential, mercantile or public assembly occupancy that involved the evacuation of more than 200 occupants.

The detailed information from the interviews and the questionnaires is studied to determine the behavior response patterns of the participants, and the psychological, sociological, educational, and physical variables influencing the predisposition to the adopted response. Thus, the total interactional context of the individual, the functional population, the time variables, the parameters of the fire incident, and the physical environment of the structure in relation to detection, alarm, protection and evacuation variables is being studied. The study has obtained data on minor or successful fires, in which the fire

incident was successfully controlled by personnel without the assistance of the public fire department. The behavior response patterns from the fire incidents of the non-threatening type are being compared with the fire incidents which were perceived to be threatening to the extent the assistance of the public fire department was requested by the occupants. The concept of realms and episodes, with mapping techniques developed by Lerup have been applied to these studies.

A total of sixty-four fire incidents were under study and analysis as of June 30, 1980, with a total of sixty-four reports having been submitted to the Center for Fire Research. Reports completed since May 1, 1979 are cited:

Reports and Papers:

Bryan, John L. and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Crownsville Hospital Center on January 26, 1979. College Park: University of Maryland, Fire Protection Engineering, June 30, 1979.

Bryan, John L. and James A. Milke, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Pikesville Nursing and Convalescent Center on February 8, 1979. College Park: University of Maryland, Fire Protection Engineering, August 31, 1979.

Bryan, John L. and James A. Milke, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Hidden Brook Treatment Center on February 15, 1979. College Park: University of Maryland, Fire Protection Engineering, August 31, 1979.

Bryan, John L. and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Montgomery General Hospital on March 28, 1979. College Park: University of Maryland, Fire Protection Engineering, May 31, 1979.

Bryan, John L., James A. Milke and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at University of Maryland Hospital on April 4, 1979. College Park: University of Maryland, Fire Protection Engineering, May 31, 1979.

Bryan, John L., James A. Milke and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Sheppard and Enoch Pratt Hospital on April 5, 1979. College Park: University of Maryland, Fire Protection Engineering, July 31, 1979.

Bryan, John L., James A. Milke and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Taylor House on April 11, 1979. College Park: University of Maryland, Fire Protection Engineering, October 31, 1979.

Bryan, John L. and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at University Nursing Home on April 13, 1979. College Park: University of Maryland, Fire Protection Engineering, June 30, 1979.

Bryan, John L. and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Kensington Gardens Nursing Home on April 14, 1979. College Park: University of Maryland, Fire Protection Engineering, June 30, 1979.

Bryan, John L., James A. Milke and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Thurston Hall on April 19, 1979. College Park: University of Maryland, Fire Protection Engineering, July 31, 1979.

Bryan, John L. and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at National Institutes of Health Clinical Center on April 21, 1979. College Park: University of Maryland, Fire Protection Engineering, July 31, 1979.

Bryan, John L., James A. Milke and Philip J. DiNenno, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Roosevelt Hotel on April 24, 1979. College Park: University of Maryland, Fire Protection Engineering, October 31, 1979.

Bryan, John L. and James A. Milke, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Mt. Wilson Center on June 10, 1979. College Park: University of Maryland, Fire Protection Engineering, October 31, 1979.

Bryan, John L. and James A. Milke, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Bethesda Health Center on June 12, 1979. College Park: University of Maryland, Fire Protection Engineering, November 30, 1979.

Bryan, John L. and James A. Milke, An Examination and Analysis of the Dynamics of the Human Behavior in the Fire Incident at Franklin Square Hospital on June 13, 1979. College Park: University of Maryland, Fire Protection Engineering, October 31, 1979.

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CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: University of Maryland

Grant No: NB80-NADA-1011

Grant Title: An Investigation of the Water Quality and Condition of Pipe in Existing Automatic Sprinkler Systems for the Analysis of Design Options with Residential Sprinkler Systems.

Principal Investigators: Dr. Harry E. Hickey
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Other Professional Personnel: James A. Milke

NBS Scientific Officer: J. O'Neill

Technical Abstract

The objectives of this study are established as follows:

1. to investigate the potential effect of backflow of sprinkler water into potable water, thereby assessing the need for backflow prevention in residential sprinkler systems.

2. to investigate the potential severity of the pressure reduction due to tuberculation in pipes in residential sprinkler systems.

The first objective will be achieved by physical, chemical and biological analyses of water samples drawn from selected locations on existing sprinkler systems. The latter objective will be accomplished by measuring the discharge flow and pressure from selected orifices to subsequently calculate the Hazen-Williams coefficient for the pipe. The selection of certain sprinkler systems and specific locations will be based on the provision of a wide variety of conditions for the project relative to the study parameters of pipe material, pipe age, size of pipe, and the pipe network configuration.

In particular, this study will attempt to compare the quality of water in dead-end and other sprinkler system pipes with the potable water supplied to the building. The detailed analyses should facilitate relevant and significant comparisons to be conducted to assess the necessity for backflow prevention in residential sprinkler systems. Derivation of the Hazen-Williams coefficient from measurement of the water discharge parameters and comparison of the resultant value with the coefficient for new pipe will permit approximation of the degree of tuberculation in the pipe. This result will provide sufficient information to assess the severity of the pressure reduction and the useful life of the pipe as affected by the tuberculation.

During the first quarter of the project, approximately 25 samples have been obtained for the water quality analysis. The samples are analyzed for chemical composition, including metals, dissolved ions, etc. The biological analysis utilize the following tests: total coliform tests, fecal coliform tests, total bacteria plate counts, yeasts or mold tests, enterotube analysis and streak tests.

Some difficulty was experienced in the first quarter calculation of the Hazen-Williams coefficient due to the limitations of the measurement system employed, especially the attempts of measuring the flow rate through the use of a Pitot gauge. This problem was alleviated through the use of a large calibrated container into which the water is discharged.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: The Maryland Institute for Emergency Medical Services Systems, University of Maryland

Grant No.: NB80NADA1023

Grant Title: Psychometric Testing and Carbon Monoxide Poisoning

Principal Investigator: Roy A.M. Myers, M.D.
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NBS Scientific Officer: Dr. Merritt Birky

Technical Abstract:

In March, 1979, the Maryland Institute for Emergency Medical Services Systems (MIEMSS) initiated a study to determine a more accurate method of assessing the neurological effects of acute carbon monoxide poisoning. A number of psychometric tests were evaluated and a short (10-15 minute) screening battery for perceptual motor and high cognitive function deficits (diffuse brain dysfunction) was developed. This was to supplement the assessment by clinical and chemical analysis of alveolar and blood carbon monoxide levels. The tests are easily administered and can be evaluated by examiners with a minimum of training. They can furthermore be utilized on a wide range of patients, despite differences of intelligence levels and backgrounds.

The basic premise underlying the use of psychometric testing in the assessment of CO poisoning is that any disturbance of brain tissue or brain function will result in deficits in answering the questions, and the ability to relate to one's self and to one's environment.

An orderly and careful mental status examination is crucial in the proper assessment of carbon monoxide poisoning. Mental status examination is incorporated into this screening battery. This measures memory, comprehension, attention, concentration, abstract thinking and one's ability to learn.

Trail Making Test A measures spatial orientation, perceptual motor speed while Test B measures the ability to shift concepts. These tests have good reputation for indicating diffuse cerebral deficits.

The Benton Visual Retention Test is useful as a measure of visual perception, visual memory and visioconstructive abilities.

The battery is concluded with a block design subtest from the Wechsler Adult Intelligence Scale, 1955 and measures the spatial orientation, constructual speed and accuracy, fine motor control, visual motor coordination and perceptual analysis.

A scoring system with the high of 60 has been devised to assist in the assessment of the patient. The higher the score, the less diffuse the brain dysfunction would appear to be.

Sixty-four patients have been evaluated in terms of the diffuse brain dysfunction screening battery. Several patients have been eliminated because their dysfunction was clearly linked to alcohol intoxication. Data for sixty-four patients is to be presented. Preliminary evaluation indicates several important considerations.

1. Hyperbaric Oxygen Therapy results in a more rapid and more dramatic elimination of carbon monoxide from the system.

2. Patients with HbCO of 15% or less demonstrated minimal diffuse brain dysfunction.

3. Patients with HbCO levels higher than 15% demonstrated moderate to severe diffuse dysfunction. Their scores were lower on the estimated pre-treatment mental impairment index. The post-treatment re-evaluation of some of the cases demonstrated a higher score on the mental impairment index indicating an improvement of the effects of CO poisoning.

It is obvious that more study is necessary in this area before final conclusions can be drawn. Psychometric testing of carbon monoxide poisoned victims greatly enhances the ability to predict which patients will benefit more from Hyperbaric Oxygen Therapy as opposed to those only requiring the routine 100% oxygen for two half lives, i.e. four hours.

Since March, 1980, MIEMSS has been testing the MINICO carbon monoxide analyzer at the scenes of multiple alarm fires. The analyzer is used for accessing the alveolar air CO content from samples from fire fighters, fire victims, and bystanders. These results are compared with carboxyhemoglobin blood samples obtained at the same time. All sampling is done on a voluntary basis. The MINICO is being tested for its accuracy in evaluating alveolar air samples of carbon monoxide victims. Some 200 alveolar air/blood samples are required for correlation and standardization of the equipment. To date approximately 25 have been obtained. MIEMSS is testing the MINICO with the aim of providing an additional mechanism for field triaging by the EMT/CRT rescuer in smoke inhalation victims. The EMT/CRT is following a written protocol developed by MIEMSS in their evaluation of the smoke victim. At the present time the EMT/CRT is triaging the smoke victim based on history and clinical appearance. Utilizing the MINICO will allow them to make a more accurate diagnosis by using alveolar air sampling with its proven close correlation to blood HbCO levels.

With cooperation of the fire departments' central alarm, the MIEMSS "Smoke Team" responds to all two or more fire alarm fires in the Baltimore metropolitan area. The fire departments' central dispatch activates the smoke team through MIEMSS SYSCOM. The team member closest to the fire then responds by notification of SYSCOM via a two-way radio system.

The members of the Smoke Team have developed a successful working relationship with the fire departments and have no decision making role in patient triage. This duty belongs with the fire department personnel. The team is however a valuable resource if required.

The Smoke Team is also actively involved in establishing training programs in diagnosing and giving initial treatment for Smoke Inhalation/ Carbon Monoxide poisoning for field personnel. Many requests for these programs have been received. Through these training programs, the care of the smoke victim in the State of Maryland will be improved.

Reports and Papers: None

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

INSTITUTION: University of Massachusetts

GRANT NO.: NBS Grant DA0001

GRANT TITLE: Waking Effectiveness of Household Smoke Alarm Detector Devices

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NBS SCIENTIFIC OFFICER: Richard Bright

TECHNICAL ABSTRACT

Experiment A assessed intensity-frequency characteristics of several smoke alert detector signals. Overall dBA levels of detector acoustic signals were obtained at 10 feet and 15 feet from the source in an anechoic chamber and a reverberant room. Smoke alarm signals were analyzed at nine octave bands and refined analyses at 1/3 octave bands.

At 10 feet the detector alarm output mean was 85 dBA with a range from 80 to 92 dBA. In the anechoic chamber octave band energy peaks generally occurred at 4000 Hz with a second energy cluster at 2000-3000 Hz. Reverberant room energy peaks occurred at 4000-5000 Hz. Directional axis variations in energy were up to 10 dBA in the anechoic chamber and 3.5 dBA in the reverberant room.

Experiment B quantified sleep-waking behavioral performance relative to alarm decibel levels and extraneous environmental noise background. This component employed 30 college-aged subjects (18-30 years) who received an electronically controlled recorded detector alarm signal. Subject responses were the waking trial durations from "signal-on" presentation to the "signal-off" response and a phone call to the Amherst Fire Department. Experiment B included several variables, i.e., three alarm sound levels (85, 70, 55 dBA), 63 dBA air-conditioner background noise, hours into sleep, night of the week, sex, VCR/TV. Alarm intensity equated to alarm levels calculated earlier from 10 feet (85 dBA), at ear/pillow site, bedroom door open (70 dBA) and bedroom door closed (55 dBA). Sound level was controlled using a tape recorded

alarm signal of the current electromechanical horn used in most household dwelling detectors. One dwelling member served as respondent and performed two tasks when awakened by the alarm: (1) deactivated the automated apparatus and (2) phoned the local fire department. Responses were recorded in second units as S-R latency. The subject also filled out a pre-alarm and post-alarm questionnaire for pertinent behavioral and supplemental data. Latency responses and other behavioral data from the two questionnaires provided an index of expected behavior to current alarms in households by profiling stress-reaction patterns of individuals and families when suddenly awakened from nighttime sleep in different living conditions, day(s) of the week, alarm levels, alarm modes, alarm installation sites, environmental noise masking conditions, age, etc.

Data for the 30 subjects who received 55, 70 or 85 dBA (10 Ss each level) in quiet listening condition showed 13.60, 9.50 and 7.40 seconds mean latencies (alarm-on to alarm turned-off by Ss) respectively, for the three levels. T-tests revealed significant differences between 55 dBA and 70 dBA, 55 dBA and 85 dBA, but not between 70 dBA and 85 dBA. Other data also included phone call interval latency to the fire department.

Data for the 20 subjects who received the 55 dBA alarm (10 Ss) and the 70 dBA alarm (10 Ss) with a taped air-conditioner background noise (63 dBA measured 12 inches from source, but 51 dBA mean at ear/pillow position) showed a mean waking latency of 43 seconds for 55 dBA alarm (for the 7 of 10 subjects who awakened within four minutes of the onset of the alarm), and 19 seconds for the 70 dBA level. T-tests revealed signigicant waking-time differences; two subjects never awakened and one took 433 seconds at the 55 dBA level of alarm.

Twenty subjects received alarm levels of 55 dBA (10 Ss) and 70 dBA (10 Ss) while viewing a video-taped recording in the privacy of their own bedroom. These subjects were awake when the alarm signal was activated as compared to all other data obtained after subjects were awakened from sleep. The video sound volume was set at "comfortable level" by each subject. Thus, the video volume range extended from 40 dBA to 68 dBA. Mean shut-off latency was 10 seconds at 55 dBA alarm level and 6 seconds at 70 dBA level. T-tests revealed significant latency differences between the two mean values.

A series of t-tests were performed comparing the alarm levels relative to the three listening condition variables, i.e., quiet, air-conditioner noise, video-taped TV movie. Generally, it took significantly longer time to be awakened and respond with the air-conditioner background noise occurring although the absolute values amounted to 30 seconds or less. The shortest response latencies were with the VCR/TV mode; it is noteworthy that VCR/TV subjects were not asleep in the VCR/TV experimental condition. Means were also significantly different when the listening conditions were compared to each other at the various alarm levels. Thus, when the alarm alone (Experiment B) means were compared to alarm plus air-conditioner noise (Experiment Bacn) with 55 dBA vs. 55 dBA, the difference was significant; the same held true for the comparison with video tape and comparing air-conditioner mean differences comparing listening conditions.

Pre-trial and post-trial questionnaire data on 25 items were analyzed using Pearson correlation and multiple regression. Generally, subjects were able to self rate themselves accurately as "light" or "heavy" sleepers and estimate speed of performance. Also, the number of times subjects were normally awakened at night correlated with performance to alarm waking episodes.

Conclusion: Subjects can be awakened and alerted by smoke detector alarm levels as low as 55 dBA, even with extraneous background noise, when sufficiently sensitized to the signal and motivated to respond accordingly. Air-conditioner background noise significantly increased waking time latency and in the 55 dBA condition 20% never awakened.

REPORTS AND PAPERS

Nober, E.H., Peirce, H., Johnson, C., Well, A. and Clifton, C., "Waking Effectiveness of Household Smoke Alarm Detector Devices." Twentieth Meeting of the Association for the Psychophysiological Study of Sleep, Mexico City, Mexico, March 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: University of Montana, Missoula, MT 59812

Grant No.: NBS Grant G8-9011

Grant Title: Ignition and Fire Spread of Cellulosic Materials

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NBS Scientific Officer: Dr. William Earl

Technical Abstract

Objectives

The objective of this project is to investigate the kinetics and chemical mechanism of smoldering combustion and to determine the effects of inorganic additives in order to provide a chemical description of the processes involved in ignition and fire spread in cellulosic materials.

Experimental Approach

It has been shown that smoldering combustion of cellulosic materials involves; (a) pyrolysis of the substrate to a highly reactive and pyrophoric char, (b) chemisorption of oxygen on the fresh char, (c) gasification of the chemisorbed char and propagation of the process. Therefore, the experimental approach has been focused on investigation of the kinetics and mechanism of these reactions and how they are influenced by various inorganic additives, using various methods of chemical analysis, spectroscopy and thermal analysis.

Results

Pervious studies in this laboratory have provided considerable information on the mechanism and kinetics of the charring reactions.[1,2] the significant characteristics of char,[3] the mechanism and kinetics of oxygen chemisorption[4] and ultimately gasification of the char.[5] Current investigations are aimed at showing how various inorganic additives could enhance or inhibit the smoldering combustion by altering the course and kinetics of these reactions.

The results obtained from pyrolysis of treated cotton fabrics at

550°C are shown in Table I. These data show a strong correlation between the tendency for smoldering combustion and relative intensity of the ESR signals. These signals are related to the concentration of free radical sites that are available for chemisorption of oxygen on the char. However, contrary to the process of flaming combustion, there is no correlation between the amount of char formed during the pyrolysis and the inhibition of smoldering combustion.

In the previous studies it was shown that the kinetics of oxygen chemisorption on chars left after pyrolysis of cotton follow the Elovich equation, as shown below:

$$dq/dt = ae^{-bq}$$

Where a and b are constants and q is the amount of oxygen chemisorbed.

According to this equation the rate of oxygen chemisorption decreases with the level of surface oxides formed during the chemisorption. The magnitude of a indicates the extent of the chemisorption and the magnitude of b relates to the quenching process. The Elovich parameters obtained for oxygen chemisorption at 228°C on chars formed from untreated and treated fabrics are shown in Table I. These data show a general correlation between the tendency for smoldering combustion and the pre-exponential constant a which provides a measure of available sites for chemisorption. This also fits in with the data in Table I for concentration of free radicals measured by ESR spectroscopy. Higher a and b constants for the enhancers means a rapid quenching and high intensity chemisorption reaction. The constants obtained for the inhibitor indicate less abundant and slower-reacting sites for diammonium phosphate and less abundant sites of medium reactivity for boric acid. The differences in the nature and reactivity of available sites have also been observed by the IR spectroscopy of the chars subjected to chemisorption in previous studies[4] and the theory of the stable and mobile surface oxides which affect the gasification process.[5]

The kinetic parameters obtained for the production of CO_2 and CO by gasification of chars formed from untreated and treated cotton fabrics are shown in Table II. These data again show the tremendous effect of the various additives on the reaction rates and composition of the product (ratio of CO to CO_2) which affect the rate of heat release and the driving force for propagation of smoldering combustion. For the production of CO_2 which is the main contributor to the heat release, the energy of activation is almost the same for the untreated substrate and those doped with diammonium phosphate (an inhibitor) or sodium chloride (an enhancer). However, the pre-exponential factor is reduced for the inhibitor and increased for the enhancer which closely parallels the variation of the pre-exponential factor observed for the oxygen chemisorption of the char.

A direct comparison of these data is rather difficult because the magnitude of the two parameters affect the rates inversely. The ratio of these reactions and the associated rates of heat release at 500°, 750° and 1000°C given in Table II provide better data for comparison.

These data show that the rate of heat release is substantially reduced by boric acid and diammonium phosphate which are known inhibitors and increased by sodium chloride which is an enhancer; borax and aluminum chloride have marginal effects.

Conclusions

Inorganic additives change the nature of the pyrolytic reactions and combustion characteristics of the remaining pyrophoric char. This includes changes in concentration and reactivity of the sites involved in oxygen chemisorption by the char and ultimately the rates of gasification and heat release which provides the driving force for propagation of the smoldering combustion. The catalytic effect of the additives at the pyrolysis rather than the chemisorption stage was confirmed by the fact that post-treatment of char obtained from untreated cellulose did not affect the Elovich parameters for the oxygen chemisorption.

Reports and Papers

Recent Publications.

[1] Shafizadeh, F. and A.G.W. Bradbury, "Thermal Degradation of Cellulose in Air and Nitrogen at Low Temperatures," J. Appl. Polym. Sci., 23, 1431 (1979).

[2] Bradbury, A.G.W., Y. Sakai, and F. Shafizadeh, "A Kinetic Model for Pyrolysis of Cellulose," J. Appl. Polym., Sci., 23, 3271 (1979).

[3] Shafizadeh, F. and A.G.W. Bradbury, "Smoldering Combustion of Cellulosic Materials," J. Thermal Insulation, 2, 141 (1979).

[4] Bradbury, A.G.W. and F. Shafizadeh, "Chemisorption of Oxygen on Cellulose Char," Carbon, 18, 109 (1980).

[5] Bradbury, A.G.W. and F. Shafizadeh, "The Role of Oxygen Chemisorption in Low Temperature Ignition of Cellulose," Combustion and Flame, 37 85, (1980).

Table I. Properties of chars formed by pyrolysis of cotton fabrics at 550°C.

Additive	Added to Fabric	Char Yield	Relative ESR Peak	Elovich Parameters *a*	Elovich Parameters *b*
NaCl	0.21% Na	13.3%	1.90	1.31 ± 0.41	2.96 ± 0.04
$Na_2B_4O_7$	0.35% B	33.3%	0.95	1.26 ± 0.28	3.59 ± 0.37
Untreated	-	5.7%	1.00	0.87 ± 0.19	2.20 ± 0.14
$(NH_4)_2HPO_4$	0.22% P	21.8%	0.81	0.38 ± 0.09	1.76 ± 0.08
H_3BO_3	0.39% B	18.7%	0.35	0.41 ± 0.06	2.34 ± 0.11

Table II. Arrhenius parameters and calculated rate constants for production of CO and CO_2 from chars formed by pyrolysis of cotton fabrics at 550°C.

ADDITIVE	Arrhenius Parameters				Calculated Maximum Rate Constants								
	CO PRODUCTION		CO_2 PRODUCTION		500°C			750°C			1000°C		
	A min^{-1}	Ea Kcal	A min^{-1}	Ea Kcal	k_{CO} min^{-1}	k_{CO_2} min^{-1}	Rate of Heat Release*	k_{CO} min^{-1}	k_{CO_2} min^{-1}	Rate of Heat Release*	k_{CO} min^{-1}	k_{CO_2} min^{-1}	Rate of Heat Release*
NaCl	66	10.1	194	11.1	0.092	0.141	-14.6	0.46	0.83	-83.5	1.22	2.41	-241
$Na_2B_4O_7$	2810	16.9	245	12.4	0.047	0.076	-7.8	0.69	0.55	-64.3	3.52	1.82	-242
Untreated	163	11.5	115	11.2	0.091	0.078	-9.0	0.57	0.47	-54.2	1.73	1.37	-161
$(NH_4)_2HPO_4$	1526	16.0	39	11.2	0.046	0.027	-3.4	0.58	0.16	-27.3	2.73	0.47	-104
H_3BO_3	108	11.4	33	10.3	0.065	0.040	-5.4	0.40	0.21	-27.5	1.19	0.56	-77
$AlCl_3$	45	9.5	48	10.0	0.093	0.071	-8.4	0.42	0.35	-40.6	1.05	0.92	-105

* Units: $kcal \cdot min^{-1} \cdot mole\ C^{-1}$

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: University of North Carolina, Chapel Hill

Grant No.: NB79NADA0020

Grant Title: Plans for Action in Fire Emergencies in Group Homes for the Developmentally Disabled

Principal Investigator: Marcus B. Waller, Professor
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University of North Carolina
Chapel Hill, NC 27514

Other Professional Personnel: Robert G. Vreeland, Research Associate

NBS Scientific Officer: Bernard Levin, Ph.D.

Technical Abstract:

The objective of this grant was to create guidelines for fire emergency planning in group homes for the developmentally disabled. The method used was to hold a conference of experts from the various areas of impact. The experts were drawn from local fire service, fire inspectors, fire protection engineering, group home owners and operators, developmental disabilities professionals, group home licensure officials, state regulatory authorities, and fire research professionals. Following the circulation of a preliminary assessment of significant issues and a proposal of guidelines, the conference of experts was held in Chapel Hill, North Carolina on June 2 and 3, 1980.

The purpose of the conference was to generate a full and candid discussion of the issues involved in recommending particular guidelines for fire emergency plans for group homes for developmentally disabled people. We also attempted to lead the discussion into controversial areas in which strongly held differences of opinion might be expected. We anticipated that in this manner we could estimate and perhaps resolve major problems before they arose within the guidelines themselves.

We view the conference as successful. We discovered numerous areas of agreement among the participants, several areas in which consensus was possible following discussion, and a few areas of disagreement. The report of the conference and the resulting guidelines constitute a report submitted to NBS. Recommendations for further effort in the area of fire emergency planning in group homes for the developmentally disabled were also discussed.

CENTER FOR FIRE RESEARCH

NATIONAL BUREAU OF STANDARDS

Institution: The University of Notre Dame

Grant No.: NBS Grant G7-9002 Mod. No. 2

Grant Title: Fire and Smoke Spread

Principal Investigators: Professor K. T. Yang
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Other Professional Personnel: H. C. Chiou, Ph.D. Candidate
C. J. Huang, M.S.
K. Satoh, M.S.

NBS Scientific Officer: J. Quintiere

Technical Abstract:

The objective of this continuing project is to develop a three-dimensional UNDSAFE (University of Notre Dame Smoke and Fire in Enclosure) computer code based on first principles for predicting smoke and fire spread in rooms and corridors, as well as to apply this code, together with the previously developed two-dimensional UNDSAFE-II code, to physical problems of current interest in the fire physics field. In addition to the demonstrated capability of UNDSAFE-II, the current code is also capable of treating passive smoke movement, two-dimensional thermal gaseous radiation, and both algebraic and differential field models of turbulence. The current progress may be summarized as follows:

1. The calculation of the E-84 tunnel flow was completed, and details of the analysis and results are now contained in the M.S. thesis by C. J. Huang. The calculated convective heat flux to the surface neglecting radiation was in reasonable agreement with the empirical data. Adiabatic boundary conditions were assumed in the model on the floor and on the first 1.07 m of the ceiling, and consequently the calculated results over estimated the temperature distributions in the tunnel. It was found that the air inlet velocity and spatial distribution of the heat source and turbulent heat transfer mechanisms all had a significant influence on the temperature, velocity and pressure distributions.

2. A numerical study has been initiated to study the effects of vertical venting on fire and smoke spread in an enclosure. Smoke generation and the appropriate species equations is incorporated into the basic UNDSAFE-II code. Calculations have been carried out for six

basic combinations of floor and ceiling vent locations and five volumetric heating rates. Velocity, temperature, smoke concentration, and opacity have been determined. If has been found that when the floor heat source is located between the floor and ceiling vents, the long time venting phenomenon is oscillating, while steady state behavior is observed in all other cases including those where the heat source is situated in a corner. The mass rates of flow at the ceiling vent and the depths of the smoke layer are now being correlated with the strength and location of the heat source and the geometries of the enclosure together with the vent locations.

3. The complete three-dimensional code has been written and debugged on the basis of limiting cases for which solutions are known. This code includes more effective routines for the pressure correction and the tridiagonal matrix algorithm, and is more self consistent in the finite differencing schemes than UNDSAFE-II. Additional features of this code consist of inclusion of species equations and flexibility in accommodating various turbulence models including the κ-ε-g differential field model reported a year ago. Controversies on turbulence models for elliptical flows still persist and a flexible position is maintained by the Fire Research Group at Notre Dame in the development of the three-dimensional code. This code is now operational.

4. Another numerical study has recently been instituted to study the three-dimensional single doorway venting in a cubical enclosure with a volumetric heat source located over the floor at the center of the enclosure. The doorway openings are varied to yield results which could indicate the small and large opening limits of ventilation. Preliminary results show that these limits are associated with the characteristic vertical and horizontal dimensions of the door opening. Difficulty has been experienced in adequately providing pictorial three-dimensional velocity, temperature and smoke concentration fields from the computer output, and a joint effort with the Notre Dame Computer Center has just been initiated to resolve this difficulty.

It is generally recognized that fire losses can be reduced in instances where the physical fire and smoke spread phenomena are better understood and can be adequately predicted in advance. Research efforts in the area of mathematical fire modeling specifically address this problem by the development of fire models such as zone models and field models, of which the present project is but one example. Despite early controversies, there is a general agreement now that both the zone and field models should be developed simultaneously and made to complement each other. While field models are not yet ready for general application, they nevertheless can serve a good purpose to provide needed detailed information for the benefit of the zone models. This is particularly critical in view of the fact that zone models are much easier to use and are now on the verge of being applied to realistic fire problems.

Reports and Papers

1. Lloyd, J. R., Yang, K. T. and Liu, V. K., "A Numerical Study of One Dimensional Surface, Gas and Soot Radiation for Turbulent Buoyant Flows in Enclosures," National Conference on Numerical Methods in Heat Transfer, University of Maryland, September 24-26, 1979, pp 142-161.

2. Kanury, A. M. and Lloyd, J. R., "A Numerical Study of Interacting Transient Two-Dimensional Laminar Buoyant Plumes in a Semi-Infinite Enclosure," 1979 Technical Meeting, The Eastern Section of the Combustion Institute, November 7-9, 1979, 5 pp.

3. Huang, C. J., "A Numerical Study of Flow and Heat Transfer in a Long 2-D Tunnel with Interaction Between Longitudinal Forced Flow and Transverse Buoyant Flow," M.S. Thesis, Department of Aerospace and Mechanical Engineering, University of Notre Dame, January 1980, 150 pp.

4. Lynch, N. P. and Lloyd, J. R., "An Experimental Investigation of the Transient Build-Up of Fire in a Room-Corridor Geometry," accepted for publication at the 18th International Symposium on Combustion, August 1980, The University of Waterloo, Ontario, Canada.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

INSTITUTION: The University of Pittsburgh

GRANT NO.: NBS Grant #NB79NADA0009

GRANT TITLE: Toxicity of Plastic Combustion Products

PRINCIPAL INVESTIGATOR: Professor Yves Alarie, Ph.D.
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OTHER PROFESSIONAL PERSONNEL: None

NBS SCIENTIFIC OFFICER: M.M. Birky, Ph.D.

TECHNICAL ABSTRACT:

The objective under this grant is to arrive at classifications of the potency of thermal decomposition products of synthetic and natural polymers for toxic reactions of relevance in either impeding escape from a fire or recovery from smoke inhalation following a fire. Several toxicological indices are being used:

- sensory irritation
- physiological stress
- asphyxiation
- acute lethality
- pulmonary irritation
- histophathological examination of various organs

We have been able to classify materials for the first 4 indices given above using a concentration-response approach and comparisons to a "standard" material such as wood have been made. Currently the same materials are being investigated for pulmonary irritation. Using the toxicological data for acute lethality a Toxicological Hazard Index (THI) was formulated for a series of materials used for insulation and comparisons made with a "standard", i.e. fiberglass insulation.

In terms of reducing fire losses, we believe that the toxicological methodology developed under this project permits the very rapid recognition of highly toxic thermal decomposition products from polymers and alerts manufacturers of this property in a very reliable manner. Better selection of materials for a particular function will be achievable using the THI approach.

REPORTS AND PAPERS (1979):

Anderson, R.C., Stock, M.F., Sawin, R. and Alarie, Y. Toxicity of decomposition products of urea formaldehyde and phenol formaldehyde foams. Toxicol. Appl. Pharmacol. 51, 9-17, 1979.

Alarie, Y. and Anderson R.C. - Toxicological and acute lethal hazard evaluation of thermal decomposition products of synthetic and natural polymers. Toxicol. Appl. Pharmacol. 51, 341-362, 1979.

Anderson, R.C. and Alarie Y. - Acute lethal effects of polyvinylchloride thermal decomposition products in normal and cannulated mice. Toxicol. Appl. Pharmacol. A3, 1980.

CENTER FOR FIRE RESEARCH
NATIONAL BUREAU OF STANDARDS

Institution: The University of Washington

Grant No.: DA1053

Grant Title: "Post-Fire Interviews: Development and Field Validation"

Principal Investigator: Dr. John P. Keating
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Seattle, Washington 98195

Co-Principal Investigator: Dr. Elizabeth F. Loftus

NBS Scientific Officer: Bernard Levin

Technical Abstract:

During the past two years, a new technique for interviewing victims and witnesses has been developed. This technique differs from previous approaches developed by Bryan, Lerup and Wood in that (1) it does not require (but can be used in conjunction with) graphic mapping of the building environment, (2) it yields readily quantifiable data, (3) it is adaptable to large and small numbers of witnesses and various size fires and types of occupancies, and (4) it is relatively resistant to the biasing effects of conventional interview and questionnaire methods.

The method employs a two-step procedure where the witness first provides an unobstructed narrative account of his or her actions during the fire. The interviewer only keeps the narrative "on-track", but does not ask questions pertaining to the content. This step serves to enhance the accuracy and completeness of the account as well as prepare the interviewer and witness for subsequent probing.

Following the narrative, the interviewer obtains a retelling of the incident, but this time using a predetermined structure. This structure breaks the narrative account down into a sequence of discrete actions. The interviewer accomplishes this by assisting the witness in creating a statement for each action. Each statement has three components, a situational or cognitive cue, a behavioral response, and a reason why. An example of such a statement follows:

Situational Cue	Behavioral Response	Reason Why
I saw smoke seeping from under Mr. Smith's door	So I opened the door using my pass key	to see how serious the fire was

This technique has been tested during the last year in 35 interviews with persons present during residential fires. Based on these interviews, we have made adjustments in our procedures, and we are confident that the technique is now ready to be applied to other types of fire incidents. Therefore, in the coming years, we are turning our attention to a program of research to identify and compensate for various threats to the accuracy of interview data.

Our plans are to investigate the following research needs:

1) Scientific parameter testing of <u>three</u> critical variables of the post-fire interview situations:

   a) Fire-related, affective processes which influence the recall process during post-fire interviews.

   b) Time as a factor which affects quality and quantity of information recalled.

   c) Salient cues which affect the recall of participants/witnesses of domestic and arson fire incidents.

2) Structured field-testing of the proposed instrument.

   a) Analyses related modifications will continue to be made and assessed from current Seattle based sample.

   b) Field-testing suggested by the ongoing laboratory studies will be conducted each quarter in cooperation with the Seattle Fire Dept.

   c) The developing data bank will be continuously assessed, and pertinent theoretical issues formulated for empirical tests when appropriate.

3) The final need is for increased quantities of data enabling the research team to:

   a) Assess limitations of premature generalization about the validity/reliability of the instrument.

   b) Identify additional parameters that constrain application of the instrument (cf. above: witnesses must be articulate, have reliable memories, and be accessible.)

   c) Assess the practicability of instrument administration by on-line fire personnel.

In order to accomplish these objectives, we will be employing a combination of laboratory research, field validation of the results of the laboratory research, and the training of on-line fire personnel in the use of the "action-sequence" interview technique.

Progress report: Arrangements to train fire personnel in the interviewing technique have been made with fire departments in Houston and Seattle. Research plans for the laboratory studies have been largely completed.

Accomplishments: The interview technique as applied to small residential fires has been completed and tested.

Potential applications: The project provides a technique for obtaining a large quantifiable data-base in an efficient manner. This large data-base has the potential of providing information pertaining to models of human behavior in fire situations and the reduction of counter-productive behaviors.

Future milestones: During the coming year we expect to have completed laboratory studies, field tests, and fire personnel training as described in this abstract.

APPENDIX A

CONFERENCE PROGRAM

ANNUAL CONFERENCE ON FIRE RESEARCH

Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
October 22, 23, 24, 1980

Tuesday, October 21

7:00 p.m.	Registration and Informal Reception Ramada Inn, Rockville, Maryland

Wednesday, October 22

8:15 a.m.	Registration, Green Auditorium Lobby
9:15 a.m.	Introduction and Welcome, Green Auditorium - Dr. F. Clarke, Director, Center for Fire Research

I. Fire Risk Management

9:30 a.m.	Session Chairman (Overview) - B. Buchbinder, CFR/NBS
9:35 a.m.	Data Collection and Analysis - J. Slater, CFR/NBS
9:55 a.m.	Decision Analysis - Dr. F. Offensend, Stanford Research Institute
10:15 a.m.	Decision Analysis - Residential - A. Gomberg, CFR/NBS
10:35 a.m.	Coffee Break, Employee Lounge
11:05 a.m.	FSES for Residences - H. Nelson, CFR/NBS
11:25 a.m.	(FSES) Evaluation of Risk - Dr. N. Groner, CFR/NBS
11:45 a.m.	Cost Comparisons - Dr. R. Chapman, Center for Applied Mathematics/NBS

II. Home Hazards

12:00 noon	Session Chairman (Overview) - J. Winger, CFR/NBS
12:05 p.m.	Practical Aspects of Cigarette Ignition of Upholstered Furniture - J. Krasny, CFR/NBS
12:25 p.m.	Overview of Wood Heating Safety Research - R. Peacock, CFR/NBS
12:35 p.m.	Fireplace Inserts: Creosoting and Chimney Fires - Dr. T. Maxwell, Auburn University
12:55 p.m.	Fireplace Inserts: Thermal Hazard on Surrounding Combustibles - C. Gibbons, Underwriters Laboratories
1:15 p.m.	Lunch, NBS Cafeteria

III. Fire Response of Materials and Structures

2:15 p.m.	Session Chairman (Overview) - S. Davis, CFR/NBS
2:20 p.m.	Laboratory Tests for Fire Properties of Materials - Dr. V. Babrauskas, CFR/NBS
2:40 p.m.	Room Fire Testing - W. Parker, CFR/NBS
2:50 p.m.	Standard Room Fire Test Parameters, Dr. B. Williamson, University of California, Berkeley
3:10 p.m.	Role of Fire Retardants on Heat Release - Dr. S. Martin, Stanford Research Institute
3:30 p.m.	Coffee Break, Employee Lounge

Fire Response of Materials and Structures (cont'd)

4:00 p.m.	ISO Flame Spread Tests - Dr. A. Robertson, CFR/NBS
4:20 p.m.	Structural Fire Endurance Tests - D. Jeanes, Research Associate from American Iron and Steel Institute (Washington, D.C.)
4:30 p.m.	Fire Tests of Reinforced Concrete Beams - M. Abrams (M. Gillen, Speaker), Portland Cement Association (Chicago)
4:40 p.m.	Creep Tests at Elevated Temperatures - M. Gillen, Portland Cement Association (Chicago)
4:50 p.m.	Analysis of Reinforced Concrete Fire Performance Structural Behavior - Dr. J. Shaver, Center for Building Technology/NBS
5:00 p.m.	Adjourn
6:30 p.m.	Volleyball Game and Barbecue at Smokey Glen Farm

Thursday, October 23

IV. Human Behavior in Fires

9:30 a.m.	Session Chairman (Overview) - H. Nelson, CFR/NBS
9:40 a.m.	Response Variability in Escape - Dr. R. Pearson, North Carolina State University
10:00 a.m.	Waking Effectiveness of Alarms - Dr. E. Nober, University of Massachusetts
10:20 a.m.	Project People - Dr. J. Bryan, University of Maryland
10:40 a.m.	Post Fire Interviews - Dr. J. Keating, University of Washington
11:00 a.m.	Coffee Break, Employee Lounge
11:30 a.m.	Actions in Fire Emergencies - Dr. R. Vreeland, University of North Carolina, presented by Dr. Bernard Levin, CFR/NBS
11:50 a.m.	Rapid Emergency Escape Time-based Capabilities of Building Occupants - Dr. F. Stahl, Center for Building Technology/NBS
12:10 p.m.	Model for Building Evacuation - Dr. R. Francis, University of Florida
12:30 p.m.	Analysis of Escape Potential for the Developmentally Disabled from Group Homes - Dr. S. Gupta, Northeastern University, presented by Dr. J. Berlin, Consultant, Modeling Systems Inc., Boston, Massachusetts
12:50 p.m.	Fire Safety for the Handicapped - Dr. Bernard Levin, CFR/NBS
1:10 p.m.	Lunch, NBS Cafeteria

V. Toxicology

2:00 p.m.	Session Chairman (Overview) - Dr. M. Birky, CFR/NBS
2:10 p.m.	Toxicity Screening Protocol - Dr. Barbara Levin, CFR/NBS
2:30 p.m.	Large-Scale Correlation with Test Method - M. Paabo, CFR/NBS
2:50 p.m.	Concepts of Tenability Limits - Dr. S. Packham, Consultant
3:10 p.m.	Time-Concentration Effects of Toxic Products - Dr. Y. Alarie, University of Pittsburgh
3:30 p.m.	Coffee Break, Employee Lounge
4:00 p.m.	Incapacitation Models and Effects of Alcohol - Dr. Z. Annau, Johns Hopkins University
4:20 p.m.	Treatment for Fire Injuries - Dr. R. Myers, Maryland Institute for Emergency Medical Services Systems, Baltimore, Maryland

Toxicology (cont'd)

4.40 p.m.	Fire Fighter Exposures - Dr. G. Hartzell, Southwest Research Institute
5:00 p.m.	Adjourn
5:45 p.m.	Buffet Dinner at Urbana Fire Hall

Friday, October 24

VI. Fire Protection Systems

9:30 a.m.	Session Chairman (Overview) - E. Budnick, CFR/NBS
9:40 a.m.	A Fundamental Program in Sprinkler Research - Dr. D. Evans, CFR/NBS
10:05 a.m.	FMRC - L.A. Sprinkler Project - Dr. H. Kung, Factory Mutual Research Corporation
10:25 a.m.	Backflow Preventer - Prof. H. Hickey, University of Maryland
10:40 a.m.	Smoke Control - J. Klote, CFR/NBS
11:00 a.m.	Coffee Break, Employee Lounge

VII. Modeling as an Engineering Tool

11:30 a.m.	Session Chairman (Overview) - I. Benjamin, CFR/NBS
11:40 a.m.	Compartment Fire Zone Modeling - Dr. J. Quintiere, CFR/NBS
12:00 noon	Post-Flashover Models - Dr. V. Babrauskas, CFR/NBS
12:20 p.m.	Smoke Movement - Dr. E. Zukoski, California Institute of Technology
12:40 p.m.	Recent Developments in Fire Modeling for Evacuation Safety - Dr. L. Cooper, CFR/NBS

Closing Remarks

1:00 p.m.	Closing Remarks - Dr. J. W. Lyons, Director, National Engineering Laboratory, NBS Dr. R. Levine, Chief, Fire Research Resources Division, CFR

APPENDIX B

ANNUAL CONFERENCE ON FIRE RESEARCH

Center for Fire Research
National Engineering Laboratory
National Bureau of Standards
October 22, 23, 24, 1980

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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This report contains descriptions of the internal programs of the Center for Fire Research as well as extended abstracts of grants and contracts sponsored by the Center for Fire Research, National Bureau of Standards.

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